Consumer product invention: some developmental, economic & consumer aspects

Thesis

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Consumer Product Invention:
Some Developmental, Economic & Consumer Aspects

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ABSTRACT

This study of the British Bicycle and Domestic Radio Receiver industries produced a model of invention/product design having the following features: Invention depended mainly on the combined effect of three factors, each with changing significance over a three-stage life cycle.

Technology Factor: Induced a cumulative sequence of inventions to improve product performance, of various origins (ideas, problems, techno-transfers or science). This factor most important in the first Incubation stage, of equal importance in second Early Growth stage and of incremental importance in final Mature stage.

Economic Factor: Induced invention to suit market, mainly for cheaper, lower performance products but also for superlative models. This factor inoperative at Incubation stage, very important at Early Growth stage and important at Mature stage.

Consumer Factor: Induced invention to make products more appealing to consumer; for simpler/automatic operation, greater reliability, accessories and new uses. This factor inoperative at Incubation stage, important at Early Growth stage and supremely important at Mature stage.

Product life-cycle pattern a sequence of new models subsequently improved until an basic satisfactory design achieved, later incrementally improved. Empirical invention often systematic and as important as scientific invention; science often used to define design problem. Peak invention in Early Growth stage to explore all technical possibilities, design trade-offs and for market share.

Invention and Demand: No direct and proportional relationship. Initial demand due to novelty appeal of function, subsequent rapid increased demand due to better technical product performance, lower product prices and increased income-related purchasing power. After market saturation demand declined despite better, sometimes radical, designs; as consumers sought other new products.

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1. CHAPTER ONE: INTRODUCTION

1.1 Introduction

The analysis of invention (technological change) involves two quite separate topics; one is the economic aspect of invention, the other is the pattern of technological development itself. A satisfactory explanation of the role and contribution of invention to economic growth requires some combined theory of these two topics and in spite of considerable effort in the past no satisfactory theory has yet been given. In this introductory chapter an outline will be given of the range and scope of previous studies of invention and growth to guide the design of this research.

1.2 The Background

It is sometimes said that successful research depends more upon the choice of problem and the approach adopted than upon originality and insight. This is particularly true in the case of invention and growth, for, as Lewis (1965, originally 1955) observed, much research on this topic had led to a multiplicity of diverse theories none being entirely satisfactory. Historians, economists and those concerned with technological development generally concede that economic growth critically depends upon invention and technological progress, yet no one has been able to give a satisfactory explanation of this.

Rosenberg (1982), in his review of recent literature on technical progress, has summarised the main concepts used by economists, economic historians and sociologists who seek to explain the causes and effects of technical progress. Researchers on various features of technical progress such as its rate, direction, diffusion and economic aspects have found it necessary to abandon a narrow definition of technology and incorporate broader organisational or social aspects. Rosenberg considered that many of the present controversies on this topic were due to misconceptions on the part of researchers and Rosenberg believed that the fundamental feature of advanced industrial societies was that they were able to generate not just a single new invention but a multiplicity of inventions for equivalents or substitutes and that a fuller comprehension of this technical capacity lay in revealing its social determinants.

Past theories can be broadly divided into four categories:- a) Social theories which emphasise the importance of general cultural forces; b) Socio-economic theories which are concerned with more specific social forces and their interaction with proximate economic variables; c) Purely economic theories which have limited their interest to economic variables alone and d) Empirical micro-level innovation studies which generally concentrate on the historical patterns of development of new industries or new products.
Early theories have been greatly influenced by two basic but opposing views; one, put forward by Weber (1968, originally 1922) was that the forms of social organisation primarily determined economic and technological development; the other, given by Marx (1977a, originally 1849; and 1977b, originally 1867, 1885, and 1895) considered that the social order was primarily determined by economic and technological forces.

1.2.1 Social Theories

Social theories of development are of ancient lineage and attribute progress to the ´spirit of the people´. Perhaps the most famous example of this type of development was one suggested by Weber (1965, originally 1904) who believed that the social values associated with Protestantism had directly accelerated technological and economic development by inculcating ´rational´ action into every area of life so that objectives and developments were founded upon prior intellectual analyses. The results of this approach had been responsible for rapid change and the overthrow of many earlier customs and practices.

Weber´s theory has been controversial; critics pointed out that many modern advanced societies have never experienced Protestantism yet had made rapid progress. Later proponents of the Weberian thesis have emphasised different motivational factors or modes of change - McClelland and Hagen have both created theories in which the train of causation is said to run from childhood assimilation of social values leading to an adult personality valuing achievement and desire for change and growth. Recent efforts to promote growth in under-developed countries have also led to a new appreciation of the importance of social forces in such change. The study of the development of technology and science has further underlined the importance of social and cultural factors in their development.[1]

Social theories of development have considerable support but encounter a major difficulty in attempts to define, identify, quantify and demonstrate the mechanism of their operation. Social forces act diffusely at general levels and it is difficult if not impossible to specify their influence upon growth and technology. Later economic determinists attribute economic and technological progress primarily to availability of resources for such development, rather than social determinants.

1.2.2 Socio-Economic Theories

There are a broad range of socio-economic theories of grow, ranging from the early Classical to recent ones, which consider that a mixture of social and economic forces are involved in growth and invention. The modern types of socio-economic theory use the concept that the main influence of social factors is more specific and acts at micro-level, two examples of these theories are described here to illustrate their similarities and differences.

Lewis's Socio-Economic Theory

Lewis (1965, originally 1955) considered that there were three proximate causes of growth; one was the effort to economise (reduce costs or improve yield from a given input), the second was the increasing resources (including capital) devoted to production and the third was increasing knowledge and its application to commercial ends. Other factors lay behind these three

[1] Comprehensive accounts of such theories are given in the journals Technology & Culture, and History Of Science, as well as in the literature covering sociology and economic history.

proximate causes and these were generally institutional ones. Explanations of the effects of institutional factors upon growth met with difficulties as it was impossible to specify their causes; for example if it was said that differences in growth rates were due to differences in religious attitudes why did only a particular religion hold these tenets and why was it only accepted in a particular place and not elsewhere.? Lewis's whole book discussed the role of institutional forces upon the three proximate causes of growth and covered such topics as asceticism, the relation between wealth and social status, attitudes to work, the right to reward, individual and collective economic actions, institutional aspects of saving and investment, the labour supply, government relationships and policies towards economic objectives. No attempt will be made to summarise Lewis's discussions on these but a brief note will be made of his views on invention.

Lewis considered that there was no single entity called 'invention' but rather that technological progress, which made an important contribution to growth, depended upon three inter-related aspects of knowledge. One of these aspects was the process of the growth of knowledge, another was the application of this knowledge and the third aspect was training - the passing on of knowledge. Social and technological factors were involved in each of the three aspects but the overall pattern changed with time.

Growth of Knowledge

Knowledge grew, Lewis said, because men were curious and not because they were concerned with economic or practical problems. Knowledge grew cumulatively because each succeeding generation built upon earlier knowledge and the most interesting feature was the reasons for the increasing rate of growth of knowledge. Because man was curious, knowledge grew regardless of his method of acquiring knowledge though later developments such as writing and the scientific method had also permitted a much more rapid rate of increase in knowledge. Not all invention had been due to science; the modern layman was "often astounded to learn that over large realms of industry the practical men had no use for (or had even contempt) for scientists." (p.169). The great inventions of the eighteenth and nineteenth centuries had all been made by practical people who knew little or no science. By the twentieth century this had changed as inventors now needed to be scientists and teamwork had replaced the individual inventor of the earlier age.[2] Lewis then presented what would now be called a science-push model in which pure science created new knowledge, applied research transformed the knowledge to working principles and others (inventors) developed designs for a manufacturer who used them for commercial purposes. These three stages were inter-related and did not progress uniformly in all industries so that it was possible for a country (Britain was one example) to be good at pure science but fail to apply it and gain from it.

Application of Knowledge

The application of knowledge, Lewis said, essentially depended upon a society's attitude to change, and if a country had conservative social values it would be slower to adopt changes than one which was progressive. The application of knowledge also depended on other factors; one was the idea itself, if it gave good results then it would be adopted much quicker than if it did not; the social status of the sponsor was important too as was the potential profit or benefit of the idea. The entrepreneur was the key in the whole process of the application of knowledge and his actions embodied a combination of all the factors affecting application.

Training

Training was essentially concerned with passing knowledge to the rising generation and was achieved by education. Training was needed at many levels, management needed training as much as apprentices. The development of education was greatly affected by social values; a society which valued and rewarded knowledge and ability would have a better educational system than one which did not. Some social forces opposed education and its potential benefits, apprenticeships and entry into professional associations could be regulated; management may doubt the value of training and, in the absence of competition and the threat of bankruptcy, be content with old methods and ways. Change was generally most rapid in societies which had decentralised decision-making arrangements.

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2 This view is not shared by all modern investigators, see for example Jewkes, Sawers & Stillerman (1969, originally 1958).

Peterson's Socio-Economic Theory

Peterson (1967) (Chap 14) has given an overview of the nature and problems of economic growth with a greater emphasis upon economic aspects. One basic problem is that of the concept of economic growth itself. Peterson noted that the simple definition of growth used in most modern growth theories was the change in real income per capita, but that attempts to enlarge upon it ran into severe difficulties.[3] Modern growth analyses have established that economic growth is not simply an expansion of existing activities but involves structural change in the form of decaying old industries and rising new ones.

Peterson then described why modern interest in economic growth had increased rapidly from 1945. The overriding concern was with human welfare and modern governments had desired economic growth partly because of the legacy of the 1930s depression, the post-1945 desire for full employment, the concern for growth in 'underdeveloped' countries and partly as a response to claims about the Soviet economic system. Modern research on economic growth, Peterson said, had led to general agreement that four fundamental proximate growth factors existed; these were 1) the quality and quantity of the labour force, 2) the quality and quantity of natural resources 3) the quality and quantity of real capital and 4) the level of technological attainment of the society. However other important factors lay behind these proximate ones and they were difficult to deal with either because they could not be easily measured or perhaps had indirect links with growth; some examples given included economic and non-economic influences upon the supply of labour, the stock of capital and the level of technology. Another set of indirect forces was connected with the operation of the economic system including the competitive element, the distribution of income and wealth, the pattern of consumer tastes, the dominant form of business organisation and other institutional forces. A third set of indirect forces affected demand. Although Classical economists

3 Shearer (1961) has discussed this problem at considerable length and pointed out that growth primarily refers to evolutionary change in which the main features are increasing complexity, specialisation, inter-relatedness and elimination of 'unfit' activities. Most modern references to 'evolutionary' concepts imply gradual change, though some assume the term refers to 'survival of the fittest' meaning elimination due to competition. Usher (1980) has also addressed the measurement problem more directly and concluded that orthodox measures of growth were inadequate and described how his measures based on real consumption included a term for improved product qualities due to the effects of invention.

had written a great deal about growth, modern growth theories had only really emerged after 1945 and had since specialised. The two main branches of modern economic growth theory were now Development Economics (which deals with growth in underdeveloped countries) and Modern Growth theories (which are limited to economic changes in advanced industrial countries). Peterson considered that the omission of consideration of demand-related factors in growth was a serious defect of many modern growth theories.
These two socio-economic theories illustrate clearly the concept of socially influenced economic variables but both differ in their identification of them. Socio-economic theories then suffer from the same disadvantages as general social theories outlined in the previous section and these disadvantages led others to attempt explanations based solely upon the operation of economic variables.

1.2.3 Economic Theories

Modern economic growth concepts stem from Classical economic theory but do not include the social theories which Classical economists wove into their economic ones. Economic growth theory has concentrated upon supply-side changes and involved many sub-theories dealing with prices, investment distribution etc. In simple terms, Classical growth theory was based on the concept that growth was due to an expansion of productive capacity which depended upon investment and an increased labour supply, while invention (along with division of labour) increased the efficiency of production by creating or improving machinery (and work organisation) thus reducing the costs of production and hence the price of products so that demand was increased.

Classical economists believed that two mechanisms exerted control over all economic activity; one was the price mechanism, the other was investment. Classical, and later economists believed that invention and growth would be highest when prices or investment were high or rising. Actual tests of the price hypothesis showed that this was not the case; business cycle studies revealed that periods of great economic activity occurred at times of low or falling prices while Maynard (1963) has shown that long term growth is not directly associated with price changes. Maynard's analysis of the course of

British economic growth and price movements led him to conclude "This brief survey of the British economy from 1800 to the mid-1930s indicates pretty clearly that the British economy did not grow faster when the price level was showing a long term tendency to rise: on the contrary, a secularly falling price level seems to have been more conducive to growth" (p.189). Similarly tests of the simple association between investment and growth, produced inconclusive results. A fuller discussion of this issue will be given in the next chapter and of the differing interpretations it has given rise to, what is clear is that growth is not singularly dependent upon price changes or investment alone.

Post-Classical Economic Theory

The concept of price-reducing labour-saving invention continued to influence economic theorists and they interpreted the results of statistical studies in its light. During the 1920s these statistical studies led to the establishment of the production function concept which mathematically related changes of 'input' (labour and capital) to changes of 'output'. At the same time it was noted that labour productivity trends exhibited a long and gradual upward trend, this was attributed to the effects of invention. In the 1930s economists and thought that invention had suddenly become 'capital-saving' and led them to attempt to classify inventions in terms of their economic effects.

Modern Economic Growth Theories

Although the publication of Keynes's General Theory in 1936 was said to have heralded a 'new view' of economics, it embodied many Classical concepts in particular the relationship between investment, labour and output. Keynes himself was not interested in long run (growth) theory but soon others sought to 'dynamise' it and produce a new growth theories. The first of these were called Harrod-Domar models which combined the production function concept with Keynes's concept of the dual role of investment (to expand productive capacity and to generate increased income). Invention was at first ignored in these Harrod-Domar models but later versions of this model were formulated so that the discrepancy between changes of input and changes of output were attributed to a 'residual' which was designated a measure of both invention and other non-technological input factors. By the late 1950s the neoclassical growth model had superseded the Harrod-Domar ones and resulted in initial claims that invention accounted for about ninety per cent of long run growth, while changes in capital apparently contributed the remainder. These high initial estimates of the effects of invention were soon challenged and much reduced. A further refinement was the inclusion of Research and Development (R&D) expenditures as a direct input to the production function. Growth Accounting was a further later extension of the neoclassical model, the initial concern was to measure and explain changes in labour, capital and total factor productivity. Then growth accounting procedures were used to identify and quantify additional (and often quasi-social) input variables. Invention (advances in knowledge) was included and consequently, because of reduced the added variables, the proportion of the residual said to be due to invention. However from 1974 it became apparent in all advanced industrial economies that the rate of productivity increases had decreased and comparison with R&D expenditures led to some doubts about the role of R&D in productivity growth; macroeconomic and institutional factors now appeared to be more important.

Product Invention in Economic Theory

Classical and modern economic growth theories concentrate on process invention but by the beginning of the twentieth century a number of economists had begun to recognise that product invention was important. A common concept at this time was that growth involved some kind of balance between product invention (which created new industries or new demand) and process invention (which cut labour and costs). Ravenshear (1908) put forward an interesting version of this theory and later so did Lederer (1935). However Schumpeter (1961, originally 1911) gave a new theory which has had a lasting influence; in his view growth critically depended upon innovations (new products etc.) which came from invention (and invention was exogenous to the economic system) and these innovations were implemented by entrepreneurs who took into account the state of the economy. Growth, in Schumpeter's schema, was not uniform and continuous but proceeded in spurts, with innovations tending to cluster together in time. Schumpeter emphasised the importance of scale and believed that large corporations dominated economic activity.

The present state of modern economic theories of invention and growth has been commented upon by Nelson (1981) in his broad survey of this field. This survey included recent theories which incorporated social effects and Nelson concluded that modern concepts and theories had entered a stage of decreasing returns and had not yet provided a convincing explanation of the causes of growth and the role of invention in it.

1.2.4 Invention and Innovation Studies

The relative failure of economic theories was partly responsible for the rise of more empirically oriented innovation studies. The main research method employed was the case history analysis of particular new products or new industries. The primary concerns of innovation researchers are with the causes and patterns of technological development and innovation. Social factors are strictly limited to demand-side and marketing variables.

Innovation research has covered a wide range of topics; Rosegger (1980) has described the field of this innovation research, which covers macroeconomic studies of the relation of R&D, patents or Qualified Scientists and Engineers (QSEs) to growth; and microeconomic studies of the relative costs of the branches of R&D (pure and applied research, and development); inter-industry comparisons of the relation between R&D and patenting or output; the process of the diffusion of innovations, the effect of size of firm upon R&D, the effect of market structure upon R&D and the organisational and managerial criteria for success (or failure) of new projects. In general none of these efforts has adequately explained the role of invention in aggregate growth though it has led to a better appreciation of the process of invention, and the adoption of invention (innovation). These studies have demonstrated some important features of invention (and product design as invention now tends to be called) and typical patterns of technological development, and some of these features and theories will now be discussed.

Concept Of Invention

Popular use of the word 'invention' poses no difficulty, beyond this it proves troublesome and many attempts to give a precise definition of invention have encountered difficulty.[4] The main concepts of invention stem from the patent laws with their emphasis upon novelty and an 'inventive step' having something more than a mere extension by 'one skilled in the art'. Invention is used to describe novel creations in many fields so that artistic, literary and musical works can be called inventive when original. Throughout this study the term 'invention' will refer solely to technological change.

Technological progress has various causes including invention, discovery, science, engineering design, and industrial design. Many have unsuccessfully sought to define these different activities; science is said to have the advance of theoretical knowledge as its primary aim. Discovery is said to be new knowledge which has been obtained without prior consideration or investigation (implying an accidental cause); engineering design is considered to be a more routine type of advance "made by one skilled in the art" and dependent upon the application of established engineering principles. Industrial design is said to be mainly concerned with the external aspects of a product so that its appearance, colour, form and texture are made pleasing and its function is made ergonomically sound. More general design criteria often rely on vague statements such as "fitness for purpose", or "form follows function" but there is little doubt that at least two levels of design exist, one is the creative pioneer invention, the other is the low level incremental invention.

Pioneer Invention

The idea that technological advance was primarily due to pioneer inventions is inherently attractive and is known as the Heroic theory of invention. This view has partly developed because of the natural belief that 'great inventions came from great minds' and partly because of patent law definitions of 'novelty' which stressed that a patent could only be granted for something which is completely new, and if a strict interpretation of patent laws were applied, the degree of novelty should be greater than a mere

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4 See Gilfillan (1952,1970, originally 1935) and Jewkes, Sawers & Stillerman (1969) for a discussion of this point.

application of known technical principles, so that a new invention should exhibit some "inventive step" or "flash of genius". Naturally no one can say precisely what these are. Early industrial histories and biographies concentrated on pioneer inventions and virtually ignored incremental inventions; Smiles (1968, originally 1862) typifies this approach.

Incremental Inventions

Gilfillan (1970) was a member of the Chicago School which considered that previous theories of invention had concentrated too much upon the pioneer invention and obtained evidence of the importance of incremental inventions from the characteristic curves of technological performance; Hart (1931) illustrated this with reference to a variety of products showing how performance increased rapidly in the early stages of their development. This rapid early improvement was then followed by a period of decreasing performance gains which led Kuznets (1967, originally 1930) and others to believe that decreasing returns applied to invention.

Complexity and Inter-Relatedness

Invention involves many types of technologies. Technology is not a single unified discipline but comprises a number of very different specialisms including mechanical, electrical and chemical engineering with some of these combining to form hybrids such as electro-mechanical or electro-chemical engineering. Specialists in one field are rarely specialists in others. Gilfillan (1970) gave an example of how the steam engine involved many different types of engineering and how the final design rested upon a fusion of advances in metallurgy, mechanical engineering, physics, chemistry and other specialist technologies.

Technological progress often involves a cluster of advances in related fields or industries. Gilfillan (1952) illustrated how an apparently new invention had many different origins. He did this with reference to the evolution of television. If invention could be defined as the emergence of the idea of pictures at a distance, then television was invented in 1847 when the idea was first put forward. However if the production of a working model defined invention then the mechanical raster systems developed in the 1870s and 1880s designated "invention" of television. On the other hand if the first demonstration of the modern cathode ray tube system was the criterion, then Zworykin's 1929 model defined this; while if the commercial introduction or extensive commercial use were the criteria, then invention could be dated either in 1928 or 1938. (Gilfillan has confused invention with innovation here). He also noted the inter-related nature of invention and technological progress; for example many elements contained in the television set such as the supply of electricity which dated from the invention Volta's battery, or from Fessenden's radio-telephony system, or radio-telegraphy and wired telegraphy, or even methods of producing copper used in television sets.

Stages Of Development

Many theories of technological progress usually imply that a 'new' invention and the commercial start of the new industry are common and pay little attention to the usually prolonged inventive efforts to make the 'new' invention work. This is implicit in the Product Life Cycle concept. Gilfillan (1970) showed that the temporal course of development for a number of "important" inventions was very lengthy indeed with a time interval between the idea and its reduction to practice being of the order of 176 years. This period is often called the Incubation period. The interval between reduction to practice and commercial use was about twenty years, and the interval between the first commercial use and widespread commercial use was a further twenty years. Such historical data did not exist for minor inventions, but the explanation for such temporal lag was essentially due to cultural factors and the Chicago school claimed that Cultural Lag applied to ideas and fashions as well as invention and innovation.

More recently studies of Technological Forecasting have led to the appreciation that the typical long run course of product development is for an initial new product to be invented and improved then for this to be superseded by an equivalent product. Technological progress appears to take the form of a succession of models, each having a better performance and rendering the earlier types obsolete. The 'fittest' type emerges as a standard one which remains the basic design for many years.

Science-Push

Innovation studies have concentrated mainly on post-1945 developments and consequently have been involved with mainly 'high technology' products. As a result the importance of prior scientific research has been emphasised. This led to the science-push concept of technological development in which the origin of invention (design) was depicted as proceeding from original advances in scientific research. More recently as innovation researchers have included low technology industries and products in their studies, there has been a tendency to question the validity of the science-push concept.

Uncertainty

Another important feature of invention is the great uncertainty which usually surrounds it. Nelson (1959) has shown how many important new products such as linear superpolymers, came from 'undirected' research, while Cardwell (1972) illustrated that correct designs can be made although these were deduced from the wrong principles, as in the case of Otto's 1876 four stroke engine; Cardwell designated these types of invention as 'precocious'. Cardwell also pointed to prolonged efforts along unfruitful paths, as in the case of the Direct Rotative steam engine, which lasted until the steam turbine principle was demonstrated. Gilfillan (1952) has shown how a variety of different inventive efforts to combat aerodrome fog were pursued until radar was evolved. In addition it has been noted by Jewkes et al (1969) that invention (technological ability) can be ahead of the market so that inventions can be ahead of their commercial time.

This uncertainty is also manifest in the the large losses associated with new product programmes which failed and has led to extensive studies of the reasons for failure and the appreciation of the importance of marketing factors and consumer aspects of new products. Freeman (1974) pointed out that inventions are uncertain at both the technological and market levels and believed that the risk and uncertainty surrounding invention was inherent and that it was unlikely to be reduced by better management techniques or project planning.

Demand-Pull

Studies of industrial innovation have revealed that many new products have failed been designed or re-designed to cater for consumer desires or market appeal. Consumer behaviour is essentially the concern of marketing, though some earlier economic research had pointed to the importance of ´non-price´ factors in demand. The importance of consumer appeal has long been recognised and may best be illustrated by reference to Emerson´s alleged aphorism "Make a better mouse-trap and the world will beat a path to your door."[5] Emerson had a very clear appreciation of the consumer response to a better designed product and its relation to increased sales, and innovation researchers now consider demand-pull to be a most important factor in product design.

Innovation Theories

Innovation studies have done more than clarify some features of invention, they have provided new explanations and new theories of invention and the way it helps growth. Innovation studies have made four important theoretical contributions.

Firstly they have shown that ´invention´ is not a single event but is a cumulative temporal sequence of events having two dimensions. One dimension is the typical pattern of a succession of product models which are introduced and subsequently improved over the life of the industry; the second dimension is the multi-stage nature of typical development programmes from the primary scientific research stage to the final commercial development stage and that the later stages in this sequence absorb greater efforts and expenditures.

Secondly it has been shown that manufacturers are far more concerned about product invention than process invention and that greater effort and expenditure is devoted to the creation of improved products rather than fundamentally new ones. In short that incremental invention is more important in commercial practice.

Thirdly innovation studies have attempted to classify the stimuli causing innovation and invention but in general these are so diverse and varied that no general model has so far achieved widespread acceptance but are greatly influenced by demand considerations and this has led to science-push and demand-pull classifications. Many demand aspects of innovation, and to a

5 Emerson originally said "If a man has good corn, or wood, or boards, or pigs, to sell, or can make better chairs or knives, crucibles, or church organs, than anybody else, you will find a broad, hard-beaten road to his house, though it be in the woods." Steveson (1967) has traced the later variations of this speech which, by 1871 contained the immortal "mouse-trap".

lesser extent demand aspects of invention/product design, have been further investigated by innovation researchers although these relationships are complex and no satisfactory general model as yet exists.
Finally, although innovation researchers have failed to establish any direct relationship between invention and growth they can partially specify the pattern of development and the importance of design features which can offset the decline in demand, profits and competition encountered in the later stages of the product life cycle, and of the market and economic significance of new or improved products.

Innovation studies have therefore contributed much to a further understanding of invention and its economic role by introducing new concepts and new theories which are very different from the earlier social and economic theories and concepts.

1.3 Design Of Inquiry

This broad survey of the scope of growth theories and of the nature of invention has been presented in order to clarify some of the issues involved and guide the final form of this inquiry.

This summary overview of four categories of theory has revealed changing concepts; early theories tried to be universal or 'grand' while later ones have been much more specific and narrow. The most concrete contributions have come from the later theories and the most promising avenue appears to be the innovation method as that has thrown most light upon invention. These innovation theories (or models) provide guides about the objectives, features and patterns which should be explored in this research. Several issues require further clarification; for example the role of science in product design, or the relative importance of pioneer and incremental inventions, or the complexity of the whole invention-design process, or the role of consumer desires upon product design. Such research could provide results which would serve as the basis for a general model of consumer durable product development and the relation between product invention and demand.

These considerations can be brought together to give an ideal specification of the design of the final enquiry. The chosen industry or products should focus only upon products which have a substantial technological content and which ideally have been the result of British invention and developed and produced in Britain. Ideally a comparison would be desired for the pattern of technological development for an 'empirical' and a 'science-based' invention to show if (or how) they differed and the value of science. The chosen industry should be sufficiently old to allow it to have developed through all the product life-cycle stages and have been in continuous production all that time and with evidence of the influence of the consumer upon invention and design. Data concerning invention, production and sales should, if possible, be complete.

In practice ideals are unattainable but two industries come reasonably close to the specification; these are the bicycle industry and the domestic radio industry. Both have good records of early inventions and later design changes partly because the general population were enthusiastic about them and created a market for journals and books which described the progress of invention in the early years, and also because annual exhibitions were held and the specialist journals or newspapers gave annual comments on the nature of these changes. There is also a limited literature of consumer attitudes towards popular new products, and of the problems which consumers experienced with them. Details of changes in production or sales technology are not so rich, and both suffer from a lack of production statistics in the early years of the industry concerned. These two new consumer products have a further advantage that they were not introduced to the market at the same time and that each involved different branches of engineering, the bicycle depended primarily upon mechanical engineering while the domestic radio depended primarily upon electrical engineering.

Analytical Method

The design of this research is based on the idea that it is exploratory rather than a formal test of any hypotheses. To this end it will analyse the course of product invention from the earliest incubation stage to the mature stage. Some consideration will be given to process invention. This analysis of invention will not be a formal engineering history but will primarily be concerned with the trends of invention and the factors which affected it. This analysis of invention will take inventive activity (as measured by patents granted for appropriate British patent classes) and indications of improvements to the technical performance into account. The influence of economic changes and consumer tastes, upon invention will also be considered. The nature of demand and the factors which influenced homesales will also be analysed with reference to economic and social factors.

The results will be used to create a general model of invention and growth for consumer durable goods.

1.4 Organisation of This Research

Chapter Two

The Literature Review

The first section of the literature review will deal with accounts or theories of invention; the second section will deal with the economic aspects of invention then an outline of the main modern economic growth theories which have dealt with invention (technical progress). A variety of Innovation studies will then be examined. This will be followed by a brief survey of the literature on Demand and consumer-design relationships. This literature will then be appraised.

Chapter Three

Method and Data

In this chapter a short discussion will be given of an appropriate innovation model chosen to serve as the framework for subsequent research and of the modifications and reasons for modifications of that chosen model.

This will be followed by a description of the sources and nature of data to be used.

Chapter Four

The Bicycle

In this chapter bicycle product inventions will be analysed at the level of Overall Configuration (types of bicycle) and Component level; cycle patent data will be obtained to show inventive activity and finally a brief account of process inventions for bicycle production.

The factors influencing demand (homesales) for bicycles in Britain will be analysed with reference to both social and economic factors.

Chapter Five

The Domestic Radio Receiver

In this chapter the basic approach used in the analysis of Bicycle development will be applied to the Domestic Radio Receiver; though an additional section dealing with the relation of science to product invention will be included as the radio industry is regarded as a leading example of a science - based one.

Chapter Six

The Model

A general model of the factors and patterns of the development of consumer durable goods, based on the results of the analyses of the bicycle and the domestic radio receiver, will be presented and described in this chapter.

Chapter Seven

Meaning of Results

In this chapter the results of this research will be discussed with reference to the main modern theories of invention and growth. This will suggest some changes in current concepts, improvements and indicate possible areas for future research.

Chapter Eight

Statistical Appendix

Chapter Nine

Bibliography

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2. CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In this chapter the aim is to show the various concepts and theories which earlier researchers have held about invention, its economic and consumer aspects. Previous research on these topics has led to an enormous literature which cannot be exhaustively dealt with here but fortunately others have compiled surveys of particular fields and reference will be made to these throughout this review.

Organisation Of This Chapter

2.1.1 Theories of Invention

In this section the main theories of invention and engineering design will be reviewed to illustrate the nature of technological development and the factors which have been considered to be important to it.

2.1.2 Economic Theories of Invention and Growth

This section will examine a range of Classical economists' views of invention and its economic effects. This will be followed by an account of various theories about invention put forward in the period 1870 to 1939, then a survey of business cycle theories and invention, followed by an outline of the main concepts of three modern growth theories, an illustration of historical growth accounting analysis, the use of R&D expenditures in models and attempts to consider product design in economic theories.

2.1.3 Innovation Studies

In this section a review will be given of the main features of invention brought to light by case studies; these include sources of invention, demand-pull, R&D budgets, new product design processes and recent models of invention/innovation.

2.1.4 Demand and Invention

This section will review the literature dealing with the economic theories of demand, and saving, economic features of durables, consumer aspects of demand and the literature pertaining to the consumer-design relationship.

2.1.5 Appraisal

In this section the concepts, theories and findings of the literature reviewed will be appraised.

2.1.6 Definition Of Terms

It was noted in the previous chapter that there had been some confusion about certain terms which are frequently used in technological economics and some definitions are given here to clarify their meaning.

Invention: Throughout this whole research the term ´invention´ will be taken to refer to technological change alone; this refers to both product and process inventions and pioneer and incremental inventions. The term ´invention´ will be regarded as synonomous with ´engineering design´ but will exclude ´industrial design´ (which is taken to refer to mainly changes in style, form, texture or colour which have no technological content).

Innovation: The term ´innovation´ will be taken to refer to the acts of adopting an invention for the first time and the events surrounding the spread (diffusion) of this adoption.

Technical Progress: The term ´technical progress´ (and its equivalents including ´changing efficiency´, ´the residual´, ´advances in knowledge´) will refer to both technological and non-technological process changes used by economists when dealing with the economic effects of invention.

Consumer Aspects: Throughout this study the term ´consumer aspects´ will be used to refer to the non-economic aspects of buyers´ behaviour.

2.2 Theories of Invention

A natural starting point for the investigation of invention is to regard it as the outcome of mental operations alone. No one can specify which mental operations are involved but since the time of the Classical Greeks it has been recognised that thinking and ideas are important. No really satisfactory theory of invention has ever been given and the actual process of invention remains a mystery. As a result modern researchers have tried to provide a technique or set of rules to aid inventors rather than an explanation. The topic has generated a huge literature, here only a summary of the main types of theories of invention and models of engineering design will be given:- some psychological theories of invention and creativity, this will be followed by other theories of invention which take some environmental factors into account, including the Mechanistic theory, and Usher's 'Cumulative Synthesis' theory. A brief note is then given about scientific invention and the historical development of professional invention and then a descriptive account of the invention of Holography. The section will conclude with a review of models of Engineering Design and some features of it which are not usually included in current models.

2.2.1 Psychological Theories of Invention

Most psychological theories of invention exclude the effects of environmental forces upon the inventor and concentrate upon the mental processes thought to be involved. In general each psychological theory of invention focuses upon a limited set of features and employs a small set of principles to explain the inventive process. Interest in the psychological aspects of invention has a long history; in the period before about 1950 psychological theories of invention owed much to general psychological concepts, especially those used in the study of thinking and learning. Bourne, Ekstrand and Dominowiski (1971) have described the historical development of the most influential theories of thinking although none of them have been satisfactory partly because mental operations are not overt and observable, partly because no two inventors seem to adopt the same procedures and themselves cannot explain how they arrived at their inventions and partly because unconscious forces appear to be important. Psychological theories range from early Associationist ones which explained invention as the creation of novel combinations, to recent Information Processing models which portray the inventive process in cybernetic terms.

Gestalt Theory Of Invention

One of the most influential psychological theories of invention was the Gestalt one which was derived from the Gestalt theory of perception and whose central concept was that perception was holistic and consisted of the organisation of a changing field of mutually interacting elements. The ability to perceive holistically was innate and not due to learning or previous experience but resulted from a reorganisation of the field elements, often because they had been viewed from a different perspective. Its key feature was the ´insight´ (or sudden flash of inspiration) which has long been associated with inventive solutions.

The Gestalt theory of the inventive process was a four-step one. The first step involved the perception of an unsatisfactory pattern or field stresses and a recognition of the problem. The second stage involved resolving these stresses by thinking (bringing elements or information together) and restructuring the problem. The third stage was an act of insight to a solution of the problem based on the previous restructuring and the fourth stage was one of testing the solution and critical revision. Wertheimer (1945) has exemplified the Gestalt method of invention.

Other Theories Employing Psychological Mechanisms

Heroic theories of invention hold that great inventions are the product of great minds and that environmental factors are of little importance. Smiles (1968, originally 1862) produced biographies of early British inventors which exemplified the heroic theory though he added an additional strand by emphasising the importance of character traits such as diligence and application. Theories of heroic invention placed great stress upon mental ability and this theme was expanded by others in later years. Galton and Ellis independently put forward heredity theories to account for geniuses.

A modern ´How To Invent´ book by Thring and Laithwaite (1977) is essentially a heroic account of invention. These authors suggested that the ability to invent was innate rather than learned and required originality of thought rather than the application of a direct logical process or systematic search of a predetermined field of knowledge. They also considered that motivation was an important factor, especially persistence to overcome obstacles and negative attitudes expressed by others.

Geniuses themselves did not wholly agree with the heroic theory; Edison considered that invention was ten per cent inspiration and ninety per cent pespiration. Later criticisms of the heroic theory pointed to the undue concern with pioneer inventions and a tendency to ignore incremental ones.

Chance theories of invention claim inventions arise primarily because of chance accidents, discoveries or serendipity. Mach (1896) has dealt with the role of chance and accident in invention, he believed that at the early stage of any new invention chance or accident could be very influential and lead to new concepts or new ways or discoveries because the chance finding often differed greatly from existing knowledge or concepts and prompted further investigation. Chance, discovery or accident was most influential when knowledge or concepts were vague, but chance, he said, by itself was insufficient to produce a new invention; it altered the train of thought causing new ideas or images.[1] There can be no doubt that chance events and chance inspirations have been associated with dramatic breakthroughs but most critics point to the steady effort and a repeated pattern of technological development and consider that something more than chance is responsible for that. Pasteur commented "Chance favours the prepared mind." Mach emphasised the importance of ideas in invention and considered that the important event was the recognition of the significance of the idea or new discovery; not all inventors recognised the significance of their inventions or new principles.

Cognitive Approach

Since the 1950s psychologists have largely abandoned attempts to create a theory of invention as they did earlier but instead sought to advance

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1 The relation between invention and discovery is a perplexing one. It has been said that both are inter-related; for example that the discovery of electricity led to later inventions to make use of it.

knowledge about thinking and its associated sub-processes - creativity, problem-solving and concept formation - all which had been of interest to psychologists before the 1950s. The basic premise of the modern cognitive approach is that the inventor acquires new information which he somehow uses in conjunction with prior knowledge or experience, to create a new invention.

Rothenberg and Greenberg (1976) have produced an extensive index to mainly psychological literature on creativity, spanning the period 1566 to 1974. Taylor and Barron (1963) have, in their introductory chapter, briefly described the historical development of research on scientific creativity and later in their book have shown how they have attempted to devise ways in which it can be identified and fostered. Whitfield (1975) has described the major features of scientific creativity, while S.A. Gregory (1972) and Jones (1974) have dealt with creativity in relation to engineering invention. Finkelstein and Finkelstein (1983) have given a review of more recent literature on creativity and engineering design. In general modern creativity studies are mainly concerned with stimulating original thinking using techniques such as brain-storming or synectics and, as Finkelstein and Finkelstein note, have "a singular lack of any analysis of the (creative) process." (p.216)

Problem-Solving

Modern theories of problem-solving have synthesised earlier psychological, philosophical and mathematical concepts and, as far as invention is concerned have primarily attempted to present a procedure or set of rules to assist inventors and designers to arrive at novel solutions. Interest in such procedures is not new; Samson (1896) gave an early version and considered that invention was the result of trained imagination. He presented a sequence which began with the instruction to get a clear idea of the objective (which could be difficult). The next step involved two views about prior knowledge; one was that aspiring inventors should read all they could about their topic, while others said that it was preferable to know nothing and begin with a fresh mind. The next step was to study all possible solutions that have or could be used to attain the objective then compare these alternatives and check for errors. He observed that the course of invention usually began with

crude designs which were later refined step by step.
Samson added some interesting observations about invention; he rejected chance theories saying that accidents and chance led only to ideas which had to be followed up and that practicability had to be shown by demonstration of a working model. Samson noted that quite often a principle was reversed, for example the dynamo was developed into the electric motor, the atmospheric brake into the vacuum one and the galvanic battery to the storage battery (the former gave out current, the latter takes in current). Samson added a few general comments; he advised his readers to deal first with problems and produce inventions which eliminated the defects. Only later should inventors tackle scientific inventions as these involved the need for scientific knowledge and technical education. He noted the short life of most patents and considered that only ten per cent were ever used (assigned) often because of reluctance on the part of those financing development though some inventions, such as the paper fastener, led to high rewards.

Dewey's Model

For Dewey (1933, originally 1910) thinking and problem-solving involved an iterative sequence of speculation (ideas), inferences (about solutions) and facts (observations or data). He presented a five-stage model: a) the recognition of the problem or 'felt difficulty'; b) the definition of the problem and/or the isolation of its relevant features; c) the formulation of possible or alternative solutions; d) the determination of the best solution by either testing or reasoning through the various possible solutions and e) the selection of the best solution and its implementation. Dewey added a caveat that this sequence was not invariant but nevertheless Dewey's model has spawned many linear variations and these form the core of most modern models of problem-solving and theories of engineering design.

Cognitive psychology has not made great advances in understanding mental process but regular reviews of each branch is given in the Annual Review Of Psychology. For example Medin and Smith (1984) in their review of recent psychological research on concepts and concept formation, noted that much effort in this field had led to little advance in understanding.

Inner Logic Theories of Invention

Another theory of invention supposed that technological change occurred primarily because of the action of "inner forces" and owed nothing to external changes in the socio-economic environment. The central tenet of this theory in its simplest form was that one idea led to another; or that the folution of one problem threw up another or that progress was due was due to inner forces. The earliest problem-triggered theory of invention appears to have been given by Hearn in the 1860s, technology historians call this the ´internalist´ perspective.

A modern version of the inner logic theory of invention has been developed by Rosenberg (1976 chapter 6) who considered that the principal causes of invention are problems or hindrances in the product or process itself, and that the trend of invention is guided by technical links or inter-relatedness cf other parts to that giving trouble. For example once a satisfactory method of cotton spinning had been created, inner logic pressure forced the invention of a mechanised method of weaving; and again that increased automobile speeds forced the invention of better braking. This type of theory has difficulty with the explanation of the original cause of the first invention and also in with entirely new inventions, but it has found hncreasing favour to explain the progress of incremental inventions. Whyte (1975) has presented twenty case histories of modern improvements due to the solution of technical problems.

Cardwell (1972) also pointed to problem-triggered invention. "But once the process became established, once the great cotton mills began to spring up, a host of new problems (italics added) arose and stimulated scientific enquiry and that were to give rise to new forms of industry. Thus by a process of chain reaction, new techniques were established that could hardly have been foreseen at the outset". (p 100).

Although this type of theory also has poor explanatory power it drew attention to the inter-related nature of technological progress and for a need for a ´balance´ among the technological elements. The inter-related nature of technological progress has been noted by Ashton (1968) and Sayers

(1950) who independently emphasised that invention was triggered in technologically related industries, Ashton gave some specific examples in early industries. One good early example was of the rapid improvements in bleaching, dyeing and steam engine technology due to the pull caused by improved cotton spinning industry. Scherer (1984, Chap. 15) has explored modern inter-industry technology flows to try and ascertain the nature of the links between invention in originating industries and their effects in industries which used them. His research represents a novel quantitative method of demonstrating the importance of such links which earlier observers had noted. Rosenberg (1982) has also noted the importance of inter-relatedness in technical development.

2.2.2 Invention Theories With Environmental Forces

Evolutionary Theories Of Invention

By the mid-nineteenth century in Britain it had become obvious that technological development did not consist solely of pioneer inventions but that a succession of incremental inventions followed and improved the original design. This feature had been noted in the development of cotton spinning machinery by Babbage (1832) who observed that after a period of minor inventions, a mature design emerged which seemed to remain relatively unchanged for some time.

Cardwell (1972) also noted the decline of the rate of improvement in maturity. By the early nineteenth century the requirements for more power had led not only to the experiments with new types of water-power (the water-column engine was one example) but also to the near perfection of the water-wheel. "Indeed the water-wheel had reached a point of perfection beyond which only detailed improvements would be possible." (p.104).

A comprehensive history of mainly British inventions and discoveries was given by Routledge (1876) who described the pioneer and some incremental inventions for the main industries of that time.[2]

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[2] This book was frequently revised to incorporate the latest developments, the fifth edition is by Crowther (1966).

Modern theories of invention and technological development use the term ´evolutionary change´ to denote a series of incremental inventions and imply that these are often the result of environmental forces.[3] Early evolutionary theories were more complex and stemmed from Herbert Spencer´s version of Darwin´s biological theory, which he used to describe changes in human institutions. Spencer incorporated earlier ideas too; one which deeply impressed Spencer when he read it in 1854, was Baer´s assertion that the trend of development was from Simplicity to Complexity. Other principles included "the instability of the homogeneous" by which he meant the tendency to heterogenity due to environmental forces which differentially modified it, another principle was "the multiplication of effects" meaning that effects became increasingly differentiated from each other, and that specialisms developed. Growth, for Spencer, was not just expansion but was a process accompanied by increased complexity and specialisms which formed a unity in which the parts and wholes changed over time with the fittest surviving. The central feature of early evolutionary theory was that change came from two sources, one was ´from within´ and said to be due to ´genetic´ causes, the other was ´from without´ and said to be due to adaptation to environmental forces. Although Spencer did not present a theory of invention, he did present an evolutionary account of industrial development which showed the increasing differentiation and specialisation of industries.

H. S. Harrison (1930) has given a mature evolutionary theory of invention. Harrison´s central aim was to explain technological development from early times and he incorporated ´objective´ and ´subjective´ aspects. Harrison did not believe that early man had foresight or preconceived ideas to the extent that modern man has, and thought that early technological developments were mainly ´opportunistic´. H. S. Harrison distinguished clearly between discovery and invention. The earliest technological improvements, Harrison said, were due to discoveries and their subsequent adaptation; for example early man discovered that stone had useful material properties which he used in later adaptations as stone tools. Discovery led to new knowledge which could later be applied to other fields. Invention involved a conscious search for means

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[3] The term ´evolutionary´ is also used in modern times to denote a competitive economic system.

or methods which demanded foresight as the inventor designed his products before making them and this required the use of previously evolved principles or ingenuity thus invention was a new combination of structures or devices already in existence. Invention, according to Harrison, involved an 'inventive step' or major change and he designated this a 'mutation'; however Harrison also recognised that many technological developments involved only small advances and he designated this kind of invention 'variation' which was usually the consequence of selection and imitation of earlier known types or principles. The broad pattern of technological development was then one of mutation followed by variation. Another feature was secondary invention (large changes) based on earlier variations; if this involved foresight on the inventor's part it was designated 'cross-mutation' but if it was opportunistic it was designated a 'free mutation'. These secondary inventions showed that much invention was due to a combination of existing knowledge or ideas.

Mechanistic Theory Of Invention

The Mechanistic theory of invention laid great stress upon the importance of later incremental inventions and their effects. This school considered that invention was primarily the result of Social Determinism so that social needs directed inventors to a problem and they provided a suitable solution.

Ogburn (1923), Hart (1931) and Gilfillan (1970), each traced the improvement in performance over time of various man-made products such as railway locomotives, machine tools, ships, aeroplanes and so on. They concluded that the effects of incremental inventions had been as great if not greater than the early ones and decided that early 'heroic' theories which concentrated on pioneer inventions had been mistaken. This led to their concept of 'mechanistic' invention, meaning that the particular inventor was of no real importance as another inventor would have made the same invention or an equivalent one. The numerous instances of 'duplicate' (identical or equivalent inventions made at about the same time) was offered as proof that invention was largely determined by social forces. They also believed that inventions emerged from the general culture and would be made 'when the time was ripe'.

Cumulative Synthesis

A.P. Usher (1954, originally 1929; 1955) stressed the cumulative nature of inventive progress. He was concerned to refute both the heroic and mechanistic theories of invention and his observation of the pattern of technological development led him to believe that progress was based on a "cumulative synthesis" in which advances were later combined with earlier ideas or knowledge to provide a new solution, so that mental and environmental factors were included in his theory. Usher was influenced by Gestalt theory and the patent law definition of invention which stressed novelty (or the flash of genius) which made Usher distinguish between pioneer invention and "acts of skill" or routine changes which did not involve any novelty.

Usher employed a four-stage model. The first stage was the perception of an unsatisfactory pattern and the recognition of a problem or solution. The second was "setting the stage" in which elements or information were brought together. The third stage was the act of insight in which the solution was found; this was a highly uncertain process and because of that it was not possible to predict the timing or configuration of the invention in advance. The fourth stage was one of critical revision in which new solutions became fully understood. This whole cycle was designated a ′cumulative synthesis′.

Usher considered that the invention produced by the four stage process noted above was then modified by environmental forces to make it one of three types, either primary, or secondary or tertiary. Primary types were developed either from the results of pure science or for use in situations where cost was of no concern. These inventions could produce articles of technical excellence which were not carried to commercial use. Secondary types opened up either a new practical use or extended a new principle to other fields; these secondary (or pioneer) inventions were very important in the market and as a result financial aspects of invention became more important. These inventions often formed the basis of limited monopolies which made them very profitable and part of the resulting growth came from the diffusion of these inventions. Tertiary types did not extend the field of use and were essentially incremental inventions.

The progress of invention was thus a series of advances based on technical and commercial influences. When secondary inventions were well launched or even complete, the diffusion of the invention often called for further inventive efforts usually because of the need for more profit, and these inventions were iterative, incremental and increasingly subject to economic constraints.

2.2.3 Science and Invention

Since 1945 most theories have stressed the science-push concept - that ´science discovers, technology applies´. Inventors are presumed to build upon new knowledge which has been created by scientists (usually pure scientists) and translate this new knowledge into practical designs.[4]

One British theory of this type was given by Blackett (1968) who said "--- successful innovation can be envisaged as consisting of a sequence of related steps: pure science, applied science, invention, development, prototype construction, production, marketing, sales and profit." (p.1106).

This was an example of the early linear multi-stage science-push model which was soon superseded by a more complex one because of later evidence. One influential result came from the TRACES (1968) study of the origin of five innovations (magnetic ferrites, video tape recorder, oral contraceptive pill, electron microscope and matrix isolation) which found that about seventy per cent of the key events originated from "non-mission" research (projects undertaken without a clear initial objective but which produce useful or usable results), while only twenty per cent were "mission" directed and the remainder (about ten per cent) were classed either as Development or Application events. This American TRACES project was interpreted by some as stating that "non-mission" scientific research was important and this idea

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4 The American ´National Science Foundation´ (N.S.F.) has provided definitions of the different types of research categories; Basic (or Pure) Science refers to original investigation for the advancement of scientific knowledge which has no specific commercial objectives, Applied Science refers to investigations to discover new scientific knowledge with specific commercial objectives, while Development refers to technical activities of a non-routine nature to translate research findings and other scientific knowledge into commercial projects. Kennedy and Thirwall (1972) note that British definitions are very similar. It may be added here that N.S.F. finances a great deal of ´research into research´ and that these publications form the largest source of references upon economic and non-economic aspects of science, invention and their effects. In Britain official R&D related statistics have been published by the government since the 1960s and closely parallel N.S.F. practices.

was incorporated in the model by Byatt and Cohen (1969) who suggested a method of quantifying the economic benefits of science, and who included a category for "non-mission" research as well as "mission" research in their model.

Qualifications of Scientific Invention

The scientific theory of invention has never been without its critics. Webster (1872) observed that although science had been responsible for many inventions, especially in chemistry, he drew attention to the many inventions which had preceded scientific knowledge and indeed suggested that inventions had been an important factor in scientific advance and wished the British Association to examine this idea.[5]

Plant (1974, originally 1934) quoted an even earlier statement made by Hearn who in the 1860s, said that even then many processes of our successful arts have not yet received a scientific explanation. (p.40). Rolt (1977, originally 1970) (pp.167-170) considered that until about 1860 British engineers largely mistrusted science and preferred empirical methods of design. These engineers regarded science with suspicion and believed that it was no substitute for practical experience. British engineers up to that time had been regarded as more or less geniuses and when British scientists ventured to pronounce on engineering matters, Rolt said they made fools of themselves and confirmed the suspicion about science. The anti-science legacy proved to be a great handicap soon after as other countries began science-based investigations, while in Britain ´practical´ engineering education continued.

The results of many modern empirical studies have shown that basic science forms only a small part of the input to industrial invention and even this is usually confined to science based industries. In America Price and Bass (1969) discussed the results of case-studies in that country which showed that the discovery of new knowledge (from basic science) was not the typical starting point for the inventive process although interaction with new knowledge or scientists could be essential. Industrial invention, they said, depended upon information which could not be specified in definitive terms in

5 Rosenberg (1982, p.14) refers to L.J. Henderson´s pithy comment ´that science has been far more indebted to the steam engine than the steam engine has been to science´.

advance, while the application of new scientific knowledge critically depended upon an entrepreneur whose values and interests were much more commercially oriented than to science. Thus science and technology were separate worlds and in general 'technology fed upon technology'.

Jewkes, Sawers and Stillerman (1969) studied 70 modern innovations in order to establish if these originated from scientific discoveries made either by large firms or research institutes. They found that about half of these innovations came from outwith large firms and that few had depended upon any prior scientific discovery. They also established that individual inventors were important sources of pioneer inventions. They concluded that the alleged change in the nature of invention (to modern invention by professional personnel and organisations) was not as widespread as many claimed and that much modern invention was still of an empirical nature and dependent upon individuals rather than scientific research institutes.

Langrish, Gibbons, Evans & Jevons (1972) found that the sources of 102 British innovations came from outside the firm including technology transfers from new personnel joining the firm (the most frequent source), 'common knowledge' from industrial experience and education, commercial agreement and know-how, scientific and technical literature, personal contact, collaboration with customers or suppliers, overseas visits, conferences and consultancies (their table 7, p.79). In their discussion of the role of science they questioned its importance firstly on the supposed acceleration of technological changes noting the difficulty of timing lags and observing negative lags (i.e. inventions occurring before science had developed), and considered that a better representation was of a two-way flow between science and technology. They then turned to the Byatt-Cohen model and its non-mission research and concluded that it was difficult to pin-point specific curiousity- oriented discoveries although they had encountered two cases outside the Queen's Award list; and generally concluded that the transition from 'pure' knowledge to wealth was less simple and direct than is commonly supposed. They believed that science somehow contributed by occasionally producing discoveries which could lead to new technology, which provided techniques which assisted in the solution of industrial problems, and trained people in its theory and methods.

Langrish et al were surprised by the relative unimportance of basic science as a cause of innovation, especially as they had sought it.
Price (1965) said that historical evidence pointed to an independent relationship between science and invention. Gibbons and Johnston (1970) traced the history of the development of semiconductors and found that empirical inventions and design methods were very important in the early stages of its development. Gibbons and Johnston (1974) examined the background to a number of ´ordinary´ (low technology) innovations and found that only about 30% involved the use of published scientific research findings. They concluded that the relationship between science and technology (invention) was much weaker than portrayed in current science-push models.
The Third Report Of The Council For Science Policy (1972, Cmnd 5117) questioned the validity of the Byatt-Cohen model and considered that proof of the economic benefits of science had not been convincing.

Jevons (1976) has described how he and his colleagues, while working on the innovations described by Langrish et al (1972) had concluded that none of their cases fitted the Byatt-Cohen model. Jevons´s criticism of the Byatt-Cohen model was that it assumed an innovation had a single origin and also that it was oriented to ´push thinking´ - that inventions pushed the innovation process thus ignoring need-pull which Jevons et al found to be twice as frequent as ´push´. As a result of these criticisms Gibbons and Johnston undertook a study of 30 recent British new product innovations and specifically enquired about the origins of invention/information. They found that these origins could be classified into three groups; a) those depending upon previous knowledge b) those obtained within the company and c) those obtained from outside the company. In all there were 900 invention/information inputs and the ones from outside the company were classified as either ´scientific´ or ´technological´; there were 300 in all of which 100 were ´scientific´. Jevons said this indicated that science played a supporting role rather than an initiating one, and in none of the cases did scientific discovery induce innovation. It was also found that the science-technology coupling was unevenly spread across innovations, a few innovations required a cluster of science inputs while the majority involved no science inputs at all. This evidence was forwarded to The Third Report of the Council for Science Policy noted above and Jevons made reference to later publications embodying this research.

The autumn issue of Technology & Culture (1976) contained papers presented at an earlier conference held to discuss the relationship between science and technology. The main conclusions reached were that the 'problem' about the science-technology relationship owed much to American and British cultural attitudes about science, engineering, design and technology and the relative social status of each activity. The findings by various speakers showed that invention need not involve science but that many forms of engineering research employed the same method(s) as science and aimed to provide 'laws' or general formulae which could be used by any later designer. Science was considered to be most concerned with 'understanding' while technology was most concerned with practical or economic results. Musson and Robinson (1969) had examined the relative role of both science and technology throughout the course of the industrial revolution in Britain and Robinson said that technology was not so empirical in nature as many historians made out and that science was only one of many elements in a complex process of technical and economic development. Many speakers at this conference had found it commonly the case that scientific investigations were caused by technical difficulties which came to light during development.

Sahal (1981) pointed to the more recent evidence for much empirical invention and technological progress which is not based on prior scientific knowledge and that at the aggregate level there does not appear to be any direct relationship between economic growth and prolific scientific advances for particular countries, Britain being a good example. Moreover, as Blackett recognised, only a very small percentage (about ten per cent) of the R&D budget was spent on Basic Science. The present position is that the contribution of science to invention is not clear but it is fashionable to speak of a two-way interaction, and perhaps follow Rosenberg (1982) by suggesting that much modern invention is due to empiricism.

British Science and Industry

It is briefly noted here that British concern for science and industry only began in earnest during the first world war when it was discovered that much of the advanced equipment and materials had, in pre-war days, been supplied by Germany and that British inventors and manufacturers were apparently unable to create urgently needed substitutes. This prompted Peddie (1915) to reproduce the texts of British Association meetings and other literature warning of ´England´s neglect of Science´. After 1918 immediate steps were taken to promote science-based industrial development by various measures such as the establishment of industrial and government research organisations, and the introduction of better technical education. The even more dramatic demonstrations of science and military technology in the second world war led to a universal recognition of the importance of science and its close connection with invention and technological advance. In 1945 and 1946 The Advancement Of Science carried lengthy reports of two conferences dealing with the need for British industry to become more aware of the potential contributions which scientific research could make, and of a new emphasis on science and industry, which led to the creation of many government/industry research groups.

2.2.4 Historical Development Of Professional Invention

Notwithstanding the inconclusive view of the relationship between science and invention, there is a considerable amount of agreement that most invention up to 1914 could be classed as empirical but from the end of the first world war invention has become more professionalised and executed either in special research units or the laboratories of large industrial organisations who have the necessary resources; Rosegger (1980) and Cardwell (1972) have commented on this.

Cardwell (1972) traced the development of British invention and engineering practice and believed that they had evolved through four stages. In the earliest stage, during the middle ages, inventions had been precocious as they were ahead of scientific knowledge but as inventive effort had occurred over a vast range of activities and also over a long time these had cumulative effects upon economic development (and perhaps even more important, changed the medieval outlook). The significant feature was that these precocious inventions were used. The second stage of development occurred in the early seventeenth century when inventors used two modes, one was the empirical mode which was essentially precocious, the other was science-based. This new development was founded on Baconian and Galilean scientific concepts and methods and led to experimental results being applied to designs. The third stage, which began at the start of the industrial revolution, saw a further extension of scientific types of invention and also the continued use of empirical invention. Cardwell described the new scientific types of invention in this period; one was the 'Newtonian' approach which applied new scientific knowledge directly, another used the scientific method to analyse technical problems and hence develop solutions - Watt was cited as an example of this type, the most important method was called the 'Smeaton' approach in which the scientific method was used systematically to design products having the maximum possible efficiency - these were evolutionary inventions not revolutionary ones. The fourth modern stage, which began about 1870, saw a rapid convergence of science and technology in the form of new institutions in which teams of professionally trained scientists and engineers used advanced techniques and theory at all stages of a technological project until the invention was technically feasible after which engineers developed it in a form suitable for production and sales. This had recently been further evolved to emphasise the role of pure science.

2.2.5 Descriptive Account Of Invention

Holography

A descriptive history is now given of the development of holography to show how real life projects proceed, the great uncertainty connected with pioneer inventions and the stark contrast of its actual development compared to the theories of invention.

An account of the progress of holography from 1948 to 1971 was given by its inventor Gabor (1972) who considered its origins began with Young's demonstration of mutual interference by light waves. In 1947 Gabor considered how the images from an electron microscope might be improved so that they would reveal the atomic lattices. This was impossible at the time because of the limitations of the electron microscope due to problems with diffraction and spherical aberration. Gabor had an idea that the imperfect image given by the electron microscope might be corrected after, by optical means, thus using the whole (but distorted) information in the original image. Gabor believed that this could be done by a method which utilised the phase differences.

Gabor considered that a system of "reconstructed wave fronts" (later called holography) could be used. These were essentially interference patterns which were to be obtained from a second source of radiation. Previous researchers had evolved two stage methods of obtaining these, but Gabor had the idea of an extension embodying the reconstruction principle.

Gabor conducted some early experiments but encountered a variety of problems most of which were due to weaknesses or limitations of the equipment, but one - the problem of secondary images - being inherent in the interference method and for which Gabor provided a solution and obtained small but clear holograms; a demonstration of the feasibility of his idea.

Gabor published accounts of his findings and this led others to pursue investigations and experiments resulting in advances in theory and new techniques.

Then by 1955 holography apparently entered a period of "long hibernation" as no one else seemed to be interested in it; but unknown to Gabor and the scientific world, holography had been taken up by U.S. military interests and was used as a basis for "side-looking" radar. This military (and secret) development had involved not only a further theoretical advance but was also combined with the development of the laser which eliminated the problem of secondary imaging and provided a method of producing very clear images.

Progress was rapid once this information became public and developed in directions which would not have been predicted at the outset. This involved many previous ideas and techniques which will be very briefly summarised here.

The use of laser light made it possible to record two different holograms on one photographic plate in 1962 and gradually this was increased to a capacity of about three hundred holograms on one plate. This new and unexpected property formed the basis of most of the later inventions.

The ability to store very large amounts of information proved to be a major feature of holography which changed from an image-processing technique to that of information storage. The storage was made possible by the "distributed memory" condition in that each interference pattern of an object was repeated many times so that each individual image contained "the whole".

In addition because the image was an interference pattern which was reconstructed, the image was not degraded by scratches, hairs and other imperfections which affect normal photographic images. This application of holography has now been introduced to commercial use.

Another property of multiple image storage is the ability to simultaneously compare two (or more) images on one plate. The development of pulsed laser beams in 1965 allowed very short and rapid flashes to be produced and in conjunction with multiple imaging, led to the ability to record a succession of images which could show detailed motion in a series of 'frozen' shots.
Another application which was commercially very useful, was in the field of non-destructive testing. An image of an unstressed object was compared with one of a stressed object, and the resulting interference fringes showed the differences and therefore the stress effects.
Gabor noted that these new techniques and applications were devised simultaneously and independently by more than one inventor.

The use of laser light made much larger images possible, and whereas the first holograms had to be viewed through a microscope, laser images could be viewed by the unaided eye. This led to three dimensional pictures being available in monochrome and later led to attempts to produce coloured holograms. The attempts to produce coloured plates began with techniques devised much earlier for other purposes, the standing wave technique dated from 1908. Two colour reflecting holograms were satisfactorily developed but two and three colour (non-reflecting) holograms have not as yet been perfected.
Gabor considered that future applications will include pattern recognition, panoramic holography, three-dimensional cinematography and the possibility of viewing atomic lattices.
This account of the development of holography has revealed many features noted in various theories of invention and some exceptions. The original objective (to view atomic lattices) was never achieved. Gabor's inventive step was his method of reconstructed wave fronts, which embodied his key idea namely to use the whole-but-distorted image and later add a corrective thus leaving the undistorted original. It has portrayed the origin of the idea, its relation to previous theories and methods, of problem-induced invention, of

stasis in progress, of unanticipated later applications, of uncertainty throughout the whole project and of applications which were not foreseen at the outset. It also shows that social forces were not important while economic forces were only marginally important in later stages.

2.2.6 Engineering Design

There is some difficulty in distinguishing Engineering Design from Invention. One witness, quoted in the Feilden Report (1963), considered that a distinction should be drawn between creative engineering design and "sheer professional competence reflected in the ease with which a product could be manufactured, its reliability etc. Both types of design are necessary." (para. 23) The Feilden Report defined engineering design as that activity which involved the use of scientific principles, technical information and imagination, but excluded stylistic design (industrial design), for all stages of the design process from conception to production. The Feilden Report considered that engineering design was a two stage process; the first stage being concerned with the conversion of the customer's specification (if he could supply it), and the second stage being concerned with the detailed design of components etc. This concept shows that engineering design is different from invention and that the stress on novelty or originality is not as strong as in the case of invention. Finkelstein and Finkelstein (1983), in their review, classified modern design methods into three groups:- 1) Creativity approaches (described earlier in this chapter), 2) Systems approaches which were primarily rules for project management and 3) basic problem-solving models which were most numerous and which will now be described.

<u>Simplest Engineering Design Theory</u>

The simplest concept of engineering design is one which conceives that it is solely a matter of applying scientific or technical principles to a given problem. In its crudest form this simple theory is implied in engineering textbooks for students which usually introduce their subject by a statement or proof of a formula and then present 'examples' (problems) which can be solved completely by the application of the formula. More refined versions of this crude theory are given in design books which again introduce their subject with a statement of the principles and an illustration of some design solutions although they often point out that there is more than one technical solution. The key theory behind both models is one of 'principle-push' as no other factors are taken into account.

More Complex Design Theories

More complex theories or models of engineering design involve combinations of more elements. One very common combination is that of Dewey's problem-solving model with the typical activities which span a new engineering project. Stephenson and Callender (1974) have given such a model which they regarded as basic whatever the magnitude of the problem involved. Their stages were

Statement of the problem.
Collection of relevant data.
Selection of preferred design.
Development of detailed design.
Prototype testing and development.
Production.

They noted that in practice the steps were not clear cut, that there were difficulties in formulating the initial problem and that much feedback occurred among the stages. However this model typifies many with its linear sequence.

Theories of Engineering Design Incorporating Economic Aspects

In real life and engineering designer has to contend with more than technical factors as this quotation from the English Mechanic (anon, 1874, p.135) shows. "The object of all practical science is to produce economical results, to arrive at a mode of contrivance or making a thing that shall be not only the most efficient or perfect we can accomplish for the end proposed but also, and at the same time, one that shall simple in construction and requiring the least amount of material --- the most efficient contrivance produces the least wear and tear and required the least attention and repair".

That emphasis upon the economic aspects of engineering design has been greatly developed since 1874 and finds its expression in Value Analysis - a

method of designing low cost products. Buck and Butler (1970) in their analysis of economic product design and the practice of value analysis, have noted at the outset that engineering design has to satisfy Technical, Ergonomic and Aesthetic criteria as well. In value analysis engineering design is used to modify product design, component design, materials and manufacturing methods in order to reduce costs. This technique often achieves its goal by reducing the number of components, or making a single element perform more than one technical function or using either cheaper materials or materials which will allow cheaper production methods to be used. These authors gave an example of a re-designed aircraft tail lamp cover which reduced the number of components from four to one, cut its cost by 96%, reduced its weight by 38% and increased the product's reliability.
Value Analysis has an even broader scope and in practice further cost reductions can often be made by reducing waste in the production processes, easing tolerance limits where possible, considering alternative types of finish and assessing the savings of other non-technological practices such as buying standardised assemblies or components and bulk purchasing. Gage (1967) has given a comprehensive account of the engineering and costing techniques. Value Analysis shows how important the economic influence is upon product design.

Even more comprehensive models of engineering design have been given. Gasson (1974) in his book of the theory of engineering design, has presented a BASIC sequence of five stages (Brief Analysis, Synthesis, Evaluation, Implementation and Communication) which is largely based on the application of engineering principles. Each stage is inter-related and is considered as a decision-making process with many choices each of which has to be evaluated. The trend of design is one of narrowing choice so that at the outset a designer has great freedom and can make many assumptions but as the design process continues his scope is reduced and towards the end the cost of fundamentally changing the design would be so great that it would not be normally contemplated. Gasson provided for a variety of sources for the original 'problem' which could arise because of social change, or competition, or changes in consumer preference or from a new invention and together they formed the basis for the perceived objective. The solution to the problem involved a synthesis of constraints and influences which had to satisfy technical, economic and other criteria and produce a design which had a ´sum total´ of desired effects. This design was then evaluated by assessing it against a matrix of factors and then communicating the design for production and sales. Thus Gasson´s model takes economic and consumer factors into account although it primarily rests upon ´principle-push´.

Pahl and Beitz (1984, originally 1977) have presented a systematic and complex theory and method of engineering design developed principally from earlier German theories and procedures. Their model, depicted on p.41 of their book, is a four-stage one (Task Clarification, Conceptual Design, Embodiement Design, and Detail Design) and provides for technical and economic choices. These authors intended their model to give rational design solutions quickly, optimally and in detail.

Additional Features of Engineering Design

Two additional features of engineering design which are not normally included in models of invention or innovation have been described by Cardwell (1972) whose illustrations of engineering design practice are briefly summarised here.

Engineering "Trade-Off"

One characteristic of invention and engineering design is that solutions are frequently required which satisfy two or more conflicting objectives; these can be purely technological objectives or a mixture of technological and say economic objectives. Cardwell has given, but not elaborated on two beautiful examples of a wholly technological trade-off. In clock development a weight-driven model had a problem which was fully appreciated at that time, and its solution was the essence of invention. If a free weight was used to drive the clock it naturally accelerated and if some form of braking was introduced there were further complications due to uniform action and wear. The ultimate solution was the escapement mechanism which was an ingenious and precocious invention based on a design using two opposing motions for the wheel and pallet and giving a uniform rate of fall. The next major clock invention was the use of energy stored in a coiled spring which was released by an escapement. This too had an initial problem which was widely known at the outset, namely that as the spring unwound the driving force weakened. This problem was overcome by the invention of the stackfeed compensation mechanism, and later still by the fusee mechanism which performed the same function. The final step in medieval clock invention was the pendulum clock in which the pendulum controlled the escapement.

The invention of printing provided another example of trade-off invention. The first type of design was based on the principle of movable type so that the use of individual letters could be composed to print any text. The second feature was the way in which variations of the mould dimensions were controlled by transferring precision to the mould for the individual types thus obviating cumulative errors of the assembled type and ensuring a uniform printing force.

Multiple Invention

Another well known characteristic of technological development is that a new invention attracts the attention of other inventors who produce either an equivalent or an improved design.

Cardwell (p.107) noted that Watt's success with the piston steam engine led other inventors to experiment with other types of heat engine and the triumph of the piston steam engine was the outcome of a long and sustained struggle for survival among the many varieties of heat engine that inventors proposed. These included simple reaction types, simple steam windmill types, 'buoyancy' engines, direct rotative engines, unsuccessful designs intended to harness the expansive force of metals and liquids, and many attempts to find a different working substance (air or liquid). This implies that 'duplicate' inventions arise as much from invention-push as from social needs, and that ideas can be communicated.

2.3 Economic Accounts of Invention and Growth

2.3.1 Classical Theories

Classical theories laid the foundation of many modern economic concepts and concentrated upon supply factors such as resources, technology and the institutional structure as determinants of capacity output and especially stressed the contribution of high rates of capital accumulation in a laissez faire environment. They also provided interesting and differing accounts of the economic aspects of invention and these will form the main focus of the following review. It is noted here that classical growth theories were divided into two main types; one was the 'optimistic' group and the other the 'pessimistic' group; these groups reflected the belief in the possibility of long run growth the pessimistic group considered that this was not possible because of Diminishing Returns, food costs and wage rates.

Adam Smith

Adam Smith's[6] 'Inquiry Into The Nature And Causes Of The Wealth Of Nations', (1961, originally 1776), combined many old ideas into a coherent economic system.

Smith presented three inter-related growth theories; his starting point may be regarded as his definition and classification of growth given in Book 1 chapter 8. He noted that different countries had experienced different growth rates and defined these states in terms of his measures of growth which were Population (the most important) and wage rates. In a 'progressive' (high growth rate) state population and wage rates were increasing, 'our North American colonies' were an example of this. A 'stationary' state was one in which neither growth nor decline occurred, while a 'declining' state was one which had experienced both a reduction of population and wage rates; examples were given of both types of states.

Smith's Historical Growth Theory

In Book 3 chapter 1 Smith gave his historical growth theory. He believed that growth proceeded through four stages from an early and rude economy to a

[6] Invention had attracted the attention of even earlier economists Heertje (1979) considered that Steuart was the real founder of an economic theory of invention; this view is not shared by Skinner who gave his reasons in his introduction to Steuart (1966, originally 1761).

progressive state. This growth followed a 'natural order' in which Agriculture was first developed, then Manufactures then Foreign Trade and associated activities. This sequence was not necessarily invariant and examples of an 'inverted' growth pattern were given. The chief factors which influenced historical growth were social and determined the rate of capital accumulation; thus if societies wasted resources on wars and military spending, religion or ostentatious life styles and similar 'non-productive' activities, the capital necessary for improvements to create growth would not be available and growth would not take place.

Smith's Capital Accumulation Growth Mechanism

The second of Smith's growth theories can be regarded as a purely economic one which described the mechanism of capital accumulation. This involved other economic mechanisms including Distribution, the Price mechanism, Wage theory, Bank Credit and Money which all affected capital accumulation. The action of capital investment was to improve production facilities and its organisation (Division of Labour). The decision to invest depended upon the prospective rates of return which followed the 'natural order' noted above and the whole sequence was iterative.

Smith's 'Division Of Labour'

The third of Smith's growth theories was essentially a theory of production and its central mechanism was Division of Labour (which included invention) which greatly increased productive efficiency. Division of Labour comprised two elements; one was non-technological improvement due to better organisation of the work processes which primarily consisted of breaking the whole productive sequence into its single component operations and having one man perform each function. This improved efficiency by allowing one man to specialise at his own task and by saving the time which would be wasted in setting up each individual process; it also ensured that those with a natural talent for each task were attracted to the job and naturally benefited from further training and improvement. A third benefit noted by Smith was that the limited and repetitive tasks of uniform operations led 'naturally' to the invention of machines for production.

The other part of Division of Labour was essentially an economic theory of invention and became the core concept which exists in most modern economic theories. Smith believed that inventions led to the development (or improvement) of machinery which 'saved labour' and therefore reduced production costs which, in turn meant lower product prices and therefore increased demand as well as increased profits which later allowed further improvements. Smith's invention theory was one of process invention effects. In his 'History of Astronomy' Smith also described product invention development and noted that normally a newly invented device was no sooner introduced to the market than other inventors set out to improve the design and frequently did so by simplifying it.
The progress of Division of Labour was governed by demand (the extent of the market) although other minor factors such as location and transport affected it too. Smith's famous illustration of the application of Division of Labour to Pin manufacture showed its results; the physical volume of output was greatly increased, product prices were reduced and the consequent increased demand led to higher profits which were (or should be) re-invested to further increase Division of Labour.

Smith cited the sources of invention; one was the talented workman himself who saw the way to make improvements; another was the machine-makers who had been a fertile source of improvement inventions; and finally there were 'philosophers' and 'projectors' (scientists and inventors). Scientists engaged in no particular trade and could therefore attend to any matter of interest though the majority had specialisms on which they concentrated and were also divided into ranks of ability.

Malthus

Malthus is most famous for his 'Essay on Population' first published in 1798 in which he expressed concern that the rate of population increase, unless restrained, would outstrip the rate at which food supplies could be increased. Many have interpreted Malthus's work as a pessimistic forecast about future growth but, as Malthus made clear in his 'Principles' (1974, originally 1820) he was not and neither was he fearful of the effects of machinery. In Part 2

Book 2 of his 'Principles' Malthus presented a growth theory partly to show how food and industrial production grew. This was based largely but not totally on Smith's earlier theory.

Malthus adopted a distinctive approach to the analysis of growth; he began by testing four propositions: that growth could solely be explained by the action of a single factor. These factors were Population, Fertility Of The Soil, Capital Accumulation and Inventions To Save Labour. He concluded that not one of these acting alone could explain growth but that the joint effects of Fertility Of The Soil, Capital Accumulation and Inventions To Save Labour appeared to be the main ones but even so were insufficient. In the second part of Book 2 Malthus gave his theory of Effective Demand (by which he meant demand at prices sufficiently high to be profitable) and that this had to include the 'non-productive' portion of the population. If this was done then there would not be the need for the great frugality which Smith had emphasised as crucial for rapid capital accumulation.

Malthus's chapter on Inventions To Save Labour included many interesting observations. He thought that all inventions would be used because they were man-made and, unlike Land, would not lie fallow. He considered that the profits from invention were not uniform but depended upon price elasticities (in today's phrase) and highest when elasticity was highest. Malthus acknowledged that inventions displaced labour but that new employment would be created so the prospect was one of long term growth as the Wage Money saved by the labour displacing invention would lead to future investment in another industry. Some inventions destroyed capital by making old equipment obsolete. In general Malthus considered that invention had created growth and he illustrated this with reference to the Board Of Trade Returns for 1817 which, he said, showed that the greatest increase of exports had been in products produced by machinery and this was due to their low prices.

The Machinery Question

During the 1820s and 1830s a great deal of discussion took place about the imagined effects of machinery upon the economy with a sharp division of opinion about growth (or stagnation) and unemployment. Berg (1980) has given a comprehensive account of the arguments advanced by various British economists about this matter in the period 1815 to 1848. In this section the concern is with the advances in understanding of the effects of invention; although it may be noted that by 1848 it was realised that Britain had experienced long run growth as Porter's 'Progress of The Nation' illustrated. These statistical accounts did not explain how invention had achieved its effects.

One form of explanation centred on price reductions. In the year following the publication of the first part of Tooke's 'History of Prices' an article gave illustrations and reasons.[7] It was noted that although the prices of meat and drink had fallen since 1812, the wholesale prices of manufactures had fallen even more and quoted examples of the extent of the reductions between 1818 and 1834 which included Buttons (per gross) from 4/6d to 2/-; Gun Locks from 6/- to 1/3d; Plated Stirrups from 4/6d to 8d. All these items were made in Birmingham and the price reductions were due to two factors; one was the price reduction in raw materials, the other was invention which had led to "the amazing improvement in our machinery which enables an increasingly large quantity of work to be executed now than formerly".

Many had observed the relation between the use of machinery and growth; Baines's history of the cotton industry and Ure's philosophy of manufactures gave illustrations. However an early systematic investigation was conducted by Babbage (1832) who set out to establish the effects due to the change to power loom weaving in 65 British establishments over the period 1822 to 1832. Babbage accepted the core Classical concept of invention leading to the development of machinery which saved labour, cheapened products and increased demand. His investigations showed that the adoption of power loom weaving had led to a fourfold increase in the physical volume of output and that this was accompanied by a twenty per cent increase in the numbers employed.

Babbage made further observations about invention. He noted that price

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7 (Anon) "Political Register: Wages and Prices" Tait's Edinburgh Magazine 1839 6 pp.197-198.

reductions were not all due to the effects of invention but that increased scale of operations and currency changes contributed to price reductions as well. Invention had indirect as well as direct effects upon production; for example the steam engine had been used to make previously water-logged mines economically active again. Babbage described the characteristic pattern of technological improvement in which later minor inventions contributed and often these changed machinery to a self-acting type. The adoption of inventions depended upon economic circumstances too, and periods of competition forced manufacturers to seek the most economical methods of production and calculate returns in advance; these returns were affected by the durability of the product. Although invention displaced labour, the general increase of economic activity meant that further invention created new employment.[8]

J.S. Mill

J.S. Mill (1965, originally 1848) presented the mature version of Classical theory which was embellished as a result of observation of later developments. Mill noted that growth had been considerable in Britain since the 1820s so that earlier fears about a stationary state had been unfounded although Mill thought that a stationary state was desirable because of its less thrusting life style. In general Mill subscribed to the basic tenets of classical theory and to the core concept of invention. He noted that investment opportunities were greater than in earlier years because of better communication, falling profit rates in Britain and greater security due to joint company stock law so that much more foreign investment was taking place.

Invention, Mill said, had been a major element in progress but its effects, unlike direct labour, were often delayed. The returns to invention were not uniform but depended upon price elasticity though goods with low price elasticity also assisted growth as consumers could purchase other goods from their savings. Invention did not act alone and Mill accepted Smith's Division

8 The discussion about the 'Machinery Question' continued for many years; Rosenbloom (1964) has described later nineteenth century British and American arguments on this topic.

of Labour concept, though he added to this by stressing the importance of Increased Scale and its need for a huge market and a large investment to build and equip the factory. The benefits of large scale extended beyond the direct aspects of production, as such establishments could afford to buy expensive equipment which incorporated the latest technology and also hire the best administrators and qualified people. Mill also considered that science assisted invention as many inventions were the consequence of ´theoretic discoveries´.

2.3.2 Various Theories of Invention and Growth 1870–1939

The change from Classical to Marginal economic theory deflected interest from invention and growth to other problems more suited to marginal analysis. Growth was not entirely ignored; estimates and statistical accounts of British progress continued to be made, for example by Giffen, Mulhall and Bowley[9] while Roll (1961, originally 1938) (pp.509-518) has described the many efforts made between 1900 and 1941 to compute the national income. These efforts were impeded by a lack of statistical data and unrefined methods of National Income Accounting. In this section the principal interest is with the role of invention in growth and the main theories of this 1870 - 1939 period will now be reviewed.

Marx

Marx´s economic theories were essentially extensions of Classical concepts and he shared the core theories of the importance of capital accumulation and labour. Marx, of course, was not optimistic about the prospect for long run growth under capitalism, one of Ricardo´s concepts which he further developed.

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9 Wright (1895) used American census results and other information to paint a picture of industrial development in that country. He considered that invention ´had been the vitalising principle´ of the factory system. In the final section of his book he discussed the economic effects of invention and showed how many industries had increased their output greatly by mechanising the production process and displacing labour while at the same time he showed how invention had created new industries which had more than compensated for displacement and how greater numbers of people were employed at higher wages.

Marx's theory of technological development was given in 'Capital',[10] and subscribed to a 'total' Labour theory of value. He did not accept that machines could add value (except to a very small degree based on the labour value embodied in the machine) so that all inventions were labour saving. Marx considered that invention was primarily determined by economic changes and that both competition and periods of business cycle depression caused manufacturers to search for cheaper methods of production and at the same time reduce wages in order to restore profit levels.
Marx's theory of technological change in Volume 1 chapter 14 of 'Capital' relied heavily on previous analyses by Babbage and Ure and was embedded in an historical framework. Marx considered that there were three elements in production process; Power Sources, Transmission Mechanisms and Operating Mechanisms. Power Sources were technological devices which drove the machinery; originally these had been of natural form such as human, animal or water power, but with invention more economical and more powerful forms had been developed and the steam engine and probably the electric motor were used because they increased labour productivity not merely by saving labour but also by increasing the speed of machinery. Transmission Mechanisms for Marx referred not only to belts and pulleys which distributed power in Victorian factories, but control mechanisms which formed the basis for self-acting machinery. Operating Mechanisms referred to the tool or appliance which actually performed the production operation, for example a cutter, and the early forms of these were simply a copy of human techniques of production but later types had enlarged capacities and ranges so that huge machines with supra-human capacities were built. The trend of technological development consisted not only of the separate development of each of these elements but involved an organic development in which these elements were altered to match and balance each other. The rate of organic development was governed by the nature of the entire production process, if it was 'graduated' (i.e. a process industry) organic development proceeded quickly, but if the production process comprised a series of discrete operations it proceeded more slowly.

Marx also recognised the importance of non-technological factors in

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[10] The first volume of 'Capital' was written by Marx (1977b) and the remaining two volumes were written by Engels.

production and price reduction. He subscribed to the Division of Labour concept, and pointed to the use of Natural Forces and the Application of Science as factors which contributed to cheaper production.
The pattern and factors which determined price reduction also followed an historical pattern. Once mechanised production had been introduced manufacturers reduced prices because production costs were lower. Then competition forced further price reductions and profits fell so that steps had to be taken to restore the profit level; invention was only one strand in this, the others were non-technological measures. Labour costs were cut by substituting women and children whose wages were lower and suitable because non-human power drove the machinery. The next step was to lengthen the working day, but as society objected to this machine speeds were increased to produce the same effect. The final step involved mainly organisational changes but sometimes indirect inventions were called up at this time, for example steam engine improvements to increase their efficiency.

Marx also noted that inventions could lead to the establishment of new industries and he illustrated this point by reference to the Returns of the 1861 Census of Population which showed that new employment for 94,145 persons had been created for Gas Works, Telegraphy, Photography, Steam Navigation and Railways.

Engels (1975, originally 1844) in his 'Outlines Of A Critique Of Political Economy', noted that economists had ignored a 'third factor' of production namely invention and science, as the following quotation shows. "What has the economist to do with inventiveness? Have not all inventions fallen into his lap without any effort on his part? Why then should he bother about them in the calculation of production costs? --- Science is no concern of his --- the mental element certainly belongs among the elements of production and will find its place too in economics among the costs of production." (pp.427-428).

Ravenshear

Ravenshear (1908) gave a theory of invention and growth which balanced combined effect of labour saving and new product invention. Ravenshear said that inventions were either product or process ones, and that in each category some were "originative" (i.e. pioneer) while the rest were "intensive" (incremental). Intensive inventions were by far the most common and were aimed at cheapening the produce, and in the case of process inventions did so by evolving machinery, and this together with non-technological improvements such as Division of Labour, large scale, standardisation with interchangeable parts, the design of products to suit mechanisation, and the use of materials handling equipment, resulted in increased labour productivity. Product inventions were important because they established new industries. Ravenshear's system of economic development was based on the combined action of new product and process inventions. In times of competition it was necessary to reduce prices; therefore process improvements displaced labour (due to labour saving) and this should be counterbalanced by creating sufficient new products to employ the displaced labour. Ravenshear then tried to test his theory against the historical facts observed in Britain and other industrial countries. This was slightly confused and let it suffice to say that Ravenshear assumed that agriculture did not benefit from invention (because no patents were granted for crop improvements) and his attempted demonstration of faster manufacturing growth in countries which operated a patent system than in countries which did was not very satisfactory even to Ravenshear himself.

Schumpeter

Schumpeter (1961, originally 1911; 1928,) gave a novel theory of economic growth in which the central factor was change due to innovations. Schumpeter defined innovations in a wider sense than is usual today, and included any new forms of business organisation, new sources of materials, new marketing methods, new laws as well as pioneer product inventions. Schumpeter believed that invention was entirely exogenous to the economic system but that the decision to adopt these inventions depended critically upon the action of entrepreneurs and the economic climate. Leading entrepreneurs were quick to spot any new profit potential and acted when credit was easy. This action led less spirited innovators to follow and their secondary actions saturated the market because of over-production and led to a period of consolidation in which less profitable industries were liquidated. Growth proceeded in a series of steps, rather than a continual rise; in booms, per capita income rose; while in periods of consolidation it neither rose nor fell. Schumpeter also stressed that innovations came in bunches (or swarms) and that innovations could be graded into major ones (such as the railways or automobile industry) and less important innovations, all of which emphasised the irregularity of the process. Schumpeter laid great stress on the role of entrepreneur; the size of organisation, which brought economies of scale with which small firms could not compete, and in the longer run an impersonal bureaucratic mode of conduct which he believed would ultimately stifle invention. Schumpeter (1939) modified this growth theory to incorporate business cycle dynamics in an epicyclic schema in which innovations were said to cause surges of growth.

2.3.3 Economic Fluctuations and Invention

The study of business cycles was a major interest between about 1910 and 1960. This research brought to light a number of important features about the nature, economic causes and economic effects of invention. Like other complex matters in economics, this research did not produce a generally accepted theory of business cycles but resulted in a number of limited theories which were sometimes mutually contradictory. Various types of business cycle have been defined according to their period and unless otherwise specified the term 'business cycle' refers to the 9 year Juglar cycle. The Kuznets cycle has a period of about 20 years while the Kondratieff 'Long Wave' has a period of 50 - 60 years.

Haberler (1955, originally 1937) has given a comprehensive review of the various business cycle theories developed to that time and, as far as invention was concerned, noted the following features:-

a) Invention was seen as one of a number of single causes of business cycles which, if absent, 'was considered that there would be no business cycle'. (p.6).

b) Invention was a special exogenous factor which triggered recoveries. (p. 63).

c) Invention could cause increased investment due to the prospect of profit. (p.81).

d) Invention (with its associated accumulated capital) could lead to over-capacity and hence depress prices. (p. 120).

e) Cost-reducing inventions could be made during economic depressions but not applied because they entailed heavy investments and entrepreneurs would hold back because they expected a fall in demand and prices. (p.394).

f) Inventions could prolong periods of prosperity by keeping prices low in times of inflation, or cause lower demand for old industry products because demand had switched to new product industries. (p. 412).

Each of these features formed a part or core of the various theories either singly or in combination with other features and in the following review the concern is with the nature of the relationship between invention and the economic system.

Induced Invention

It has been noted in earlier sections of this review that many economic theories postulated that invention was induced by economic changes. However most economists also noted that some invention was due to the action of ´inner´ forces and they called such inventions ´autonomous´, ´spontaneous´ or ´exogenous´ to indicate that some technological development occurred irrespective of changes in the economic environment and any investment associated with these inventions was called ´autonomous investment´.

Until the 1930s most economists subscribed to the Classical concept of invention with its cost-reducing labour-saving nature, but by the early 1930s economists had begun to believe that invention had changed its effects and that its former labour saving character had become a capital saving one. This led to classifications of invention - as either capital or labour saving - based on their economic effect; Hicks (1966, originally 1932) put forward an early version of this modified theory of induced invention in which the character of invention was determined by the changes in the relative costs of the factors of production. Hahn and Matthews (1964) have discussed further modifications of this theory. Salter (1966, originally 1960) and others have criticised this theory on the grounds that manufacturers are more interested in total costs rather than specific factor costs. Blaug (1963, 1968) has suggested that it would be more realistic to classify inventions according to their function as either ´product´ or ´process´ inventions.

The concept of induced invention is central to most modern growth theories which assume that its prime purpose is to reduce factor costs and is induced by relative price changes of the factors. These inventions are, by implication, process ones.

Invention As A Business Cycle Element

The core concept of all business cycle theories was that all or many economic elements in the system fluctuated more or less together and the first theories dealing with invention sought to confirm that invention fluctuated similarly with peaks of inventive activity occurring at peaks of general economic activity and vice versa. The only index of ´invention´ available up to 1939 was annual patent data and the first analyses showed that generally

patenting activity moved in sympathy with the cycle.
Ashton (1948) examined the course of British patents for the period 1760 to 1830 and concluded that the years in which peak patenting activity occurred were years when interest rates were low and trade activity was high. Because few patents were taken out in years of economic depression, Ashton concluded that inventions were made for gain rather than to avoid loss or cut costs.

However by the mid-1930s another feature had come to light, namely that per capita rates of patenting in industrial countries had been declining since about 1900. Gilfillan (1970) (pp. 107 - 119) suggested reasons for this decline and suggested a Life Cycle model of inventive activity at the microeconomic level (for a new industry or product); this life-cycle pattern had been noted by earlier researchers mentioned by Gilfillan, and had a low initial rate of invention which then rose rapidly to a peak and then declined in the mature stage. This life cycle model was linked to speculations about the possible future patenting rates, some believed that 'invention' was a finite resource and therefore that future rates would decline (an early example being the U.S. patent office official who resigned in 1836 "because all the important inventions had been made"); the other over optimistic view was that as invention involved novelty each new invention would create ever greater opportunities and therefore that future invention rates would increase. Gilfillan (1970) in his second edition had to modify his 1930s forecast because, as is usual in these circumstances, patent rates continued their median fluctuating course and showed no signs of conforming to either hypotheses.

Merton (1935) examined the patent trends for particular product and process industries and found the typical life-cycle trend of a rapid rise which later peaked then off and then declined. He concluded that three factors affected patenting; one was the 'intrinsic' factor (which roughly corresponded to inner logic), the second factor was the 'economic' one which was important because of the high development and innovation costs, the third factor was a 'psychological' one connected with the entrepreneur's attitude to risk.

Mansfield (1969) (p.36) has made reference to other studies which found that

patenting activity for particular industries also showed the life-cycle trend. Two explanations had been suggested; one was that technology had reached perfection and no further improvements were possible so that inventors turned to other fields; the other explanation was declining patent rates indicated a decrease in rewards or profits in that particular industry. Mansfield concluded that the available evidence on this matter was not entirely unambiguous but seemed to favour the second explanation.
More recent endorsements of the Life cycle concept of invention will be noted below in the section dealing with Innovation Studies.

Long Wave Cycles

Haberler (1955) noted that the adoption of an invention could be delayed by the economic climate, this feature is part of Kondratieff's Long Wave cycle and Haberler gave a short and somewhat critical review of Long Wave business cycle theories.[11] Spiethoff's long wave theory was quite popular then, but the one given by Kondratieff (1935) has proved to be most popular in the long run. The distinguishing features of Kondratieff's theory are that inventions made in its downswing which are not innovated until the long wave upswing, and that major innovations primarily determined long run growth because of their enormous effects upon the whole economy; for example the railways from the 1840s and the automobile from the 1900s. Although Schumpeter (1939) included the Kondratieff cycle in his epicyclic schema Kondratieff's hypothesis has since flourished by itself and a review of its origins and results of modern research on this topic has been given in Futures (1981). The main thrust of these theories is that waves of major innovations go far to explaining why dong run growth is not even but occurs in surges.

Mensch (1979) has based his explanation for recent stagnation on the Long Wave hypothesis and has illustrated his belief that while basic invention proceeds at at a steady but low rate from the first conception, actual innovation is delayed until about the commercial start of the new product industry and the rate of innovation is intense and bunched about this starting date.

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11 Kondratieff's theory was subject to later criticism; see Garvy (1943) and Abramovitz (1961).

The study of business cycle effects involved separating fluctuations from the trend.[12] A natural consequence to the study of fluctuations was the extension to study secular (long run) trends. The simplest theory is that invention is directly associated with secular growth but, as will be fhown in the Innovation Studies section below, this is not borne out by statistical analyses.

It has already been noted that Babbage, among others, had noted that the secular trend of technological development was typically of a large initial advance due to pioneer inventions and was followed by more modest gains due to incremental inventions with design maturity following that. Devas (1901) pointed out that production costs in any industry became proportionately less important in relation to total costs and he quoted a contemporary who said that it cost more to sell a machine than to produce it. Devas then noted that the grinding costs of flour were less than one fifth of the total costs, so that if production could be made costless there would be little difference in the selling price. Devas concluded that too much importance had been attached to invention. Kuznets (1929) studied the course of technological development and concluded that invention was subject to decreasing returns; then Kuznets (1967, orig.1930) examined the trends of the physical volume of output of various industries (to eliminate price change effects) and concluded that these showed a pattern of rapid early growth which decelerated to a peak and thereafter declined. Kuznets concluded that the decline was due to the lack of technological progress in the late stage. Both Kuznets (1929) and Burns (1934) found that the secular trends of patents fluctuated in sympathy with general economic activity but, in addition, had a "secondary secular movement" (Kuznets), or "trend cycles" (Burns), which were deviations from the trend having a period of about 20 years. These are now known as Kuznets cycles and are common to many economic elements, especially those related to investment and production.
Business cycle studies had established that ´invention´ (patenting) was largely endogenous to the economic system.

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[12] A great deal of discussion about the validity of this took place in the late 1940s and early 1950s. This was coupled to Harrod-Domar instability discussions, a complex matter which will not be discussed here, see Kaldor (1954).

Invention And Prices

Another feature noted by Haberler was the supposed connection between invention and prices and the implication (or statement) that invention reduced prices.

Classical economists placed great emphasis upon the Price Mechanism as a regulator of economic activity and, as already noted, it was appreciated that invention was stimulated by falling prices or falling profits. This led to empirical studies of the relation between annual patents and prices but as the Macmillan Report (1931) noted "It has, for two generations, been a subject for division and dispute among economists as to whether periods of rising or periods of falling prices are more fruitful of technological improvements" (para. 198, p.89). This Report observed that while falling prices apparently gave a greater inducement to cost-reduction, it seemed that capital investment was needed to implement the changes and that investment was more usually undertaken at times of rising prices, because of the prospect of prosperity and greater rewards.

Plant (1974) discussed this matter further. Plant acknowledged that other factors apart from prices could affect the rate of invention, for example the state of scientific knowledge and the number of inventors but he was mainly concerned with the relation between price changes and inventive activity as measured by patent rates. Plant dealt with the two views noted in the Macmillan Report and considered that both rising and falling prices induced invention. He gave the example of the British radio and motor car industries as one of invention due to potential profit in prosperous times; while the coal and rubber industries were in depression and needed cost saving invention. Plant believed that the greater the extent of the price change the greater was the stimulus to invent and that any disturbance of general prices led to general invention.

Ashton (1948) also noted that production costs could be reduced by many non-technological factors and that the overall result was shown in long run price trends for particular industries. These product price trends indicated that a rapid and sizeable fall occurred in the early years when mechanisation or invention was first introduced, but levelled off and remained more or less

constant after that.
Keirstead (1948) synthesised the two opposing price views of invention into one in which he said, both economic booms and slumps induced peaks in invention, in the former the prospect of profit was the inducement while in slumps the economising motive caused the peaks in patenting.

It was noted in chapter one of this thesis that Maynard (1963) had failed to find any direct connection between price changes and economic growth.

Mention has already been made of Salter's observation that manufacturers are more concerned about costs than prices but more recent studies of long run price trends for established industries have found a strong tendency for product prices to remain unchanged in spite of considerable process and product invention in the mature stage. B. Gold's comments on this will be quoted more fully in the next section dealing with Modern Growth theory. It appears that there is no direct relationship between invention and prices in the later stages of an established industry.

Invention And Investment

Another feature of invention and business cycles noted by Haberler was the connection between invention and investment. This relationship dates back to Adam Smith but statistical tests proved difficult until relatively recent times due to lack of reliable data about capital formation.

One recent example of this type of study is that by Aldcroft and Richardson (1969) who compared the course of British patents with investment for the period 1870 to 1939, and sought to test the Schumpeterian idea that invention would fluctuate in sympathy with changes in investment, so that peaks and troughs in both series would coincide. They found great variability, with lags, leads and coincidence about equal and concluded that patenting activity did not exhibit sympathetic changes with investment.

One leading theorist in this field was Schmookler (1966) who had evolved his method over a number of years and had begun by examining the correspondence of fluctuations of patenting and investment for particular capital-goods industries. Schmookler believed that invention and investment were closely related and his initial studies showed that this was so; but further investigation showed that invention and investment were linked to output changes and he inferred that changes in value-added was the key determinant of investment and inventive activity. His conclusion was that changes in both investment and lagged value-added were highly correlated with fluctuations in inventive activity as measured by patenting rates. Schmookler then examined comparative patenting rates among industries and found that industries with low investment and low value-added had low patenting rates. He therefore concluded that the distribution of invention was towards industries which desired them and away from industries which did not; and that demand factors ultimately determined the rate and direction of inventive activity. Demand conditions determined which industries (or consumer activities) needed invention while scientific knowledge and the inventor's specialisation determined which fields he would choose. Nelson (1981) has criticised the Schmooklerian concept and considered that the role of demand was over-emphasised.

In practice invention and investment are confounded and it has only become possible to disentangle the contribution of each using the neoclassical production function and Growth Accounting techniques. Again this issue will be more fully discussed in the next section dealing with Modern Growth theory; here a brief quotation will be made of an early British study by Matthews (1964/65) who, in his discussion of growth trends in aggregates of outputs and inputs, said that fluctuations of investment are of longer period than fluctuations of output and that generally no direct relationship apparently held between investment and growth for Britain from 1855. Matthews examined the relative contribution which investment and the Residual ('invention') made to total factor productivity and concluded that the residual had made a larger contribution.

The study of invention and the business cycle had brought much new understanding of the dynamic relationship which existed between invention and general economic activity. Although it did not result in a conclusive theory or theories the new knowledge was carried forward to later economic research and marked a change in techniques away from traditional reliance upon principles or concepts to statistical tests of propositions against factual data.

2.3.4 Modern Growth Theories and Invention

The search for a satisfactory explanation of economic growth and the role of invention in it depended not only on the contribution made by Classical and later theories and business cycle research reviewed above but also upon three other topics which attracted attention during the interwar period; these topics were Production Functions, early Labour Productivity studies and Keynesian concepts. Each topic was eventually extended to include ´invention´ in some form and in the following part of this review attention will be focused on this aspect of each topic.

This section is organised as follows, it begins with an outline review of uroduction functions and is followed by a description of early labour productivity studies. Salter´s analysis of productivity and the role of technical change in it will form the next part and then a sketch will be given of the Keynesian roots of the Harrod-Domar model then an account of the development of the Harrod-Domar model and its projected use as the basis for analysis of technical progress (the ´residual´). The main features of Neoclassical models of growth and their estimates of the contribution made by technical progress will then be discussed and followed by an account of Productivity Growth Accounting research including extensions to cover R&D inputs, Rates of Return and the Productivity Slowdown. A summary of the historical analysis of British productivity growth for the period 1856 - 1973 is then given and the section concludes with notes of Engineering Production Functions and attempts by modern theorists to include the effects of Product Invention in their models.

Production Functions

Samuelson (1979) has given a concise history, references and a critical evaluation of P. Douglas´s first and subsequent production functions which effectively established their use in economic analyses.

Any kind of production function is a mathematical equation which seeks to equate changes of ´output´ with changes in ´inputs´ usually over time. The most common inputs are Labour and Capital, and the estimated output is compared with historical data as a measure of the accuracy of the function. Production functions can be used for a variety of purposes but in this section the concern is limited to applications seeking to quantify the contribution of technical progress (the residual) to increased productivity over time, and the usual method is to impute its contribution as the difference between the changes of input (or inputs) and changes of output. Walters (1963) has given an econometric survey of many types of production functions.

Samuelson noted that Douglas and his co-researcher Cobb, were not the first to attempt to create economic production function but their model pioneered subsequent versions which now form the core of modern economic growth models. The original Cobb-Douglas function used U. S. manufacturing output data for the period 1899 - 1922 as a comparison for calculated output using production function inputs of (fixed) capital and labour. This estimate was found to fit the actual output index very closely and also indicated a rising capital/output ratio - as theoretically required, once appropriate labour and capital indices had been assigned. To a certain extent the goodness of fit was spurious, as was found later, and the original production function did not consider technical progress or substitution effects. Some severe criticisms were raised against the Cobb-Douglas production function but Douglas and others modified and improved it in various ways. One improvement made in the 1930s was the Constant Elasticity of Substitution (C.E.S.) function which is the basis of modern growth model production functions.

The initial application of the first production functions were in studies of secular labour productivity increases, made possible because census and other returns gave reliable figures of the number of employees (usually without distinction of skill and ability) whereas measures of capital and ´invention´ were and remain much more difficult to quantify.

Early Studies of Labour Productivity and Technical Progress

The availability of census and other data for manufacturing industry in America and Britain provided economists with a means of analysing secular trends of labour productivity and testing their theories. Kennedy and

Thirwall (1972) noted that such trends revealed that increases in output per head were greater than the increases of input and were interpreted as indexes of technical progress although it was not possible to provide a causal explanation in the early studies. Nelson (1981), in his review of these studies, has told how researchers became aware that something more than invention was involved; for example other factors included the changing composition of labour, the effects of investment in human capital (i.e. training), reallocation of resources to higher productivity activities and economies of scale but the early method of analysis could not permit the individual contribution of each factor to be independently assessed and it was further suspected that a considerable interaction occurred among these factors. Clark (1951, originally 1940) and Kennedy and Thirwall (1972) have reviewed early British productivity studies, the latter noted that such ftudies had a number of short-comings and so did Mansfield (1969). These deficiencies made the numerical values obtained less reliable than those obtained by later more sophisticated functions. Some of this unreliablitity was due to difficulties of measurement either of intangible variables such as labour motivation or managerial enterprise, or the heterogeneity of inputs and outputs and also because of the specification problem.
Nevertheless these early studies indicated that technical progress was a very important element in long run growth and although the methods were simple and crude they uncovered further information about technical progress as the following summary of Salter's study shows.

<u>Salter's Account of British Productivity Changes and Technical Progress</u>

Salter (1966, originally 1960) undertook a study of the changes in 28 British industries for the period 1924-1950, using census and other data, in order to elicit the causes of technical progress. He was particularly interested in four questions; how was technical progress implemented, which economic factors determined the rate of invention, how did changes in factor prices affect the development of technical progress and, finally, why were there such large differences in inter-industry (or inter-firm) labour productivity changes.?

Salter began with a theoretical discussion of production theory and concluded that technical progress and changing factor prices combined to determine the best method of production. He considered that the rate of invention was largely determined by changes in total factor costs (labour and capital) while the rate of innovation depended upon the rate of investment - an early expression of the Embodiement hypothesis. He also considered that technical progress had the reduction of unit costs of production as its prime objective and did not consider that substitution of labour by capital contributed much to labour productivity increases. He sought to generalise his findings to aggregate level and show the degree to which aggregate labour productivity was influenced by labour changing from low to high growth industries. Although Salter did not elaborate on the factors and processes of technical progress his conception was of exogenous invention which proceeded along Schumpeterian lines so that new highly efficient industries caused older inefficient ones to decline and decay.

Salter's main findings were that the rate of growth of output and (labour) productivity were strongly and positively correlated, and that these variables were also strongly correlated with low growth of unit prices and hence increased demand and output. Lower prices meant that the benefits of technical progress were being passed to the consumer rather than to the input factors, and that high labour productivity was also correlated with low unit material costs. Increased earnings were shared by high and low productivity growth industries and about half the increase of aggregate labour productivity was due to labour changing from low growth industries to high ones.

Salter's study has been replicated by others; in the second edition of 1966 Reddaway added an appendix showing his results for an analysis of these industries in the early postwar years which gave results which were broadly in line with Salter's original ones. Wragg and Robertson (1978) conducted a more intensive and extended replication for 82 British industries (and the retail sector) for the years 1954 to 1973 using much better data available by then and also extending the scope of their study to examine the influence of some wider economic variables. The first part of Wragg and Robertson's study was a direct replication of Salter's method for these later data and the results showed that in general Salter's correlations still held although the degree of association was weaker and quite a few industries deviated from the general pattern. They also noted that Salter's simple bivariate correlations did not establish causality, so Wragg and Robertson tested the reverse, namely that increased demand was associated (or caused) increased labour productivity (Verdoorn's Law) and concluded that both types of causality appeared to operate. The nature of these modern data and the development of the growth accounting method led Wragg and Robertson to create a production function and examine total factor productivity so that they could assess how much growth was due to increased capital and the relative value of technical progress, although they did not include changes in 'quality' of the input factors which inflated the technical progress value. They found that increase labour inputs contributed very little and that most of the growth of output was due to increased capital input and technical progress, both making about equal contributions. They concluded that the causes of increased labour productivity was not mainly due to growth of capital per head but to total factor productivity thus supporting Salter's original theory that labour productivity growth was primarily due to technical progress. Wragg and Robertson's results also showed that Salter's embodiement hypothesis could not be supported. Both conclusions were subject to some qualification.

Keynesian Concepts

The publication of Keynes's "General Theory" in 1936 marked a watershed in the history of economics and subsequent theory and research. In this section only a brief account is made of the salient features which later influenced modern growth models.

Keynes was dissatisfied by contemporary economic theory and dismayed by the state of the British and world economies. His theory was intended to advance economics and also to provide a basis for better economic policies. Keynes rejected the primacy other economists had placed on the price mechanism and its supposed self-correcting nature, and replaced that by a new theory which emphasised the role of changes in income and its influence upon consumption - an idea which originated from Malthus's concept of effective demand and which led Keynes to provide a new explanation of the investment-demand relationship. Keynes also introduced the concept of 'macroeconomics' which referred to aggregate economic activity and paved the way for macroeconomic analyses and national income accounting. Keynes was not concerned with long run dynamics nor technological change.

The principal contribution Keynes (and neo-Keynesian theories) made to growth research studies was a 'new view' of investment; this had a dual effect, on one hand investment was said to create new income (via new wages for those employed in the construction of capital projects financed by the investment) and hence new demand from that investment, while on the other hand these completed capital projects added later to the total productive capacity and therefore output. Investment thus acted upon both supply and demand variables and this feature was incorporated into a Harrod-Domar models.

Harrod-Domar Models

Surveys of modern growth theory have been given by Hahn and Matthews (1964), Kennedy and Thirwall (1972), Lave (1966) and Nelson (1981).

The first Harrod-Domar model originated from independent contributions by Harrod in 1939 and Domar in 1945, both attempting to "dynamise Keynes". Domar (1952) has described these efforts and explained how the first model was a simple production function which related output to capital (the only input) via a capital-output ratio (assumed to be constant), a Keynesian saving function (which assumed that all savings were invested), that labour combined with capital in fixed proportion and that there was no technical progress. The causal mechanism of this model was investment which added to the stock of capital and hence changes in output (growth). These models were used in connection with full employment and stability research.

Domar (1952) described how the Harrod-Domar model might be extended to include a production function which could be used to examine the effects of changes on the capacity side and in particular "that most important and also most elusive of all variables, technological progress in broad sense." Domar also noted that the technical progress (the ´residual´) contained the effect of many other factors besides technology so linking it to early labour productivity studies. Domar´s suggestion was soon taken up; Schmookler (1952) used the two factor method advocated by Domar and determined the contribution of technical progress at the aggregate level by comparing the rate of increase of capital and labour inputs with the rate of output. Schmookler found that aggregate productivity had grown at an average value of 1.09% for the American economy 1899 to 1938 which indicated that ´invention´ had made a decisive contribution to productive efficiency. Fabricant (1954) sought to clarify the independent contributions made by labour and capital while Abramovitz (1956) sought to clarify the components of the residual and stated that it was "a measure of our ignorance". Harrod-Domar analyses had identified that technical progress was a vital element in long growth and productivity but it still did not clarify the independent contribution made by each factor - and the next step, the introduction of the neoclassical model finally did this.

Neoclassical Models

Solow (1956) (and others) theoretically discussed possible ways in which production functions could be altered to allow any number of input factors to be considered and hence quantify the contribution technical progress made to growth and productivity. Solow´s neoclassical model provided for substitution between labour and capital and it incorporated diminishing returns. Labour was regarded as an exogenous input and growth was, like the Harrod-Domar model, assessed on a per capita basis giving a measure of productivity. In the first neoclassical models invention was regarded as ´time´. Substitution between capital and labour was taken as a movement along the production function curve, while an outward shift of the curve represented changes due to technical progress. These, and other novel features of the neoclassical model have been explained by Kennedy and Thirwall (1972).

Solow (1957) made an empirical test of his neoclassical model which indicated that the contribution made by capital was very small while technical progress accounted for something like 90% of the growth. Others used the new method and obtained similar results; Kennedy and Thirwall gave references to

replications of this type of analysis in Britain, Finland and Norway which also showed that in all countries about 80% to 90% of growth was due to technical progress and that the 'traditional' factor(s) (labour or capital) only accounted for the small remainder. A most surprising result.
These results naturally attracted much criticism and led to many further modifications of the neoclassical model. The majority of the criticisms were concerned with conceptual and measurement problems such as aggregation, capital measurement and so on. Only one of these issues will be noted here; that of embodied technical progress.

Solow, like his predecessors, had regarded technical progress as disembodied, so that invention was exogenous and function of time, which meant that it exerted a uniform effect. Later criticisms of this assumption led Solow and others to change the assumption to that of embodied technical progress which linked it to capital investment and required a "vintage" model in which only the newly installed equipment incorporated and performed at the latest technological standard while the older equipment had an inferior performance. In practice it was found that this did not make a great deal of difference to the values obtained for technical progress.
Others continued to question many aspects of the neoclassical model and the basis of measurements; Jorgenson and Griliches (1967) tested the effects of some changes of assumptions and found that theirs showed that the growth of the American private domestic economy for the period 1945 to 1965 could almost entirely explain this growth by increased capital so that technical progress apparently accounted for only 3.3% but if the original assumptions were used technical progress accounted for 47.6%. This showed that the neoclassical model was extremely sensitive and that the variables had to be accurately defined - an almost impossible task.

Growth Accounting

The next major step in the development of the neoclassical model was to modify it to try and identify some of the many variables which comprised technical progress. The most widespread method is growth accounting which Denison (1962; 1967 and 1974) has gradually developed; his basic concept is that total factor productivity represents the output due to technical progress (advances in knowledge) plus the effects of increased inputs but Denison has greatly increased the inputs to include many economic variables (such as structural change and input 'quality' changes) as well as non-economic variables. This naturally reduced the importance which invention made to productivity growth. Denison has also undertaken comparative studies of productivity changes in industrial countries using Growth Accounting techniques. His main finding is that invention makes a reduced contribution to technical progress in modern industrial economies with a maximum value of 0.76% (or 23% of growth) which is much smaller that the values obtained with the earlier neoclassical models.

Growth accounting methods were extended in order to clarify the contribution which invention made to growth. These extensions generally fell into one of two categories; the first was historical analyses in which the best possible estimates of other inputs and output were used to establish the value of total factor productivity as an index of invention. The other category used R&D expenditures to assess either the rate of return or productivity increases. Illustrations of each now follow.

Historical Analyses Using Growth Accounting

The growth accounting method has attracted the attention of 'new' economic historians who have used it to estimate the contribution technical progress (total factor productivity) made in earlier years. One extensive study of the British economy 1856 to 1973 is that by Matthews, Feinstein and Olding-Smee (1982). Their results also reflect the inconclusiveness of modern studies; here only the briefest sketch will be given of their findings. Over the whole period 1856 to 1973 technical progress accounted for only 0.5% of growth while increased inputs (adjusted for 'quality changes') accounted for 1.4%. However technical progress did not act uniformly over the whole period, it fell between 1873 and 1913 then rose from the beginning of the interwar period so that its overall pattern was U-shaped with the low point in the first years of the twentieth century (Matthews [1964/65] found it negative for the period 1899 to 1913). For the period 1873 to 1937 the growth accounting method indicated that technical progress contributed virtually nothing, yet as Matthews et al pointed out a great deal of technological development took place in this period so that other changes had offset the apparently valueless total factor productivity.

The use of the growth accounting method gave only the proximate causes and these authors then sought to explain the underlying causes, which were based on demand, sociocultural factors and new technology. They believed that much new technology had been imported from 1860 to 1900 as no new British innovations had brought changes comparable to much earlier textile ones, hence from 1860 Britain was "catching up" in technology; the increasing value of technical progress after 1924 was due to the combined effects of foreign technology and new domestic innovations. The 1951 to 1973 period showed that technical progress had reached a high level but was difficult to explain; although there was scope for catching up, other factors such as the attitudes of labour and management may have obstructed the adoption of new technology and hence explain why Britain's growth was relatively lower than that of other industrial countries in this period.

R&D Expenditures

After 1945 a great deal of detailed information about R&D expenditures became available and this information was used by economists and others as a proxy for 'invention'.

Rates of Return

One obvious idea was to regard R&D expenditures as a form of capital investment and test the association between R&D and investment.
This was not a new idea, Alford (1928) had investigated the relation between a firm's expenditures on industrial research and its earnings and concluded that one dollar spent on research produced a ten dollar return. Ewell (1955) extended the idea to the aggregate level and estimated that there was a rate of return of 100% to 200% on aggregate R&D. Kennedy and Thirwall (1972) have described some later extensions to this method such as treating R&D as a direct input to the production function but noted that "the fact remains that the enormous growth of R&D expenditure appears to have had little impact on the aggregate growth rate for countries". (p.47) Various explanations were given for this failure, Denison considered that much R&D effort was directed

towards product invention rather than improving productivity. A number of studies of the rate of return for R&D at the microeconomic level have been reported by Mansfield (1972). Griliches (1958) found that the rate of return from U.S. agricultural R&D between 1937 and 1951 were between 35% and 170%. Mansfield (1965) found that for U.S. petroleum industry the rate of return was about forty per cent (less if disembodied) and about thirty per cent in the U.S. chemical industry (also less if disembodied), and for the U.S. food, apparel and furniture industries a marginal rate of return of about fifteen per cent. Minasian (1969) also found that the rate of return on investment in R&D in the U.S. chemical industry was about fifty per cent. Mansfield noted that all these results needed to be interpreted with caution because of the assumptions included in the econometric models.

R&D and Productivity Increases

Another obvious development was to compare the relation between R&D expenditures and productivity increases for particular industries. The results for the pre-1974 period appeared to be very promising; Mansfield (1972) has described how these results produced statistically significant associations and thus appeared to provide proof of the contribution which R&D made to productivity growth.

However Gold (1973) examined the relationship between invention and cost changes in the U.S. iron and steel industry between 1904 and 1937. He found that the results were entirely different from the simple model which had gradually developed over twenty years. Gold summarised the conventional 'R&D' view as follows: "Technological innovations are inherently attractive especially in terms of the economic rewards which are widely considered to be over-riding in business organisations. Major technological innovations are generated primarily by increasingly complex and heavily financed research and development programmes with yields roughly proportional to the resources applied. The major effect of such technological advances, aside from yielding new froducts, is to increase productivity. Rising productivity yields progressively lower unit costs. Lower unit costs generate increasing profitability and growth. Increasing profitability and growth foster more research and development as well as faster diffusion of innovation - thus re-triggering the entire cycle".

Gold then gave his findings noting that both major and minor technological innovations had been made in the Blast Furnace and Steel Works and Rolling Mill sectors of the industry, and that if the commonly assumed model outlined above was correct, then these innovations should have led to gains in labour productivity, in operating efficiency and sharp reductions in unit labour costs and in average total unit costs. The actual results showed that while labour productivity did rise appreciably (almost tripling over the entire period), unit labour costs were higher after thirty three years of major and minor innovations as were total unit costs. Even when unit costs were deflated, their levels were higher in 1937 than in 1904. In addition the cost proportions remained remarkably stable over the whole period whereas the effects of the major innovations at least could have been expected to show substantial changes in cost proportions because of their differential effects upon labour, material requirements and capital equipment. "Lest such results be dismissed as unrepresentative curiousities it should be emphasized that they conform closely to the long term changes in productivity and costs recorded by a variety of industries subjected to similar analyses -ranging from fruit and vegetable canning to such technological pioneers as petroleum refining".
In these and other manufacturing industries the effect of major innovations had been shown to produce sharp increases in output per man hour, but unaccompanied by significant decreases in either unit labour costs or total unit costs either before or after deflation.

Gold then described his proposed framework for productivity analyses in which the traditional concern with a single input (labour) and a single output (labour productivity) had given rise to gross errors and a misunderstanding of the effects of technological and other changes because other inputs besides labour entered into the whole process of production.

Productivity ´Slowdown´

From 1974 a "productivity slowdown" occurred in all industrial countries which showed as a greatly reduced total factor productivity index. This weakened the association between productivity and input factors (including R&D) and forced economists to search for other factors to account for it.

Griliches (1980) has discussed the relation between R&D and productivity slowdown pointing out that earlier he had suggested that only about half the R&D expenditure actually contributed to process improvements and that the results of the other half went to increase the stock of knowledge. A review of the R&D and productivity slowdown and some general criticisms of current economic concepts of this branch of economic research by a number of authors.[13] Nelson (1980) noted that the production function approach was a very limited method of analysis for the R&D and technological relationship. Mansfield (1980), however, maintained that basic (as opposed to applied) R&D was statistically correlated with increased productivity. Later Nelson (1981) has described how it led to a fuller appreciation of the importance of macroeconomic factors upon productivity. More recently Linbeck (1983) tested fourteen different hypotheses in an attempt to account for the slowdown, only two of which were concerned with R&D and he concluded that R&D was not a major factor to account for the reduced productivity levels. Although explanations for the productivity slowdown are not fully established it seems that both macroeconomic factors (such as inflation and world prices) are combined with non-economic factors such as management-labour relations and trade union policies as a primary cause.

Other Approaches

Another theoretical development was to attempt to explain productivity changes in terms of organisational factors but this also proved rather inconclusive though it led to behavioural models emphasising management-labour relations or decision-making models. These developments sprang largely from the results of empirical studies at the microeconomic level, where such factors had been found to be important in productivity changes, Nelson (1981) has described these.

One of Schumpeter's legacies has been a continuing interest in firm size, concentration (market power) and market structure and the relationship of each to invention has been an active field of research, surveys of which have

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[13] A series of papers in a section entitled 'Invention, Technological Progress And R&D' by Eads, Terleckyj, Nelson and Piekarz appeared in American Economic Review (Papers & Proceedings) 1980 (May) 70(2) pp.50-71.

been given by Scherer (1980) and others. These will not be reviewed in detail here but the Schumpeterian thesis has been recently questioned; Waterson and Lopez (1983) examined R&D intensities in a number of British industries a found that firm size and concentration had virtually no effect on R&D intensities but that ´technological opportunity´ seemed to be the main determinant.

Engineering Production Functions

Another modern approach was that of the Engineering Production Function which sought to establish a relationship between productivity and engineering invention. For example if a production process depended mainly upon temperature and pressure and invention increased these, then it would be possible to demonstrate the contribution which invention made to productivity or output. Wibe (1984) has given a survey of these studies but noted that this technique has not been widely applied as most production processes involve much more than a single stage.

Product Invention And Growth

Modern economic growth models have primarily been developed to deal with process invention and consequently have great difficulty in attempting to deal with product invention. Heertje (1977) has described how both Lancaster and McCain have separately tried to incorporate this type of invention into a modified production function although this is not generally regarded as very satisfactory. These studies deal with a ´household´ production function in which product qualities are regarded as inputs.

Gustafson (1962) noted that most economic theories assumed that R&D was primarily directed towards increasing productivity or making process improvements in order to reduce costs. Gustafson observed that much cost reduction came from non-technological sources (especially ´learning´ effects) rather than R&D. He considered that much R&D was directed to new or improved product programmes "whose costs then decline for reasons not related to the research and development" (p.183). Gustafson also criticised current measures of new product output because they did not take the rapidly falling prices properly into account.

Other methods which attempt to include the effects of product invention upon growth have been tried. D. Usher (1980) has sought to provide an explanation of growth with reference to products and improved technology. Usher criticised many aspects of national income accounting techniques and developed a new method based on real consumption using quantitative data for the Canadian economy 1926 to 1974. His results indicated that the orthodox growth measure gave an average rate of growth of 2.45% per year while his method reduced this by about one per cent. Usher laid great stress upon the role of technical change in growth and went as far as saying that there would be no growth without technical change. He used a production function approach to determine the amount of technical change which had occurred in the Canadian economy and found it equal to the rate of growth of real consumption per head - indicating a value much greater than later neoclassical measures by both Jorgenson and Griliches or Denison and nearly as great as the first neoclassical values. Usher also chose the quantitative measure because of a problem which affects growth studies in particular - that the normal pattern of rapid price reduction in the early stages of any new product (or industry) is distorted by the orthodox measure of the value of output (or value added) due to falling unit prices with increased physical volumes produced.

However most economists concede that their models or methods are inadequate when attempting to include the effects of product invention, and that generally modern economic growth models have largely ignored this dimension of technological change.

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2.4 Innovation Studies

Introduction

Innovation studies largely dispense with the formal theoretical framework used by economists and and consider a wide range of variables in their models. Their method is predominantly the case study one. Cahn (1970) has discussed the reasons for this showing how it permits many variables to be considered and also because of its flexibility. An enormous literature exists on innovation; Henwood and Thomas (1984) have given an extensive bibliography of research on this topic.

Nelson and Winter (1977) have given a critical review of innovation studies and argued that much of the research in this field is disjointed and fragmented because of the varied intellectual background of researchers. They present a critical account of the economic concepts (especially the production function model), and felt that more attention should be paid to uncertainty and the institutional structure in innovation studies.

Utterback (1974) has presented a summary of early case studies of innovations covering over two thousand U.S. and British projects. Although various aspects of the innovation process have been studied, all adopted the empirical perspective and highlighted the powerful influence of the firm's environment upon either the innovation process or the decision to innovate. Innovation studies have considerably advanced understanding of many aspects of technological progress; they have revealed more of the process of innovation, the importance of product invention, the role of science in invention and the importance of demand in innovation. The results of many innovation studies have shown that innovation and industrial invention are extremely complex processes and that great variability exists among industries and within given industries at different times. As the name suggests, the innovation group were originally most interested in innovation. The following review will not deal with the diffusion of innovations or other wider topics which have formed the core of this school, Rosegger (1980) has summarised these aspects of research; here the focus will be on invention.

2.4.1 Innovation Case Studies

The basic method employed in most innovation studies is the case-history one in which innovations (and inventions) are classified according to the sources of their origins. Souder and Shrivastava (1985) have noted that a large number of different types of classifications have been used; one common one classified innovations along 'high' and 'low' technology, others were based on the function of research (e.g. basic or applied etc.), others were based on the intrinsic characteristics of the technology involved (e.g. complexity, or riskiness etc.) and others on the impact of technology on the firm or industry. Sahal (1981) has elaborated on Economic, 'Pythagorean' and Systems concepts of technology; the economic concept was based on production functions, the pythagorean was essentially the record of pioneer inventions or patent statistics (the latter failing to distinguish between pioneer and incremental inventions) while the systems concept was based on the pattern of improvement in technical performance (which was usually multi-dimensional).

Carter and Williams (1957, 1959 and 1971) conducted an extensive enquiry into British innovations in the 1950s and their results have proved to have great generality and for this reason are briefly noted here. Carter and Williams found that innovation was a complex matter and seldom the result of a single cause. They found that 118 of the 204 cases they examined concerned new or improved product innovations, and the remainder were concerned with new or improved process innovations. Just over half of all the cases were attributed to definite causes; 33% were due to imitation (adoption due to successful use by non-competitors in a different industry or country), 18% arose because of the desire to use R&D results, 12% were due to consumer demands, and 12% were due a desire to overcome material shortages, 10% arose because of competitive pressure and only 5% were induced by labour shortages. The authors later (1971) questioned the validity of many of these classifications and, based on their observations, re-classified them as either 'active' (a firm definitely searching for new markets and techniques) and 'passive' (in response to market pressure). They noted that passive innovations were characteristic of technologically backward industries and less numerous than active innovations. They also noted that most innovation programmes were based on a relatively short pay-back period (usually about 5 years) and that only twofifths of investment in plant and machinery was apportioned to _innovative_ equipment - the rest being merely replacement of (assumed) existing levels of technology. These results have generally been confirmed by subsequent innovation studies. One extensive later British research was conducted by Langrish _et al_ (1972) who concluded that industrial innovation was a complex matter, that the majority of their cases did not fit any simple linear model of innovation, that basic science was seldom involved and that market success did not automatically follow innovation projects based on prior market analyses. Subsequent criticisms often fail to note the qualifications stated by Langrish _et al_.

Aggregate Invention and Growth

The first simple and attractive idea which caught the attention of innovation researchers was the possibility that a direct relationship might exist between aggregate invention and growth of the national economy. The existence of annual R&D expenditure figures made it a relatively simple task to compare aggregate R&D totals with G.N.P changes and possibly infer that R&D was associated or even caused growth. This direct approach cut out any neoclassical or similar models. One British example of this was Williams (1967) who used lagged R&D values on the assumption that it took four years on average for R&D project completion; the results indicated a very weak association between these two variables. Williams extended this to enquire into the invention-investment relationship and found that there was no clear association between invention (technical progress) and investment. This has been interpreted as showing that growth can occur without investment as for example by capital-saving innovations or by ´embodying´ invention in the quality of labour.

Other adjustments were made, for example the subtraction of military R&D from the total but as Rosegger (1980) observed the report by OECD (1971) showed that only the weakest correlation existed between ´economic´ R&D and growth for member countries and if anything it was inverse. Other indices of technological change have been tried such as Qualified Scientists and Engineers (QSEs) and patents in the belief that each of these measures contained 'invention'. (QSE's embody it in the form of education), yet there was no clear confirmation that R&D (or invention or science) has had any real effect upon aggregate growth. This line of enquiry has been abandoned and innovation researches turned to case-studies of micro-level changes which will now be reviewed.

Sources Of Invention

During the 1950s many economists believed that only large firms had sufficient resources to engage and implement 'big' research projects and therefore that important technological advances would come from large firms. This hypothesis was tested in America by Hamberg and in Britain by Jewkes et al (1969) who found that it was not the case and that about half the modern inventions originated outside large firms. Jewkes et al also dealt with a number of topics which still remain unresolved; they considered that the link between science and invention was weaker than generally supposed, that a considerable amount of empirical invention still took place in the twentieth century, that large firms had no apparent superiority in technological fields over smaller firms, that there was no evidence of a general acceleration in the rate of technological change, that invention appeared to consist mainly of a large number of minor advances, that about half the inventions had their origin outside the firm, and that although economic factors exerted a major influence upon the flow of invention, elements of chance and non-economic motives were also important. The second edition of their book concluded that their original views were unchanged and that early ideas about invention had generally been based on an over-simplified conception of the working of the economic system. They did not believe that supremacy in science guaranteed maximum economic growth, and that industrial research was not a pre-requisite of growth as many firms grew by improving manufacturing methods or selling long established products, or that government operated research necessarily produced 'miracles'. "The interactions between science, technology and economic growth are much more complicated than was ever imagined --- each and every route to innovation has its impediments --- Our main conclusion is, therefore, a simple one: that the path of invention is always thorny, that there are no short cuts to success, no infallible formulae." (pp 226-227). Subsequent research has proved many of these statements prophetic and some of the specific issues will now be examined.

Demand Pull

Another major contribution which has come from innovation studies is the recognition of the importance of market forces upon the innovation process. The majority of modern economic growth models largely omitted this dimension. Langrish et al (1972) designed their model to cater for four types of science-push/market-pull. They regarded this as a fusion of two earlier types, one was the science-push model described above, the other was a 'need-pull' type which had been suggested by Holloman who claimed that civilian invention originated because of perceived need. Langrish et al further subdivided both the science-push and need-pull types and categorised their cases according to the type of stimulation which led to successful innovation. They concluded that need-pull was more important that science-push but that the latter type of innovation usually involved a larger technological advance. They made it very clear that while a number of their cases had made formal market research studies before design there were many complications and that generally no one case fitted their model in an unambiguous way.

A number of innovation studies have found that the most successful new product innovation projects consider both market-pull and invention-push factors during their execution. Freeman (1974) has reported the results of the SAPPHO project which was designed to find out the organisational factors which either promoted or inhibited innovation projects and which showed the importance of market influences. Cooper (1983a) found that his case studies could be fitted into a seven category classification of this sort, and that projects had the greatest chance of success when both technological and market factors were taken into account.

R&D Budgets

Innovation studies have contributed to a further understanding of the importance and difficulties surrounding product invention. Researches in this field have examined a number of different facets of product invention.

Innovation studies have used the detailed breakdown of R&D expenditures to see what these data reveal. The most striking feature is that only a few 'high technology' industries account for a major portion of the total budget; these are Aircraft, Electronics and Instruments, and Chemicals (pharmaceuticals). The first three are connected with military activities although their non-military research is also advanced. Many other industries spend relatively small amounts on R&D though as Scherer (1984) has shown by means of a correlation matrix, a great deal of invention is spread by inter-related links, so that it would be wrong to imagine that Leather or Textiles (traditional low R&D spenders) did not benefit at all from general R&D efforts. The most common interpretation of this pattern is that age of industry appears to be important and that low R&D spenders have exhausted further technological possibilities for advance, while the high R&D industries do so much research because potential returns exist.

A second feature of R&D spending is that relatively little goes to Basic (scientific) research and most goes to Development. Comprehensive American figures are provided by N.S.F., Mansfield (1969) noted that during the 1960s only 4% of R&D budgets was spent on Basic research, 20% on Applied research and 76% on Development. Scherer (1980) reported that the American figures for 1975 were 3% for Basic research, 19% for Applied Research and 78% for Development with private industry accounting for about 17% of all Basic research, 55% of all Applied research and 85% of all Development. The British structure of R&D expenditures is very similar; Kennedy and Thirwall (1972) give references on this matter.

A third feature is that most of industrial R%D budgets are spent on product invention and usually on product improvement, while relatively small amounts are spent on process inventions. Kennedy and Thirwall (1972) noted that Americans allocated 48% of their R%D budget to new product development and only 11% to new process development. In 1961 a Federation of British Industries survey of industrial research showed that 41% of R&D expenditure was spent on minor product and process improvements and 37% on new product developments. Scherer (1980) quoted the results of a 1977 (American) Business survey which showed that firm's R&D expenditures were allocated as follows:

28% to New product development, 59% to improve existing products and 13% to new manufacturing process development. These findings indicate the relative importance of product invention and incremental invention.

R&D and Patents

The relationship between R&D and patents has also been examined. The early idea was that R&D expenditures were the ´inputs´ and that patents could be regarded as the ´intermediate output´; the expectation was that industries which had high R&D expenditures would also have high patenting rates. Empirical studies of this relationship showed that this was not the case. Some industries, such as aerospace or automobile have a low propensity to patent while others such as pharmaceuticals having a very high propensity to patent. Mansfield (1969) and Kennedy and Thirwall (1972) have reviewed such studies.

New Product Success Rates

Given that product invention is the single most important target of research it should follow that some evidence would be seen in sales. Mansfield (1969) (pp 7-8) has quoted the results of Terleckyj´s 1963 study which showed that between 1956 and 1960 10% of all sales by manufacturing firms was accounted for by products which had been developed since 1956. Mansfield gave a more detailed breakdown of the relative changes for particular industries and added a cautionary noted about the alleged "newness" of some of these products which he thought might involve only minor modifications to old ones. New product introduction is a very high risk activity and Rosegger (1980) has quoted some estimates of the failure rates; one report suggested that 50% to 60% of all R&D budgets did not result in commercially used products and another study estimated the figure to be 50%. Rosegger also quoted the finding of another American study which estimated that 10,000 new products were launched each year, 80% of them were unsuccessful and of the remaining 2,000 only 100 incorporated any significant technical advance as well as satisfying economic demand. Scherer (1984) quoted similar results of another study by Mansfield which had analysed 70 projects; before development had begun three quarters of these had estimates of success rated at 80% and only 2 projects were rated below 50% likelihood of technical failure, after these projects were completed it was found that 44% were technically successful and 16% were technically unsuccessful because of later unanticipated technical difficulties. The results of another study by Mansfield and associates showed the distribution of successes among different industries, 70% of Chemical firms, 32% of drug firms, 73% of electronic firms and 50% of petroleum firms. All these projects had been screened before the R&D stage so that they were, in a sense a biased sample but showed that even screened projects can be terminated because of unexpected technical troubles. Reekie (The Centre For The Study of Industrial Invention) (1971) has given a detailed British case histories of new products which were technically sound but commercially unsuccessful. These projects were shelved for a number of reasons (usually two or more) mostly connected with the nature of the market, for example the market was too small or competition was too great. This shows that invention alone is insufficient to ensure commercial success.

Product Performance

Another consequence of product invention should be that of an improvement in the product's performance. It was noted earlier that the Chicago School of sociologists had made extensive studies of this and charted the increased speeds of cars, aeroplanes etc. - Hart (1931) provided a series of such graphs. Other studies of this nature have been made, Bright (1949) has illustrated the course of improvement in the luminous efficiency of electric lamp filaments over the years and showed the typical pattern of increasing performance at a decreasing rate. Technological forecasting studies which are based on the extrapolation method also provide examples. Sahal (1981) has shown the change in fuel consumption efficiency of fossil fuel electric power stations over the period 1920 to 1970, and of the Horsepower to Weight ratio of farm tractors 1921 to 1967 both of which show a rising trend. However Rosegger (1980) has pointed out that in most cases it is very difficult to get a quantitative index as performance tends to be multi-dimensional. This is true but the examples given indeed support the view that product performance improves at a decreasing rate and usually levels off once product development is mature.

Economic Role of Product Design

It has already been noted in the section above dealing with the allocation of R&D budgets that the greater proportion was spent on product invention and product development. This activity has attracted some further attention especially in connection with the reasons for its importance for manufacturers. Two summaries, giving different views will be presented here. The first, by Weighell (1976) reports a car designer's view; this is followed by Ruda (1974) who presents a marketing manager's account of the need for new product programmes.

Weighell (1976) has discussed the reasons why modern British motor car manufacturers have to engage in costly product re-design programmes. He considered that competition from other manufacturers was the major reason and that competition was intense in a mature industry which had become world-wide leading all makers to create very similar designs, materials and methods of production. Product design was now an essential market feature. It was needed so that a variety of consumers could be satisfied and for these designs to be competitively priced. It would, Weighell said, be much more economical to try and satisfy all needs with one standard product design with the greatest economic benefits as Henry Ford believed, but it would not satisfy a range of consumer needs and would not maintain a sufficient sales volume to keep the product in the low price range. For that reason all high volume car manufacturers produced a range of models each of which had to be designed and manufactured and updated although the aim was for a product life of about ten years (not including the development period which might be as long as seven years). These new model programmes were extremely expensive as new components and new production machinery were needed. Manufacturing operations had to ensure that the vehicles were of a sufficiently low price but high quality and that product design changes were as infrequent as possible as it was a complex matter to introduce such changes. These changes could be made because it was desired to reduce manufacturing costs, or to improve the product quality, or to meet a new law, or to add a new customer feature, or to adapt to a new supplier, or to introduce an additional model variant, or to (paradoxically) reduce the variety of models, or to simplify production, spares, stocking and financing of parts, or because of problems such as corrosion. Weighell considered that the driving force behind the motor industry was competition and that if consumers found another more attractive model the firm would lose business. Some consumers wanted a car to last forever, others dispensed with it after a year because a later model was more attractive because of its appearance, comfort, acceleration, handling or other aspects of its performance. These varied customer desires showed why demand-led design was now so important.

More extensive discussions of the manufacturer's need for new or improved products are given in books on marketing. Ruda (1974) has discussed this issue. He noted that old products became obsolete and needed to be replaced if manufacturers were to maintain earnings and, as there was a constant obsolescence, a New Product policy was essential. Ruda noted that the initial causes of need for a new product were varied; it could have been caused by the need for a new model, or to bolster flagging sales of a particular product range, or because a new material or invention had been made. All these were 'supply-side' reasons; it was equally possible that firms' engaged in market research which initiated a new product, this would be a 'demand-pull' cause. (Consumer attitudes to improved products will be discussed in the section on demand).

Cooper (1983b), in a survey of new product projects over twenty years also noted that the 'success equation' involved a number of different factors which could be roughly classified as Technical and Market but he considered that the consumer's perception of the new product's design, advantages and benefits was a vital element as well as a good R&D-Marketing link.

Therefore while no definitive answer can be given to the demand-pull/invention-push controversy, it can be said that both have been shown to be important.

Walsh (1984) set out to establish whether the pattern of inventive, innovative and economic activity in three branches (dyestuffs, plastics and pharmaceuticals) of the chemical industry could be explained either by Schmookler's demand-pull theory or Schumpeter's science-push theory. Walsh was concerned with long term trends and used national statistics of production, trade and investment as indexes of 'demand' and annual numbers of chemical patents and chemical scientific papers as indexes of invention and science 'push'. Her conclusion was that there was no discernible demand-pull or science/invention-push pattern as far as invention was concerned as at times surges of patenting activity preceded surges of sales or investment while at other times demand-pull appeared to induce the search for greater product variety, better product quality or new product uses. There was no clear evidence that science publications always preceded patents as often the opposite was true, and patent statistics were not a good indication of pioneer inventions or even later secondary 'swarms' of incremental inventions. Innovations conformed more closely to a pattern over the product life-cycle typically having a slow start and crucially depending upon entrepreneurial 'push' then being followed by a period of rapid growth of both sales, product and process improvements during 'take-off' and finally during maturity when markets tended to saturate and technical development slow down, all the indexes declined. Invention involved both pioneer and incremental advances but both were associated with a variety of causes. Her conclusion was that both push and pull factors play an important role and that the relationship between them varied with time and the maturity of the industrial sector involved. In effect this result confirmed observations made by Langrish et al (1972) that innovations had multiple causality and that neither pure push nor pure pull could, by themselves adequately account for the pattern of change seen in the cases they studied.

Criticism of 'Demand-Pull' Innovation Models

Although innovation researchers have demonstrated the importance of demand-pull in commercial life and product development this concept has not been without its critics. Mowery and Rosenberg (1979) have given a critical review of innovation models of technological change which have included references to either demand-pull or consumer (or user) needs. Such studies incorporate the idea that market forces govern the innovation process but the authors contend that this has not been demonstrated by the empirical analyses, largely because the concept of demand is vague and also because these studies did not all examine the same independent variables so that the role of demand upon innovation (and invention) has been overextended and misrepresented. Mowery and Rosenberg then give a detailed analysis of the study by Marquis and Myers which was said to be one of the most important in showing the primacy of demand upon the innovation process. Marquis and Myres's study reported that 45% of the innovations were primarily due to market pull factors but no persuasive evidence was given.

Mowery and Rosenberg then considered the work by Langrish et al which had aimed to show the effects of the environment on the development process and whose results were also frequently cited as an illustration of the primacy of demand in innovation projects. Mowery and Rosenberg considered that the four categories of 'linear models' failed to distinguish between customer and internal needs, which was a useful distinction, so that the results by Langrish et al did not present the factors underlying successful innovation but merely the factors initiating the search activities - it was "need pull" rather than "demand pull" that was being categorised. They then dealt with the TRACES and Battelle studies. TRACES made no reference to the relative importance of demand-pull or technology-push while Battelle did, thus TRACES dealt only with the contributions of basic or applied research to innovation but the Battelle study re-examined three of the five TRACES innovations to include broader issues and concluded that the relative importance of "mission" to "non-mission" research was different to the original findings.

Mowery and Rosenberg then dealt with five other innovation studies and concluded that although all the studies they had reviewed were frequently cited as examples of the importance of demand effects upon innovation, most of the original studies had little to say about the influence of market demand upon the rate and direction of innovative output and usually the original were distorted and misquoted. A more recent study by Gilpin had stressed that influence of demand pull upon innovation and cited Schmookler's findings in support but Mowery and Rosenberg pointed to the distinction between invention and innovation and concluded that the primacy of demand factors within the innovation process had not been demonstrated, that a clearer distinction between demand and "needs" was necessary as well as a distinction between internal and external factors which influenced the firm. Demand pull meant that an innovation was introduced because the demand for a product had increased (italics original) and in practice the concept ignored the complex and diverse supply side mechanisms which altered products and processes, and that innovations were responsive to both supply and demand side forces. The innovation process had uncertainty and complexity at its core and deeper analyses were needed; Abernathy and Townsend had employed such a method which yielded a substantially different set of conclusions to the original by Marquis and Myers. The electronics industry had been extremely progressive and sensitive to demand factors but it had also been fundamentally governed by the exploitation of new scientific and technical knowledge and this had not arisen because of sudden shifts in demand but had emerged over three decades primarily because of new technology although it had also been sensitive to the desires of customers. Demand changes may bring about a rapid diffusion of an existing innovation with good profit prospects but "one can hardly rely completely upon such forces for the initial generation of such innovations." (p.150).

2.4.2 Utterback and Abernathy's Model

Utterback and Abernathy (1975) have rejected the idea that development projects are so complex they cannot be reasonably represented by a model. Their model evolved from two distinct but complementary conceptual models of innovation; one was based on competitive strategy and innovation, the other was based on production process characteristics and innovation and both were synthesised into a dynamic model which was created by classifying the nature of the stimulus of the innovation.

This is a model of the general pattern of dynamic changes which occur over the product life-cycle (or age of industry) which synthesises various forces and factors both within and external to the firm, and was built from contributions of Myers & Marquis and other early studies and Abernathy & Townsend (1976) who dealt with organisational innovation factors and process innovations and their effects respectively. Later elaborations of Utterback & Abernathy's model have been given by Abernathy & Utterback (1978) and Hill & Utterback (1979), and the following summary will be based on both the original and later versions. (A summary has been given above of the latest transilience model which is essentially an extension of the basic one now presented).

Inside factors refer to those which management can directly control such as resource allocation, management policy and organisation of human facets of production including communication, product and process technology (although some of this can come from outside) and technical resources related to product and process technology. Outside factors are those over which management has no direct control but which require some alteration to internal goals or policies and include changing prices of inputs, competitive stresses, and government actions or legislation.

The essential features of Utterback and Abernathy's model are:
1) That the characteristics of the innovative process will correspond with the stage of development of the firm's process technology. (These stages are product life cycle stages).
2) That the characteristics of the innovative process will correspond with its strategy for competition and growth.
Their model depicts a coherent pattern of the stimuli for innovation; the types of innovation (i.e. product and process innovation); and the barriers to innovation. In other words it relates innovation to product and process evolution.

Product Innovation

The model of product development given by Utterback and Abernathy rests on the assumption that products will be developed in a predictable manner with the emphasis on product performance at first, then later emphasis on product standardisation and cost reduction. Different innovative patterns are based on different competitive strategies; for example one firm may wish to be first to introduce a technically advanced product (a stage and strategy they call 'performance- maximising') while another firm may be content to sit back at first yet be quick to adapt and introduce new product variations and features ('sales-maximising' stage) while yet another firm would enter the market later in the product life cycle with simpler and less expensive versions ('cost-minimising' stage). Each of these strategies led to different product innovations to suit the policy but were centred on a common core in which the type of innovation was largely determined by the stage of the product life cycle development. Product invention was very frequent in the early stage because of the need for better performance and great product diversity existed among firms at this ´uncoordinated´ stage. Products were non-standard, markets ill-defined and product change tended to be in response to user´s needs. In the next stage of the product life cycle product inventions for better performance were less likely but greater market diffusion allowed more advanced technology to be used which resulted in product variation or new components. However in this second stage inhibitory forces were beginning to build up which made it difficult to better past performance. In the last stage product variety was reduced and the product became standardised. The emphasis switched to cost minimising and product changes had to harmonise with process changes, both of which were incremental and interactive (´systemic´). At this last stage it was also possible for a radical invention or new design to be made but the prospect of this leading to a high rate of market growth was not appreciable. Many changes would not be economically justified at this stage because they offered only marginal returns and often outside suppliers developed these.

Process Innovations

The basic feature of their process model was that a process technology developed with a characteristic evolutionary pattern and became more capital intensive with increased Division of labour, with flows of materials becoming rationalised and product design becoming standardised. As productive scale increased, productivity increases often derived from incremental changes. The sources of change came from both inside and outside the firm.

In the early stage production was undertaken using general purpose machinery and flexible but highly skilled craftsmen for low volumes of production. This arrangement suited the uncertain product design and any alterations in this could be easily accommodated by both machinery and craftsmen.

In the middle stage the volume of production had increased to such a point that certain production processes could be mechanised or have "islands of automation". This, in conjunction with the now standardised product design and competitive stresses (which include reduced product prices), meant that management had to concentrate on process innovations at this stage. The adoption of some form of high volume production was paralleled by changes in

the labour force which was now less skilled and used more specialised production machinery which was relatively inflexible.
In the late stage the rate of process innovation decreased but the trend to specialisation continued with the use of automation (if applicable) and machinery which was often specifically designed to suit the product or its components. The volume of production may have increased and later declined but the high capital investment and consequent high cost of process change led to rigidity of production arrangements so that its trend became one of stepped incremental innovations. This high cost led to full utilisation of other production economies such as economies of scale, standardised product designs, the development of mass markets and changes of location to reduce costs. The firm often specified particular machinery and manufacturing materials to outside suppliers and the automated or highly controlled method of manufacture meant that labour mainly monitored production machinery.

Later Studies Using The Utterback & Abernathy Model

Abernathy and Clark (1985) have extended the basic Utterback & Abernathy model based on the historical analysis of the American automobile industry. Their primary aim was to show the product invention-marketing link and from their analysis created the concept of 'transilience' (which refers to the capacity of an innovation to influence established production and marketing systems) and which classifies innovations into four categories, namely 'Architectural', 'Niche Creation', 'Regular' and 'Revolutionary' innovations. Their fundamental model was of the changing dynamic pattern of innovation over time (with a decreased emphasis on the life-cycle) as a response to both technology-push and market (consumer)-pull.

Architectural innovations, in Abernathy & Clark's model, refer to pioneer product designs which they say have diverse origins from other earlier industries which result in a synthesised design which tended to have a long life. The role of science was not prominent in the creation of this design but that design was soon modified by consumer needs and market requirements.
Niche Creation innovations were essentially incremental ones largely due to technology building upon technology and changing market or consumer needs. The product was improved in terms of its technical performance, reliability,

styling and operation but contained little significant technical advances and such design improvements were used only to capture new market niches. Regular innovations were also incremental ones but of greater technical significance and their effect over a long period of time could be large. some examples given included the detailed changes in car engine design which resulted in superior engine performance. Here again the main stimuli were market needs and technological capabilities.
Revolutionary innovations were founded on technological advances and profoundly changed the product. Some examples included independent wheel suspension, the all-metal enclosed body and new forms of transmission. Some of these innovations could fail because of market rejection but if properly timed can create great demand and force competitors to update their designs. Abernathy and Clark showed how Ford's policy was mainly centred upon process improvement and of his achievement in the first years of the automobile industry when he reduced the price of his Model T from 1200 dollars in 1908 to 290 dollars in 1926 even although the 1926 model had more refinements (such as electric light and an electric starter). However competitive pressure, in the form of better product design forced Ford to produce his new Model A in 1927 and how Ford then reverted to his earlier policy of concentrating on process improvements while his main competitors (GM and Chrysler) went on to make revolutionary product advances which permitted them to gain the major share of the market at the expense of Ford.

This transilience model presented by Abernathy and Clark showed that all four types of innovation were needed over the industry life-cycle and that each shaped the industry in powerful but subtle ways. The transilience map was more than a simple categorisation of technical change but was rather a framework which permitted examination of the relationships among innovation, capacities and evolution of industries as well as knowledge about competitive strategies. Transilience was essentially a new way of assessing the competitive significance of an innovation.

Criticism could be made of this transilience model, in particular it does not seem to point out how Ford's models were based on simple low cost product designs which apparently contributed as much to low prices as Ford's undoubted process improvements; nevertheless it reveals how manufacturers used product design to increase their market share.

Rothwell-Gardiner Model

Rothwell and Gardiner (1983) have presented an innovation model in which they depict the evolution of product and process design as an iterative and cumulative sequence in which the consumer plays an increasingly important role, especially in the later stages of the industry or product life-cycle.

Their general 1983 model was a three stage one, each stage depicting a type of design process linking invention, innovation and reinnovation. The first stage ('design for demonstration') illustrated how design was used to reduce an idea or concept to a practical form as a demonstration of its feasibility. The second 'pre-production' stage focused upon 'makeability' and here product design was closely linked to the manufacturing requirements leading to a series of prototype designs intended for marketable production.
The third 're-design for altered specifications' stage began with the commercial launch of the new product and re-designs were made in order to suit the market in terms of product characteristics and product prices. These subsequent re-designs were greatly influenced by consumer needs in terms of product performance and lower costs and usually led to the emergence of a related series or design 'family' of products which shared many of the performance characteristics and component parts at this stage. Consumer influence was vitally important in meeting competitive pressure.

Rothwell and Gardiner (1983) illustrated the properties of their general model with reference to the changing designs in the aero-engine, agricultural machinery and textile industries. By means of a consumer survey of the reasons or preferences of purchasers of agricultural machinery, the authors found out that consumers were principally concerned with various features of technical performance and that product prices were relatively unimportant. In the case of textile machinery buyers, technical features again were most important but it was found that product prices were not nearly as important to buyers as total or overall running costs and these involved a composite mixture of technical and economic factors such as machine efficiency, reliability, production rate, labour requirement, working life and purchase price.

Gardiner and Rothwell (1985) extended their 1983 general model to include an increased emphasis upon consumer influence on design and in particular to develop the idea that a ´robust´ (good basic) design owed much to the preferences and suggestions made by ´tough´ (technologically sophisticated) customers.

This 1985 extension imposed a four-step sequence of product design upon the three-stage 1983 model. The first of the four-steps involved the adaptation of the basic idea or concept in a variety of possible new designs some of which were successful and became the kernel of later robust designs, others did not and ceased to be of further interest.

The second of the four-step sequence was a ´composite designs´ one in which some good and bad new ideas were developed into potentially fruitful models the rest being discarded. This convergent design process reduced diversity.

The third of the four-step sequence was a "consolidated designs´ one in which the robust designs of the previous step were rationalised and compromised against ´makeability´ and expected profitability features. This third step was again a convergent design process.

The fourth ´stretched designs´ step used design to re-rate, up-rate and de-rate robust designs to suit existing markets or create new markets. This involved divergent design process and usually resulted in design ´families´.

Consumer influence shaped and directed the design process by imposing ´tough´ demands upon the manufacturer. These demands were born of experience of the technical function and earlier products as well as market conditions. Gardiner and Rothwell (1985) illustrated their extended model with reference to the design evolution of the Boeing 747 family of aircraft and of the xevelopment of a rotary cultivator. They stressed that different products had different patterns of consumer influence but that in general this was greatest in capital-goods and during the post-launch stage of evolutionary design improvements.

2.5 Demand and Invention

2.5.1 Introduction

The importance of demand-pull has already been noted and in this section the aim is to review the literature dealing with economic and market research accounts of demand and product design. This field of enquiry is as complex, diverse and inconclusive as supply-side literature and here a summary will be given of the following features.

1) The importance of demand in growth; 2) Outline of economic theories of demand and saving; 3) Economic features of consumer durable goods; 4) Socio-psychological aspects of demand and 5) Consumer attitudes to product design.

2.5.2 Importance Of Demand In Growth

Phillips and Maddock (1973) considered that growth of demand had been an important element in the total growth of the British economy 1918 to 1968 but, because of the complexity of the matter, were not able to quantify its relative contribution. Two main demand features were noted; one was the general increase in consumers' purchasing power and the other was the change in patterns of consumer expenditure. Changes in purchasing power had depended not only upon increased wages and salaries but also upon changes in taxation and other factors which had effectively increased all incomes. Changes in the structure of consumers' expenditure had also been marked with a relatively greater proportion being spent upon consumer durable goods and services while the relative amount spent on food had hardly changed since 1900. This structural change had not been uniform throughout the period 1918 to 1968 as large surges of demand had occurred during the 1930s and early 1960s.

Other factors also complicated the course of demand. One was the expansion of various forms of consumer credit which became very important after 1945, and the other was the change to government economic control by 'demand management' (stop-go) which imposed marked fluctuations upon British homesales due to changes in hire purchase terms, changes in purchase tax and control of incomes ('pay pauses').

Abundant evidence of the changes associated increased demand in Britain is given by many government and market research publications as well as the literature of applied economic research. British government publications since 1945 have presented data showing the trends and distribution of income, wealth, disposable income, aggregate consumer expenditures, component consumer expenditures (for example on food etc, housing, clothing and footwear, consumer durable household goods and cars and cycles); these appear annually in Economic Trends. From 1957 Family Expenditure Surveys have been published annually giving sales and household ownership rates for many durable and non-durable household goods; these figures are frequently supplemented by reports of household samples which are continously monitored in the General Household Survey. In addition sales data are included in Census returns and in greater detail in Business Monitor. Market research surveys also give much sales data, ownership rates and market analyses - Retail Business is one of the most quoted of these journals and further market research publications can be found in Critchley (1977). All these sources clearly indicate a rapid increase of ownership of consumer durable products in British households since 1945, mainly in lower income homes.

2.5.3 Economic Theories of Demand (and Saving)

Brown and Deaton (1972) have given a brief historical account of the development of economic demand theories in the introduction to their survey of the literature. They noted that Classical theories concentrated on the effects of price changes of particular goods and their relationship to quantities demand; then by the mid-nineteenth century the analyses of household family budget expenditures culminated in Engel's law relating income and particular categories of expenditure. In the 1890s Marshall clarified the concept of elasticity of demand and also noted the importance of changes in consumers' tastes and preferences. These early developments have led to the modern core model of a demand schedule which is a function of product price, (disposable) income, prices of other goods and services and a 'trend term' for changing attitudes and tastes.

Surrey (1974) has summarised the early theories which developed from these first efforts; the Habit Persistence concept was expounded by Keynes who considered that a consumer had a 'habitual' standard of life which he sought to maintain with some margin for regular savings from his income, should his income vary the saving margin varied thus maintaining his habitual living standard. Duesenberry (1967, orig. 1949) further considered Keynes's concepts of consumption, saving and the marginal propensity to consume relatively less as income rose and considered that to some extent new demand (for new products and services) offset the relative reduction to consume.

The Stock Adjustment theory which depicted demand behaviour as a continuous process of adjustment; one version of this was used to explain the pattern of purchases of non-durable goods and services as a process of adjustment to a pattern formed by tastes and habits, Stone and Rowe (1966) examined British consumer expenditure for the period 1920 to 1938 using this method.

Ferber (1973 & 1962) has reviewed the principal theoretical developments of modern demand theory and the results of statistical demand studies from 1945. The main theoretical development was the emergence of three new theories of demand each of which was mainly concerned to isolate the influence of income on consumption holding the effects of other, usually 'non-economic' variables constant. These three theories will now be briefly described.

Absolute Income Hypothesis

The absolute income hypothesis was virtually a restatement of Keynes's original concept and led to many statistical tests to confirm it. In general it was found that very high correlation coefficients existed between changes in current income and changes in aggregate consumption although it was noted that in long-run studies an increasing discrepancy existed and this discrepancy was the reason for all later modifications of the absolute income hypothesis. One of the earliest modifications arose because of a controversy about the self-correcting action to assure full-employment, a feature which Keynes did not believe but others showed that it was possible to explain the long run discrepancy between income and consumption if wealth was taken into account. Wealth was generally regarded by economists as accumulated saving (although occasional 'windfalls' such as legacies might increase wealth) and therefore saving was regarded as a component of income which was not spent.
Only after 1945 did sufficient data become available to assess the importance of wealth in consumption and in the immediate post war years it was not found

to be a particularly influential factor. Further statistical tests were undertaken at the micro-level and the results of these appeared to corroborate the absolute income hypothesis in the short run but in the long run a discrepancy was found between budget data and saving. Budget data showed that the saving ratio rose substantially with rising income, and in America incomes had risen enormously since 1870, yet the aggregate saving ratio had remained virtually constant since that time. This problem led to the development of another hypothesis - the relative income hypothesis.

Relative Income Hypothesis

The basic premise of the relative income hypothesis was that the saving rate depended of the relative position of the individual on the income scale, and not on the absolute level of income.

This new hypothesis was tested and further theoretical extensions added, the most influential extension being Duesenberry's which postulated that a strong tendency existed in society for people to emulate others and at the same time strive constantly for a higher standard of living. If people subsequently experienced a reduction of income they would be reluctant to return to a dower standard of living and instead they would prefer to alter their rate of having. This saving rate was a function of both current income and the highest previous income level and was presumed to yield a long run constancy. Statistical analyses of the changes of consumption and the constancy of saving rate showed that the relative income hypothesis provided a better mathematical explanation of saving and consumption patterns.

Permanent Income Hypothesis

The observation that many families' income varied substantially in the short run while their consumption was relatively constant over the same period led to the idea that people averaged their actual and expected income and threw some doubt upon the use of current income in demand analyses. Once again this idea was tested and led to later variants the most notable being Friedman's who divided income onto 'transitory' and 'permanent' components. Friedman believed that long run consumption and saving was mainly based on the permanent component with short run net changes due to the transitory component. Ferber (1962) noted that this was a difficult hypothesis to test because it was difficult to quantify the components but even so there were other criticisms were raised and that some doubt still exists about Friedman's theory. In addition attempted tests have highlighted the importance of other 'non-economic' variables in consumers' behaviour; for example the recognition that individual saving ratios were affected by 'age' (or life-cycle stage) so that young people save little, retired people often dis-save while persons in later working life stages save most. (A fuller account of non-economic demand variables will be given later in this section).

Mathematical Models Of Demand

Throughout this section of the review of demand theories it has been noted that each theory was subject to statistical tests against actual data. In fact from 1945 a considerable parallel development took place in the creation and refinement of mathematical models of demand and their associated econometric techiques. These developments will not be reviewed here, Deaton and Muellbauer (1980) have given a comprehensive review, discussion and historical notes about this. The main models sought to account for observed demand for individual commodities and began with relatively simple equations which estimated price and income elasticities. This theory of consumption built upon general marginal utility theory so that a consumer experienced decreasing utility (satisfaction) with increased purchases of a particular good and therefore, as a rational man, he sought to maximise his total utility by allocating his total spending on all purchases to obtain optimal satisfaction. This led to empirical studies of price and income elasticities for common goods; for income elastic goods demand was seen to increase more than proportionately for a given increase in income, and was found to apply to luxury goods and consumer durables. Similarly for price elastic goods the change in demand was more than the proportional change in its price; basic goods with easily available substitutes are usually price elastic.

By 1939, Brown and Deaton concluded classical demand analysis in conjunction with developments in statistical methods had resulted in derivations of price and income elasticities for most goods. The next step was the Linear Expenditure System, created by Stone and Rowe's analysis of British demand based on the Stock Adjustment principle. This was followed by the Rotterdam model and later by another by Deaton and Muellbauer. In spite of considerable sophistication and refinement these mathematical models still have certain shortcomings especially when dealing with demand for a consumer durable good. (A fuller account of the factors involved in the demand for consumer goods will be given later in this section).

'Trickle Down'

One short-coming of mathematical models is that they do not explain the mechanism of growth of consumption; one important aspect of this came to light because of government and market research enquiries into family expenditures, purchases and ownership of consumer durables. These returns clearly indicated that a major source of new demand (first-time purchases) came from lower income individuals and families whose incomes had risen; this became known as the 'trickle down' (or 'trickling down') theory of demand - Anderson (1964) has described its importance in American growth. In more recent times the same phenomenon has been noted in Britain as this quotation from Social Trends (1982, p.111), referring to durable ownership changes in the period 1970-1980, "generally speaking, the ownership of consumer durables has increased at a higher rate among the semi-skilled and unskilled manual groups and households headed by an economically inactive person, than among other groups".

PEP (1950) were able to give a quantitative illustration of 'trickle down' growth due to the rapid increase for low price cars in the 1930s using annual road tax data; this demonstrated that the numbers of small cars sold in Britain increased far more rapidly than large ones. Mansfield (1969) has given further references to the "trickle down" theory, noting that the pattern of higher social status (and income) groups tending to be the first purchasers of a new product and that later purchases were made by lower income groups; often, Mansfield noted, in the form of inexpensive copies of the original product.

Product Quality

Another economic aspect of demand for products which causes great difficulty is quality differences; in general it is implicitly assumed that higher priced products have better qualities than lower priced ones; Irish (1980) has briefly noted a variety of demand theories which attempt to take this dimension into account. None of these theories are very satisfactory because it has become appreciated that 'quality' involves a 'bundle' of characteristics which are difficult to define and measure.

Saving

Personal saving at the aggregate level has been of theoretical interest because of modern growth theory and the stress upon investment (which in turn depends upon saving). This has led to empirical studies of personal saving rates which fluctuate considerably and are not easily explained.

Klein (1958) investigated British personal saving behaviour in order to assess whether Keynes's propensity to save was as constant as Keynes had implied. Klein found that while the overall marginal propensity to save was 0.1 for the whole population in the mid-1950s "the savings process was multivariate to a high degree" (p. 83) with widely vary patterns according to income, occupation, age, family size, expectations and other factors which later researchers have found to be closely associated with personal saving. Klein considered that changes in income was the principal determinant of personal saving and that it was linked to purchases of consumer durable goods.

Page (1973), in his examination of British personal saving for the period 1950-1970, found that the saving ratio had been exceptionally low in the immediate postwar years due to the special conditions which then existed, but that from 1950 the ratio began to increase reaching normal prewar levels by the end of the 1950s. Falush (1978) noted that from 1972/1973 the saving ratio in most advanced economies (including Britain) rose rapidly and that no satisfactory theoretical explanation had been given for this although it was considered that high unemployment, inflation and rising interest rates were responsible.

Modern theories of consumer saving are derived from demand theories with saving regarded as a residual ('not spending'). The earliest saving theories emphasised the prospective return to savings and concluded that saving was primarily determined by interest rates. This has now been abandoned and personal saving accounted for according to the particular demand theory, although each has its own difficulty, anomalies and complexity.

Theories of personal saving have been limited by lack of data for the pre-1939 period with the exception of Trustee Savings Bank (TSB) and Post Office Savings Banks (POSB) returns. Ashton (1929/30) attempted to explain the trends in TSB deposits and initially considered that these would be primarily linked to employment but found that during the 1920s, when unemployment was high, TSB deposits continued to increase.

Payne (1967) has investigated changes in the Glasgow TSB data for the period 1836-1914. He set out to answer three questions: Who saved? How much did they save? and Why did savings vary over time.? Payne found that the majority of Glasgow TSB savers were from the lower income groups; they saved very little each having only a small average TSB balance. The reasons for variation in saving over time were complex; Payne analysed the trend of annual net saving (deposits minus withdrawals) and concluded that employment, wage levels, changing standard of living, interest rates and psychological factors were involved. Net savings showed a very marked sympathy with trade (business) cycle movements but superimposed upon this were other influences especially emigration and rates of return from alternative investment (city corporation loan stock). In general TSB saving depended upon the level of income and employment.

It had been noted by Radice (1939) that British savings and purchases of consumer durable goods appeared to be intimately connected. Radice had analysed changes in savings banks returns for 1922-1935, which he considered gave a fairly accurate index of lower income families' saving patterns. Lydall (1955) has summarised the findings of a series of Oxford surveys into personal savings. He noted that British savings indeed tended to move in sympathy with changes in income but other factors intervened which added complexity. For example net saving showed a kinked curve with low income groups (below 800 pounds p.a.) dis-saving while those above that income level saved, and in both cases the dis-saving /saving was proportional to the income (the poorest dis-saved most, the richest saved most). Lydall compared net saving and purchases of consumer goods and found that this was much more linearly related to income, although the lower income groups purchased relatively fewer consumer durables and again there was a proportional link between income and the amount spent on consumer durables. Lydall enquired further into the factors which affected spending on consumer durables and found that various other elements affected the decision to buy, sometimes wealth (from windfalls or gifts) was used, while periods of hardship delayed purchase. Social factors also affected these purchasing decisions, often more than normal was spent at times of birth, weddings, death, moving house and holiday times. All these complicated the relationship between savings and consumer durable purchases.

Pickering (1977) found that lower income families mainly used savings banks. Pickering has also noted some income-related features of consumer durable purchasing which involved some degree of consumer judgement or expectation about future economic conditions - especially employment, future income and general economic prospects.

2.5.4 Economic Features Of Consumer Durable Goods

Every review of economic demand theories devotes a chapter or section to the special problem of demand for consumer durables. Evans (1969), in his sixth chapter dealing with the problem, noted that durables were purchased only sporadically, that durable purchases were not particularly influenced by past purchases so that the lags employed in many models of non-durable goods did not apply to durables. He also noted that sales of durable goods were highly cyclical because their acquisition can be postponed during recessions. Durable goods were relatively expensive and the empirical evidence showed that durable sales were highly sensitive to changes in consumer credit conditions and that current consumers' debt was positively correlated with purchases of durables. This meant that consumer saving and durable purchases were closely linked either directly to saving (for outright purchases) or to credit conditions (for the required deposit).

In general the main distinction made between durable and non-durable purchases is the relatively large cost and the long product life (consumption period) of the former. Downham and Treasure (1956) have defined and described consumer durable goods and the distinction from non-durable consumer goods. A consumer durable must be durable in use and must also be expensive in relation to income. These authors gave an illustration of the structure of British consumers' expenditure for 1955. 55% of total consumer expenditure was for non-durable goods, 10% for semi-durable goods, 10% for durable goods and 25% for services. Durable ownership rates were greatly affected by income and was highest among the better-off sections; ownership also diffused through the community becoming more widespread over time "until it became a standard good like radio sets". Consumer durables often have social overtones because they were exposed to social observation and formed the basis for social judgements by neighbours and friends. These features make consumer durables quite different from non-durable goods.

Brown and Deaton (1972) in their survey of models of consumer behaviour noted that special problems were involved with consumer durable goods and devoted a section of their survey to this. They noted that the relative expense of durable goods meant that consumers thought about and discussed the purchase before they made it, they could reduce the impact of one large payment by a number of methods either some form of consumer credit or buying second hand, or the consumer could delay or advance his purchase if circumstances were changing. Fashions and changes of taste were particularly important in durable goods and could hasten replacement before the previous model was unsatisfactory. For these and other reasons it had been found to be difficult to predict or even wholly explain consumer durable demand.

Most modern models of demand for consumer durables are extensions of non-durable models but when tested against data inevitably reveal a long run discrepancy and in particular do not exactly follow trends of disposable income.

An early confirmation of the importance of new demand as a source of growth of consumption of British consumer durable goods was given by PEP (1945) in an analysis and forecast for this market for the immediate postwar years. This study of the changes in demand and ownership of many household durable goods was based on prewar estimates of British data and supplemented by references to American trends. The authors of this report were able to show that increased sales of domestic washing machines, irons and similar durable goods were closely associated with decreasing product prices and that corresponding increase in ownership rates was most marked in lower income households. A remarkable feature of the PEP (1945) report was its analysis of lower income groups´ purchasing power and its stress upon the need for good design. The purchasing power analysis was based on earlier (pre-war and wartime) researches on British lower income purchasing patterns which revealed that among the many very low income households (of 160 pounds p.a.) only one shilling per week could be afforded for consumer durable goods and hence the great stress these authors placed on the need for low-priced products. They pointed out that such low income groups constituted a high proportion of the total British population.

Ironmonger (1972) has given a novel method of assessing the economic importance of new and improved goods as a proportion of total consumer expenditure. He noted that current theories of economic demand assumed that goods were ´established´ and these theories were poorly suited to elicit the market importance of new and improved goods. Indeed he observed that in some studies of British consumption the economic variables (real income per head and real prices) were quite unimportant compared with ´social variables´ and he illustrated this with reference to studies by Prest and Stone. Ironmonger devoted the first five chapters of his book to an exposition of his method which aimed to assess the market importance of technological ´innovation´ in the form of new or improved goods which had better quality. Previous research on the demand for new or improved durable goods products[14] was sparse and mainly confined to car and television receiver purchasers. Brown and Deaton (1972) have explained the technicalities of Ironmonger´s method.

Ironmonger referred to earlier studies which claimed that prior to 1909 the growth of consumption was largely due to new non-durable goods, while another study of the changes in the British retail trade had shown that structural

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[14] Ironmonger referred to ´commodities´ rather than products although he included both commodities and products in his analysis.

change in that sector largely depended on the introduction of new products.

Ironmonger then examined the pattern of growth of demand of eight new products in Britain over the period 1805 to 1953. He found some difficulty in specifying the starting date for demand for a new product, it might have been stipulated as the time when the first new product was sold but Ironmonger preferred to regard it as that time when the first marked surge in initial sales took place. This was followed by a period of consumer diffusion in which the rapid early demand rate slowed and often fluctuated. Ironmonger believed that the rate of introduction of new products was increasing because consumers had higher incomes and were more prepared to make ´experimental´ purchases.

Ironmonger classified 113 British consumer goods sales for the period 1920 to 1938 as either ´new´, ´established´ or ´outmoded´ based on the growth rate for each. New goods had a rapid growth of sales, established goods had completed the diffusion process and consumption levels were stationary, while outmoded goods had declining sales. As price and consumption expenditure data existed for each of the goods in this period it was relatively simple to calculate the values for each classification and, after adjusting for population changes, to assess the net diffusion effect which represented the importance of new or improved goods as a proportion of total consumer expenditure. Ironmonger found that the 1938 values indicated that new or improved products accounted for 15% of the 1920 level of consumption which illustrated its relative importance when compared with the 9% increase due to growth of population or the 9% due to other factors. Technological change, in the form of new products or old ones with improved product qualities was an important element in demand which was not satisfactorily registered in standard economic models of demand.

Pickering (1977) has reported the results of a survey of British buying intentions and ownership of consumer durables over the period 1972 to 1973. This survey was mostly connected with financial and economic expectations. He noted that great fluctuations occurred in consumer durable purchases. Pickering found that increased income was associated with increase expenditure but that other financially related variables were important too. These included unexpected income or wealth, (windfalls), unexpected expenditures and attitudinal variables especially expectation of buying and attitudes to prices to be important. The ownership analysis showed that ownership rates of the eleven consumer durables was strongly linked to household income and social class; expenditure also increased as family size increased (except for washing machine ownership). Stage in life and time married showed the inverted U-shape of peak ownership in middle life. Most of the goods owned had been purchased; though some were given as gifts. Lower income groups tended to have the highest rentals. The oldest models were owned by older people and lower income groups; while higher income groups had newer models and were most likely to abandon or replace faulty or unsatisfactory goods while lower income groups were most likely to have the goods repaired or buy or sell second hand. Pickering found a well defined order of preference among the eleven consumer durable goods so that all respondents placed cookers and refrigerators in high priority positions while tape recorders and similar products were given low priority.

Hebden and Pickering (1974) elaborated on the acquisition priority aspect and found that survey results indicated that British households in 1971 had a general order of purchase of household durables which was more or less irrespective of social class (and income) and concluded that this was a social phenomenon.

2.5.5 Socio-Economic Consumer Aspects of Demand

The importance of changes in consumers' tastes or preferences in demand had been recognised even before Marshall drew attention to it. One influential theory was given by Katona (1960) who considered that purchasing decisions depended upon the joint action of two factors; one was an economic factor which he called 'the ability to buy', the other was a psychological factor which he called 'the willingness to buy'. The 'ability to buy' refers to consumers' economic ability to buy and is is largely explained by economic demand models and changes in prices and incomes.

Willingness To Buy

Katona illustrated the importance of the psychological factor by showing how the sales of consumer durable goods in America did not automatically follow changes in disposable income and concluded that the inclusion of the psychological factor offered a more complete explanation. Much of the subsequent research was concentrated on consumers' expectations of future changes in economic conditions as it has been found that most consumers plan their future durable purchases and these expectations are an important element in their decisions.

As a psychologist, Katona extended his research into motivational aspects of consumer behaviour and until the late 1960s analyses of this dimension was grounded upon psychological theories of motivation; Anastassi (1964) has given extensive references to mainly 1950s literature. The concept of 'willingness to buy' has undergone a transformation due to more extensive investigations of consumer behaviour and the earlier motivational concepts, according to Engel and Blackwell (1982) "generated more heat than light".

Engel and Blackwell have given a comprehensive account of recent theories and research on non-economic aspects of consumer behaviour and note that it is a complex topic with diverse theories. It has resulted in general agreement about important variables, the relationships which exist among them and more effective practical marketing policies. Modern theories of consumer behaviour include a much wider range of socio-psychological variables to explain the forces which impel consumers and have attempted to create models of the consumer decision-making processes which depict the relationships among these variables. It is now considered that consumers are influenced by product attributes which reflect or resonate in accord with the consumer's own needs, wants, desires or preferences.

Modern theories of consumer buying behaviour recognise that there are a broad range of environmental and individual psychological variables which can both promote and inhibit consumers. Among the most important environmental factors are demographic variables such as population density, population growth rates, age structure and age characteristics; changes in birth rates have a profound effect on later demand, age structure has a more immediate effect as normally younger buyers spend more on consumer durables and tend to be impulsive purchasers, while older buyers are slower, more discriminating and tend to buy fewer consumer durables. Other environmental variables which affect demand include geographical location and climatic ones which often pre-determine consumer needs.

Environmental influences also include social forces which have been observed to act at two levels; general social forces are usually cultural norms which are learned and shared by the whole community while specific social forces usually influence sub-cultures. These social forces can either promote or inhibit demand according to the norms expected of particular social groups. Social stratification is another important influence which refers to a set of attributes consistent with each consumer's self-perceived social status and attributes must be consonant with product features and reflect the appropriate status values and class consciousness. Social stratification has been found to influence choice of product style and colour. Social stratification is also linked to social cohesion as reference groups and family groups usually share the same strata and self-concepts.

Individual Aspects

Individual attributes are superimposed upon the general or environmental factors which affect consumer behaviour. 'Life-style' refers to the global structure of environmental and individual traits. These individual traits are mainly personality variables which reflect the unique aspects of a person's character and have been found to be important in choice of products (or services) as the consumer employs them to express his or her individuality. This feature is most clearly seen when consumers buy a standard product together with some accessories or embellishments which make the standard product 'different' or customised. Explanations of personality variables are largely based on psychological theories but have proved difficult to define because sub-conscious actions are involved. 'Acquisition priorities' are part of the individual's make up and are revealed in terms of preference rankings so that regardless of price or product features, most consumers 'value' a cooker more than a dishwasher. This inner standard is also linked to response speed to new or novel products and those who are risk-takers are most likely to be the first purchasers of such goods.

2.5.6 Consumer Attitudes To Product Design

Engel and Blackwell (1982), in their eleventh chapter discuss the consumer aspects of new products, an area of enquiry which has developed rapidly in recent years because of the high failure rates of many new products, mostly for market reasons. They note that consumer acceptance (or rejection) is largely governed by the product's characteristics or what the consumer perceives the product to be. In general consumers of new products look for distinguishing features and desire these to show novelty, some superiority over existing products, and be consonant with social and psychological values and past experience. Certain features are disliked, for example lack of knowledge of the product's advantages or benefits, complexity (either in use or understanding) and relatively low risk (risk being a function of both price and product life). However some new products or trends of product design can run counter to these rules and Engels and Blackwell gave recent American audio/hi-fi product design trends as an example; it had been found that consumers had begun to prefer complex stereo products which had many controls, flashing lights, active meters and similar 'gimmicks' (which did nothing to enhance technical performance). On the other hand hi-fi equipment sales had been confined mainly to 'buffs' until the late 1970s when manufacturers considered that sales could be expanded if the product designs were altered to suit ordinary listeners who did not understand the jargon and mystique which had grown around hi-fi. New designs were created which were easy to operate, required no knowledge of jargon and which were suitably styled and advertised in simple language, the result was greatly increased market sales. These researches and examples highlight the importance of the product-design/consumer relationship and indic: nvc dhat consumers consider more than product prices.

Comments on product design were also made by the authors of the PEP (1945) report who said that future British consumer durable goods had to be of efficient and attractive design at the lowest possible price. The term efficient referred principally to technical factors so that the product did what it was supposed to done (i.e. clean or cook etc.) and at the same time be hygenic (easy to clean) and be suitable for mass production. It also had to be safe in operation and easy to control, (it had been found that boiling rings lacked a fine temperature control). Manufacturers were urged to produce a range of goods to give consumerf the widest possible choice; for example manufacturers of either gas or electric cookers should not confine themselves to just ordinary cookers (three or four rings, a grill and an oven) but to have a variety from single rings to high quality models. Designs should also be aesthetically pleasing and of good appearance as some consumers (especially older ones) were reluctant to buy some types of household labour-saving goods. It was noted that many American consumer durable goods manufacturers had prolonged the product life-cycle by updating their designs so that post-saturation demand had been raised above mere replacement demand by effective obsolescence. Some technical functions required scientific research, for example which type of cooking method (gas or electricity) was better.

Two different explanations have been given about consumers' sensitivity to product design and product performance.

Freeman (1974) said that in practice consumers could only choose from the limited range of goods which were offered and these had been determined by the suppliers before manufacture therefore the consumer had only a limited an indirect influence on technological change. Freeman pointed out that recently consumer associations had arisen which provided consumers with technical information about products and sometimes pointed to welfare costs (such as pollution).

Freeman (1979) re-appraised the demand-pull concept, which he noted had become widely accepted by the late 1960s largely because of Schmookler's research. He observed that many demand-pull models emphasised the role of incremental innovation and felt that a re-assessment was needed. Freeman undertook an historical analysis of the chemical industry and found that the results led him to reject the primacy of demand-pull and felt that a composite model which included technology-push, demand-pull and environmental influences (social problems) was more appropriate.

Knox (1969) has observed that when consumers are asked what new products or new inventions they would like to see on the market in the near future, they are not able to suggest anything very imaginative. Knox (p.146) reported the results of a competition which aimed to elicit such ideas and the organisers found the responses disappointing.

On the other hand there is considerable evidence to show that while consumers do not have sophisticated technical knowledge, they are highly sensitive to product design and product performance and will rush to buy the 'better mouse-trap'. Secondary aspects of product engineering design which are known to attract consumers include product performance, reliability, safety and serviceability, as well as industrial design. The economic importance of these secondary features has been noted in various studies. It has been especially marked in exports and NEDO (1977) in its report on the comparative status of British exports has given a short bibliography of research highlighting the importance of 'non-price' factors; a term which includes non-design features (such as prompt delivery and good servicing facilities abroad) as well as product design and product attractiveness. The Corfield Report (1979) also emphasised the British weakness and inability to create attractive product designs. An even more telling indication of sophisticated consumer attitudes to product attractiveness and design is given by the recent surge in British demand for imported consumer durable goods which do not possess any fundamental technological advantage over British designs, but which have been thoughtfully improved and designed so that they are more attractive. These improvements are usually incremental ones and linked to lower prices and other 'non-price' advantages.

A more extreme statement of demand-pull has been given by von Hippel (1976 & 1982) who suggested that consumers were the major source for new product designs. His conclusions were based on two analyses of capital-goods industries - whose users are noted for their technological sophistication and willingness to conduct their own developments later or suggest improvements to the original manufacturers or designers.

Robertson (1974), dealing with 'ordinary' consumer goods, sought the reasons for market failure of apparently technically satisfactory new products placed on the market. He found that consumers, while not technologically sophisticated, had a clear appreciation of technological capabilities in terms of the product's performance, reliability, safety and low price. Robertson noted that even totally satisfactory new products need not be instant successes at their market launch but that if the product, its performance and price was judged satisfactory by consumers, then it was highly probable that it would eventually be successful. In other words consumers have an appreciation of product design.

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2.6 Appraisal

This review of the literature on invention and of the economic aspects of invention, has shown that these are complex matters. Many different aspects of each topic have been examined from various perspectives with results which are far from conclusive. A comprehensive appraisal of each type of theory or model given in this review would be a lengthy undertaking and many of the surveys quoted in fact given detailed criticism of various issues and particular methodological difficulties. In this appraisal the central concern will be to outline the principal concepts and pass a judgement on how well each class of theory has succeeded in explaining the 'facts' it set out to explain.

2.6.1 Invention

Most theories of pioneer invention or creative engineering design employed the individualistic and psychological framework as their basis. Their prime explanation centred on assumed mental processes which are not well understood. Invention can be regarded as possessing both an irrational and a rational element. The irrational portion includes factors such as intuition, inspiration, hunches, insight, 'precocious' ideas and chance. How, or why they arise is a mystery, but they serve to create new ideas and new concepts, which to a large extent direct efforts and set desired objectives. These processes are surrounded by much uncertainty about the ultimate goal and a common explanation is that they begin either with ideas or because of prior scientific discoveries. The relation between science and invention is not clear. Ideas appear to be very important but few of these theories suggest that they can be refined by discussion or communication with others, or even inhibited. Any theory of invention or engineering design aims to account for technological progress and the review showed that there were two kinds of progress; one, was the major advance which was achieved by pioneer inventions, the other was the minor advance caused by incremental design or invention.

Pioneer Invention

Pioneer invention involves a major technological advance or 'breakthrough' and seems to involve inspiration or creative intuition. No one can explain the mental processes involved but pioneer inventions are extremely important for two reasons; one reason is their novelty, man can usually do something which previously he could not, the second reason which perhaps is economically of greater importance, is that pioneer inventions generate a whole new sequence of later technological advances, frequently in directions not anticipated.

Incremental Invention

The review showed that the importance of incremental improvements was fairly soon appreciated and that these small routine inventive steps had a different nature being mainly of a form of application of existing knowledge to given problems. The basic concept employed here was of rational design which derived from the observed pattern of historical development of technology as there appeared to be a general continuity in its course with a sequence of improvements following each other usually in a kind of logical order. The individualistic perspective, which formed the core of many pioneer theories of invention, was inappropriate to explain the cumulative and spreading nature of this technological progress. Incremental advances appeared to owe more to environmental influences including technology transfers, although the proponents of inner logic theories would not wholly agree. Evolutionary theories of invention essentially presented a combined theory of the effects of internal and external factors which operated selectively to ensure the survival of the fittest. The Mechanistic theory of invention stressed that social forces were a major determinant of the rate and direction of inventive activity, while the historical theory of invention pointed to the increasing efficiency of the process of invention and to a closer coupling with pure science. The broad pattern of technological development is a temporal sequence of the introduction of a pioneer invention or new model, followed by a sequence of incremental improvements which continue either until superseded by another new invention or until they cease because further technological possibilities have been exhausted in that particular field.

Engineering design has many similarities to incremental invention though it is considered to lack the novelty associated with invention and is more of a routine application of known technological principles. Although simple linear models of engineering design appear to be inadequate, there is strong evidence to support the view that engineering design involves a wider range of external factors than incremental invention does and that Economic and Consumer influences are important in the later stages of an industry's design, and that the objective can change from one directed solely to improved performance, to a concern with the product's reliability, ease of operation or safety.

The core concept of all theories of invention and engineering design is technology-push but the trend of theoretical development was towards composite models which took economic and consumer influences into account. These composite models became less linear as they were developed. None of these theories were particularly good at explaining the course of technological development; no 'laws of invention' (or technological progress) have been agreed. Innovation studies have shown that the invention-design process is a very complex one with a variety of causes and effects so that simple models or theories are not appropriate. It appears that pioneer inventions are subject to greater uncertainty than incremental ones and that incremental ones besides being the most numerous, have a more predictable pattern.

The review showed that the relationship between science and invention was not clear; science can - but need not be - involved. Few theories of invention or creativity take any note of demand influences.

2.6.2 Economic Theories Of Invention and Growth

The aim of all economic theories of invention is to try and explain the economic causes and economic effects of invention. The earliest notion was that invention was exogenous to the economic system but this gradually gave way to the opposite view that inventive activity could almost wholly be explained by the influence of economic factors.

The economic consequences of invention have been greatly influenced by the Classical view that they were primarily process inventions aimed to reduce production costs by the introduction of machinery and later economic theories attempted to associate this with changes in either prices or investment. However Classical economists also noted the many non-technological factors which achieved the same effects as (process) invention which some later economists ignored and have recently been re-discovered.

Modern economic concepts and theories of invention may be faulted for their adherence to process invention and to the consideration of a limited number of ´input´ factors of production. Recent Growth Accounting methods have altered this to some extent although at a cost of concentrating upon increased productivity rather than growth of output. Mansfield (1972) and Nelson (1981) have given specific criticisms of modern growth theories which incoporate ´invention´ which will not be examined in detail here.
Most modern economic theories have little to say about design or technology and find it almost impossible to include the effects of change due to product design or quality improvements. Schumpeter and others have sought to remedy these defects with more original theories but even they give no explanation of the process of technological change or of the creation and use of new knowledge; these shortcomings are acknowledged by economists themselves. The addition of R&D expenditures, assumed to be a more accurate index of invention than had previously existed, has not advanced the explanatory power of modern models very much.

The core concept of most economic theories of invention is that process invention is economically induced and is used to achieve economies of production. Growth theories incorporating invention regard more economical forms of production as the ´mainspring´ of industrial growth though the results of numerous enquiries have failed to establish that this is the case. These economic theories largely ignore the idea that invention is primarily concerned with technological advance and that this need not be linearly and causally related to economic expansion.

2.6.3 Innovation Models

This group of studies has clarified much about the nature of industrial invention and its typical path of progress especially with regard to the distinction between product and process inventions, major and incremental changes, the influence of competitive stresses and other variables normally

omitted from economic growth models.
On the other hand the Innovation School has somewhat ignored the question of the contribution and economic mechanism of invention, and to a certain extent has de-emphasised the operation of inner logic in favour of economically or organisationally determined invention.

The main contribution which Innovation Studies have made has been to portray the process of technological change and in doing so to highlight the great differences among industries and firms. It has been shown that the sources and reasons for invention are varied, that the main concern is with product and not process invention, that competition and organisational factors are important, and that both science-push and market-pull acted as stimulants for invention. More recent Innovation Studies models have demonstrated the dynamic pattern of change in which different factors have different importance at different stages and that invention (or design) is a resultant of the combination of these different factors. The core concept of innovation models is that a variety of factors affect invention (and innovation) in complex ways, and that a fuller understanding of technological development can only be achieved using a flexible framework. The evidence obtained shows generally that each case is different and that no simple formulation of the process will likely be satisfactory.

2.6.4 Demand

The main contribution which demand-oriented theories have made is to show the importance of the consumer in the economic growth process. Modern economic consumer theories have highlighted the importance of increased iocome (or income-related factors) as a mechanism of growth and to a certain extent have decreased the importance of invention. Modern demand theories of course take product price changes into account and this reflects the influence of invention.
Another very important demand factor which has emanated from marketing studies rather than economic demand theories, is the effect of consumer influence upon product design, product attractiveness and product quality.
The core concept of this group of theories is that economic activity is consumer-led (demand-pull). Such a concept leaves little scope for invention-

push although it has usefully highlighted that new project failures are largely due to commercial inadequacies rather than technological inadequacies. Economic theories of demand have not been wholly satisfactory, especially for consumer durable goods which, ideally, should take both economic and product design factors into account.

2.6.5 Conclusion

These observations of the main contributions from different perspectives form the best guide for subsequent research on this topic and suggest that the most appropriate design of inquiry would be one which was sufficiently flexible to include the process of invention and modifications due to economic and consumer influences. The role and contribution of product invention is one which looks suitable for further research and the literature reviewed here points to a concept in which product design is seen as the resultant outcome of technological-push, economic and consumer influences.

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3. CHAPTER THREE: METHOD AND DATA SOURCES

3.1 Method

3.1.1 Introduction

The review of the literature given in the previous chapter revealed that psychological and economic approaches to the analysis of invention and growth had been less than wholly successful and that the case history method used in innovation studies appeared to offer the greatest advantages. In this chapter a short discussion will be given of the modifications to the case history method which seem necessary and this will be followed by a description of the data and sources of information required for the subsequent research.

3.1.2 Case Study Method And Modifications

Most innovation models seek to establish a relationship between the adoption of a new invention and certain internal or external factors affecting it. The method employed is generally one of classifying the causes which are supposed to promote or inhibit the innovation, and the resulting models are a simplification of reality which depict the process of innovation.

The primary aim of this research is to attempt to answer the question 'Which factors affected product invention'? The central focus is therefore with the trend of product invention and the factors affecting it, and not innovation.

Two analytical techniques are generally used; one is exploratory and does not attempt to analyse the findings in terms of an *a priori* concept, the study by Langrish, Gibbons, Evans and Jevons (1972) is an example of a model created from descriptive histories of particular cases.

The other approach does employ an *a priori* concept and usually attempts to condense the results of a large number of individual studies in to this framework; the model by Utterback and Abernathy (1975) is an example of this second approach.

These approaches have been mainly used to study various organisational aspects of a firm (or industry) often with particular concern for management processes or financial or marketing strategies and also to analyse the pattern of technological development and its economic effects. They have not been used for as intensive analysis of invention as will be undertaken in the following chapters and this objective will entail some modifications to the traditional case study method.

Modifications

Many modern innovation studies tend to concentrate upon a single product or project rather than deal with the long run trend of product design. In the following analyses the principal concern will be with the product invention/design changes and the succession of models created over the industry life cycle.

Many theories of invention and quite a few models of innovation tend to assume that a new or improved product is the consequence of a single or small number of inventions and only the literature on engineering design hinted at the many additional inventions involved at the detailed sub-assembly level. In the research to be conducted, the main interest will be with changes to the product's overall configuration but considerable notice will be taken of detail inventions to point out their importance.

Most case histories ignore inventions made in the pre-commercial or incubation stage; these will be included in the following study.

Classifications of causes do not normally portray the mechanisms of the development of invention and considerable efforts will be made to describe the ways in which ideas and proposals are modified and refined either by individual inventors themselves or by discussions in magazines or journals. Instances of such mechanisms will be quoted whenever possible.

The analysis will be of two consumer durable goods industries rather than capital goods or (non-durable) consumer goods as durables have a considerable technological content and a high sensitivity to consumer influences.

The bicycle and domestic radio receiver have been chosen because each has a comprehensive record of invention and related information; the bicycle has been regarded as an example of 'empirical' mechanical engineering invention while the radio receiver is often taken as an example of a 'science-push' design in the electrical field. These claims will be assessed in the course of the research.

Previous research, noted in the literature review, suggested that product design appeared to depend mainly upon the combined effect of three factors - technology, economic and consumer influences - and this will form the framework of the research method.

3.1.3 First 'Technology' Factor

The analysis of the technology factor will focus upon invention and product design and its associated elements of ideas, problem-induced invention, technological transfers, inner logic sequences, "trade-off" aspects of design, as well as more descriptive accounts of the historical development of product technology. Any instances of inter-relatedness or cumulative effects will also be noted.

This approach, besides fusing the two analytical techniques described above, will extend the examination to some additional invention/technology related topics now noted.

Pioneer and Incremental Inventions

It was noted in the previous chapter that some researchers felt that incremental inventions were very important and often undervalued. Careful choice of products can ensure that both pioneer and incremental inventions are included, and it is possible to trace incremental improvements in the case of the bicycle and radio industries because accounts of these changes appeared in popular journals and newspaper articles.

This allows a balanced view to be obtained of the relative importance of both types of invention and the pattern of development over the industry life cycle.

Science

The relationship between science and product design can be regarded as indeterminate at present. Various views were noted in the review ranging from a pure science-push one to an auxiliary role for science in combination with empirical invention. The analysis of bicycle inventions will seek to determine whether or not they were as 'empirical' as is often claimed or if they were based on systematic investigation. The analysis of radio receiver invention will seek to clarify the nature of the relationship between science and product invention.

Patents

Patent data is another valuable source of information about invention. It was noted in the literature review that this source had fallen into some disfavour after 1945, as Gilfillan (1952) noted, largely because a new source (R&D data) later proved to be more attractive. However Pavitt (1985) has described how interest in patenting has been renewed in recent years partly due to new schemes of patent classification and the use of information technology techniques. These recent studies have employed new methods of analysis, for example concordance with Standard Industrial Classifications, bibliometric techniques (citation and co-citation analysis), and identification of 'patent families' (patents for the same invention granted in a number of countries), the identification of rapidly developing technologies and industries, and international comparisons of the patterns of technological development. In addition the traditional method of patent data analysis, which explores the causal relationships between patenting and changes in other economic variables, has continued and been refined.
All these efforts, Pavitt said, had helped to give a clearer understanding of the nature and economic importance of invention and innovative activities although many problems remained.

Pavitt considered that patenting reflected innovative activities rather than inventive activities and that the new analyses had made significant contributions by supplementing other sources of information. Above all it freed researchers from the concepts or constraints often imposed by particular theories or models, so that new aspects either had come to light or old features, previously underrated, acquired a new significance. The main new contributions had been the discovery that patenting activity was not too closely connected to R&D activity, one reason for this was that Development activities (especially production engineering) had been found to be an important source of new inventions and such expenditures were not included in R&D figures. Different propensities to patent existed at many levels, different countries had different costs of patenting; patents were often used as a form of protection due to the monopoly they gave for a time, and hence patents were part of a firm's way of preserving secrecy about its technical knowledge and this was of variable importance to different industries or firms. It had been found that the financial value of patents was highly skewed with only a few being of high value and this indicated that many patented inventions were of minor importance. There was some difficulty in deciding whether or not patents were an 'intermediate output' due to R&D inputs and again inter-industry comparisons of patenting rates showed differences. International patterns of patenting suggested that rapid technological development and high growth rates were associated with high innovative activities and patenting rates. Modern studies had revealed patent 'maps' of leading firms or technologies. Other features studies had brought out the international aspect of much modern invention and it was now easier easy to trace their diffusion; it was possible to make better estimates of 'R&D efficiency' or 'R&D productivity', to note the temporal trend of declining patents for given R&D levels and comment upon the science-technology relationship.

Few of these new developments noted by Pavitt have any direct relevance to the historical analyses which will be undertaken here but Pavitt's recognition that empirically oriented analysis of patent data forms useful supplementary information is itself of value and patent data will be used in the analyses of the bicycle and radio receiver inventions. The main concern in the following study will be with the overall annual rate of patenting as an index of inventive activity in each industry. In the case of particular types of radio receivers (such as crystal sets or superheterodynes) it is possible to obtain annual patents for each type which will reveal the temporal pattern of such invention and its relation to other changes in the radio industry.

Process Invention

Although this research is primarily concerned with product invention a brief analyses will be made of process changes to see if this feature accords with that noted by Utterback and Abernathy.

3.1.4 Second ´Economic´ Factor

The analysis of the economic aspect of invention will include observations about product designs which aim to create lower priced models or models with lower running costs rather than be limited to the traditional economic emphasis upon process inventions.

3.1.5 Third ´Consumer´ Factor

Analysis of the consumer aspect will take into account inventions or designs which make products more appealing to purchasers by adding new features, making product operation easier or adapting the product to new uses or because of changes in consumer tastes or fashions.

Overall Design

The product design will be regarded as the resultant of all three factors which might operate differentially over the life of the industry.

Demand

The analysis of demand will employ a modified form of Katona´s two factor theory; one factor (the ability to buy) will involve an economic analysis using standard econometric techniques to test a simple model. The second factor (the willingness to buy) will not be analysed in the modern way (described by Katona (1960) or Engel & Blackwell (1982)) as it is not possible to assess consumers´ opinions about either future expectations or intentions to buy bicycles or radio receivers in the early years of each industry, but by obtaining consumers´ comments about the products, their attitudes to new designs and some idea of their problems. This information can illustrate the consumer-design relationship.

Economic Analysis Of Demand

The growth of output of the British bicycle and radio industries depended upon the growth of home and foreign demand. It is not proposed to give an economic explanation for the demand for exports of either of these industries as, like British exports in general, these exports were subject to complex economic and non-economic forces. Concern will be limited to changes in domestic demand for these products.

It was noted in the literature review that previous attempts to analyse demand for consumer durables had proved to be very difficult and no attempt will be made to replicate the comprehensive demand models based upon the major constructs such as the permanent income hypothesis. Cramer (1971) in his discussion of the difficulties of building and testing empirical econometric models, believed that the creation of models was an art rather than a science as it involved a mixture of economic theory, knowledge of statistical procedures, personal experience and "sheer inspiration". Cramer noted that the aim of modelling was to yield a definite and precise formulation of the economic process and that often this could be achieved by a direct, simple and linear model - even if it was only an approximation and was affected by other unknown economic variables.

Johnston (1972) has described the essential steps in the construction of any econometric model. The first step is the specification of the model in mathematical form; the second step is to gather the relevant data needed for the model; the third step is to use these data to estimate the parameters of the model and the final step is to interpret the results according to theoretical constructs or propositions and perhaps amend the original specification and re-estimate and possibly re-interpret the original model.

Model Specification

It was noted in the literature review that three main economic variables appeared to determine demand for consumer durable goods, these variables were product prices, consumers' income and some element of consumers' saving.

The purpose of this economic model is to attempt to explain growth (or change) of home demand and deal with two subsidiary questions: 'How far can the growth (or change) of British homesales of bicycles and radio receivers be explained by the 'trickle down' hypothesis'? and 'What proportion of homesales did changes in each of the main economic determinants of demand (product prices, income and saving) account for´?

It was also noted in the literature review that changes in prices and incomes did not explain much change in demand for products at their mature stage so that the economic analyses will be concentrated on the period of growth of the home market up to saturation, in practice the interwar years to 1938. Certain additional factors in the post-1945 years, such as the imposition of purchase tax and government ´demand management´ economic policies at a time when homesales fluctuated about a declining trend all which would involve a more complicated model.

In order to assess whether or not growth of demand was principally due to ´trickle down´ purchasing by lower income groups it is necessary to use income and savings data for these groups and the chosen manual earnings and savings banks data are the best indexes obtainable.
It was noted in the literature review that Trustee Savings Bank depositors were mainly from the ´artisan class´ and Post Office Savings Bank depositors are assumed to be the same, so that the two income-related variables (manual earnings and net saving) are those of mainly manual employees.

Actual (or independent estimates) of data for each of the independent variables exists either completely or sufficiently to allow interpolated estimates to be made for bicycle demand 1920-1938 and radio receiver demand 1930-1938.
Most econometric models of demand lag income and income-related terms but it was noted in the literature review that Evans (1969) did not consider that lagging was necessary in the case of demand for consumer durables. The specification of the model is therefore as given in the following equation, with no lags.

Homesales = f(Product prices, income, saving)

Model Data

The specific data or information sources will be described later in this chapter.

Model Estimation: Equation Parameters & Trickle Down

Standard statistical computer programs exist which can perform linear regression operations; the SPSS package has been chosen because it is widely used and has all the required facilities and in addition has a 'Enter' method which enters each independent variable either singly or in combination with the others, to allow calculation of the proportion of the coefficient of determination (or R-squared) due to each variable, either singly or combined. Further information about SPSS regression capabilities can be obtained from its Users' Guide.[1]

Linear regression operations, in addition to providing an estimate of the partial coefficient parameter for each independent variable, can also indicate how closely the equation estimate of homesales corresponds to actual homesales by the value of the coefficient of determination (R-squared). If R-squared is very high, say greater than 0.95, then this indicates that the equation estimate is very close to the actual homesales value and that the chosen independent variables have a very good statistical explanatory power.

Interpretation Of Model Results

The estimation of the equation parameters and the progressive 'Enter' procedure would illustrate the importance of prices, income and net saving to changes in homesales and allow inferences to be made about the relative importance of each to growth of domestic demand for the rapid growth period up to 1938.

Consumer Aspects Of Demand

Katona's second demand factor depended upon socio-psychological consumer aspects and although no historical information exists about consumers' financial expectations or intentions to buy for the interwar period, useful comments by consumers were published in papers and periodicals. These comments give consumer observations and opinions about product design, product performance technical features, product problems, new uses for variants of the standard product and modified forms of the product.

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1 See 'SPSSx User's Guide' (second edition) published by McGraw-Hill Book Co. New York, 1986, Chapter 35, pp. 662-686 especially p.666 'Enter'.

Invention and Growth

Having separately analysed the trend of invention and demand, it will be possible to roughly compare changes in product design and changes of home demand and see if the relationship is as close and causal as has been suggested. Note that for the whole of the subsequent research the word 'growth' will refer to expansion at the microeconomic level and not the macroeconomic level as was frequently the case in the literature review.

Model

These features can be combined into a model which would represent the generalised pattern of product invention over the life-cycle of a consumer durable good industry.

3.2 Sources of Information and Data

Introduction

In this section the sources of information and data will be described and classified together with the reasons for their choice and of any need for balance between primary and secondary sources. D. Thomson (1969) has succinctly described the problems historians encounter when using old sources of information. Ideally the historian would wish to have access to a complete record of everything but in practice he faces two difficulties; one is that information for certain periods or topics may be patchy or incomplete so that the historian will need to squeeze every ounce of reliable information from a few documents and perhaps use imaginative reconstruction. On the other hand the historian may encounter "mountains of possible sources" (p.20) and a surfeit of diverse information which needs to be summarised and condensed quickly and efficiently.

Historical information about the technological and economic development of the British cycle and radio industries suffer from the difficulties Thomson noted and will require both types of approach to be used.

In general reference will be made to primary sources for original information or data when specific, highly technical or original information is needed. When summaries, condensations or less specific information is needed, secondary sources can be more helpful and will be used in these circumstances.

Information About Invention

The obvious starting point for the analysis of invention is from the time of the earliest ideas and experiments, yet this period is often bereft of much information about the aims or goals of the inventors and here especially some reconstruction from primary sources may be needed. The main sources of such information are usually accounts by the inventors themselves often given in specialist journals such as The Journal Of The Royal Society Of Arts, the Proceedings Of The Institutions (Radio, Electrical and Mechanical engineers, British and American) as well as books, articles and other primary publications.

More specialised accounts of either engineering design or science advances are available in engineering publications, science journals or special reports issued by research associations or government publications; examples include Nature, and Radio Research Board publications (which were sometimes published in books and sometimes as articles in the engineering institutions' proceedings (or transactions) or specialist journals such as Wireless World. Ideas can be refined by discussion and criticism and the columns of the English Mechanic were particularly valuable in the middle of the nineteenth century in this respect.

Patents

The best index of patenting activity for specific products are the annual figures for Patent Abridgements for patent classes. These abridgements are virtually equivalent to patents granted (although a few abridgement-applications are dropped before patents are granted for them). The 'aggregate' figure for the whole class is taken to represent the 'total' inventive activity for that product. An example will make this clear; patents for bicycles (and all cycles) were initially put in Class 136; later, from 1911 Class 136 was subdivided into three sub-classes so that the figures for the whole of Sub-Classes 136(i), 136(ii), 136(iii) gave the 'aggregate' inventive activity for cycles.

Until 1915 British patent abridgements were published annually so that it was easy to obtain annual data. After 1915 annual publication ceased and the system changed to a numbered one making it necessary to have a key in order to date each patent number; this key was published by Chas. Hude, patent agent, Copenhagen, (no date) covering the years 1916 to 1977. These key British patent numbers are tabled in chapter eight of this thesis and permit the year of publication of each abridgement to be identified, and hence making it possible to obtain the number of patents for each year. In addition the Annual Report Of The Comptroller Of Patents often contained historical data and further, often gave the annual number of patents granted for distinctive products such as bicycles and radio receivers.

However another historical source exists for British patenting activity, namely the Series A File List which gives the numbers of patents granted in each sub-class for the years 1911 to 1964 which can be annualised by means of

Hude's key.[2] These data show the inventive activity at sub-class level for particular kinds of receivers such as Crystal Sets, Neutrodynes etc.

Changing Trends of Patented Inventions

British patent classification information can throw further light on the changing trend of invention by showing the changing subject matter of these patent sub-classes. New inventions meant that new sub-classes were frequently created and the subject matter of these new sub-classes reflected the new technological topics. For example Class 136 Velocipede (Cycle) patent sub-classes revealed that many inventors had explored almost innumerable technical design possibilities for bicycle driving mechanisms, bicycle springing and a host of other technical features. A similar development took place in radio but here it is possible to show an additional feature, technological interrelatedness, as in the case of the Neutrodyne radio receiver as another associated patent sub-class for "Screening And Arranging Elements To Minimise Accidental Coupling" was included. Further details about about the British patent classification system and its use as an information source has been given in a booklet.[3] There are other difficulties with patents; for example many patents included in one particular class do not pertain to the particular product. Patents for Class 136 ('Velocipedes') covered tricycles, unicycles and other pedal cycle types but after the invention of the motor cycle Class 136 also contained many motor cycle and even some motor car inventions. Particular patent sub-classes contained inventions which were also shared by all types of cycles, for example tension-spoked wheels, tubular frames etc. This writer was advised that to try and extract solely bicycle patents from Velocipede/Cycle patent Class 136 would be virtually impossible as the majority of inventions in this class were common to all types of cycle. In view of the decline of all kinds of cycle except the bicycle from the mid-1890s, the patents in this class would be the best index of pedal bicycle inventions that could reasonably be

2 It is possible to obtain unpublished sub-class lists extended to more recent dates on an individual basis on payment. These data would not be of much use in this research as patenting activity in both the bicycle and radio receiver industries declined markedly during the 1950s.

3 "Patents: A Source Of Technical Information" pub. by the Patent Office, Dept. of Trade; H.M.S.O. 1983.
This writer has acknowledged his indebtedness to Mr. Dennehey, of the Patent Office Classification section on page 2, for help and guidance on British patent classification matters.

obtained (although they would contain a few non-pedal cycle patents). Radio receiver patents did not present such great difficulty, though they are beset by another fairly common patent problem, namely that not all "radio" inventions are included in the radio patent classification and similarly that not all patent in the radio classification are for radio as from the 1930s an increasing number of these inventions were electronic ones. Here again the most reasonable course is to regard patents for ´radio´ and later ´radio receiver construction´ as the best index of aggregate inventive activity for this product that can be obtained for the aggregate level of inventive activity. All these data can be used to show the frequency of patenting each year and therefore giving a picture of inventive activity for the bicycle and radio receiver industries.

Secondary Sources

Quite often secondary sources give summary descriptions of design trends which appeared in the primary research literature. The main secondary sources of information about bicycle and radio invention are technical or descriptive histories which often covered pioneer inventions, trends in product design, incremental inventions and sometimes notes of process inventions and general observations. Reports of annual exhibitions were often given in journals, yearbooks and newspapers and these frequently outlined new incremental product inventions. The Times gave concise reports of Cycle exhibitions from the 1890s which usually included a mention of any new feature or invention, and similar reports for radio exhibitions as well as an invaluable series of articles and readers´ letters dealing with consumer radio problems between the years 1922 and 1932.

Output and Product Prices

Data for any minor British industry for the pre-1939 period presents problems because of the prevailing belief that these data should not be made public. However because of government concern for the British economy from the end of the first world war, irregular returns or estimates were obtained for most industries for particular years which then allowed others (often Trade Associations or economists) to provide time series estimates from 1920.

The Trade and Navigation Accounts give the annual quantities of many British products exported and average export prices; in the case of bicycles these data are available from 1905, in the case of radio from 1932. This information can be supplemented by similar statistics given in the Censuses Of Production (beginning in 1907) and, during the 1930s from the Import Duties Act Inquiries (I.D.A.) which give ´total´ British production.[4] Irregular but often more comprehensive estimates of output or product prices for various industries were given by specialist trade publications such as The Cycle Trader, or The Wireless and Gramophone Trader, or The Broadcaster Annual. Limited surveys of particular industries were given by The Economist, The Times and sometimes the Trade Association itself in this pre-1939 period. Comprehensive data and returns for the chief British industries are available from government publications, the Annual Abstract Of Statistics and Reports of Censuses of Production.

After 1945 very detailed information about industrial output and prices was given in a variety of government publications; the Annual Abstract of Statistics gave annual data while the Monthly Digest of Statistics gave monthly data. More frequent yet still irregular Census Reports continued to be published. Later still some new government publications gave even more information about particular industries, for example Business Monitor and also private sources concerned with either retailing or market research activities, for example Retail Business or Readership Surveys or other similar marketing sources noted by Critchley (1977).

Sources of Demand Information

Homesales: Annual data for quantities, values and average prices of bicycles and British consumers´ expenditure on bicycles is available from Stone and Rowe (1966, Tables 23, 24 & 25, pp.58-59), while annual British consumers´expenditure on radio receivers from 1930 has been estimated by a trade association and given by Wilson (in Burn (ed.) (1961) Table 2, Col. 2, p.138). These homesales or consumer expenditure figures were reduced to a per capita basis using the annual estimated population figures for Great Britain

[4] The changing basis of these returns has been described by Devons (1955) and some of them discriminate against small producers as they were often excluded; many early British bicycle and radio companies were small ´man-and-boy´ firms.

given by Feinstein (1976) Table 55, Col.4.

Income: Annual average weekly wage earnings for manual employees has been given by Feinstein (1976) Table 65, Column 2.

Net Saving: Annual net saving figures (deposits minus withdrawals) will be calculated from data presented for both the Trustee Savings Bank and the Post Office Savings Bank, given annually in the Annual Abstract Of Statistics to produce an average annual net saving figure. This figure will then be converted to a real per capita (per depositor) value by the following method.

Conversion: Each independent variable will be reduced to 'real' (constant) prices by deflating it by the Retail Price Index for each appropriate year, given by Feinstein (1976) Table 65, Column 3. Net saving data will be changed to a 'per capita' basis by dividing each TSB and POSB annual net saving figure by the number of depositors using each bank for that year, the number of active accounts are given annually in the Annual Abstract Of Statistics. Any further use or reference to primary or secondary sources will be quoted in text.

The analyses of the socio-psychological aspects of demand will be based on contemporary reports of the industry obtained from historical, marketing and social literature which will be quoted in text.

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4. CHAPTER FOUR: THE BICYCLE

4.1 Introduction

The bicycle was a novel form of rider-powered transport which emerged in the middle of the nineteenth century. Its technological development was not the work of a single inventor; it was, as Apperson (1898) noted, the result of many inventions spread over time. This course of development was not straightforward and many different types of cycles (one or more wheels) and cycle mechanisms were tried with the eventual evolution of the Modern Safety design which rendered many of the earlier designs obsolete. By about 1900 bicycle design had virtually matured and although bicycle inventions continued to be made, the results were of marginal improvements - with the exception of the radical Small Wheel design which was not introduced until the early 1960s. The primary concern of this chapter will be with adult bicycles although many changes were made to bicycles for children and juveniles especially after 1960.

The bicycle developed largely because of British invention. Although the very first models were developed in France and America, the main improvements were made in Britain from about 1870 and because of widespread public interest in bicycle design and performance a rich history of product changes at pioneer and incremental level is available. Britain was also the world's leading bicycle manufacturer until the 1950s so that this can be regarded as an indigeneous product and industry with sufficient information available to reconstruct its pattern of invention and growth.

Organisation Of This Chapter

4.1.1 Bicycle Product Invention

The analysis of invention in this chapter will seek to combine four perspectives on bicycle product design because this will give a comprehensive view of the process of technological change. These four levels are Overall Configuration; Sub-Units and Components; Consumer Influence upon Design and Patents. An outline of Process inventions will then be given followed by an account of the Changes of Ouput of the British bicycle industry and finally an analysis of the Demand for Bicycles. The results of these separate analyses will provide sufficient information to form a judgement about the relation between invention and growth in the British bicycle industry.

Overall Configuration

Overall Configuration refers to the type of bicycle, for example Hobby Horse or Penny farthing. In this perspective the main concern will be with the general features and structure of the bicycle. Technological progress at this level involved a sequence of different types; Caunter (1955) classified these as the Hobby Horse era 1791 to 1860, Velocipede era 1861 to 1870, Penny Farthing era 1870 to 1895, Safety bicycle era 1869 to 1899, Safety 1900 to 1925. As these overlap a four stage classification will be adopted for convenience as follows; Hobby Horse era 1791 to 1860, Velocipede era 1861 to 1869, Penny Farthing era 1870 to 1884, and Modern Safety era 1885 to Present (including the Small Wheel design from 1962).

Bicycle Sub-Units and Components

The second aspect of bicycle invention examined here will be concerned with inventions and the reasons for change of some bicycle components and sub-units. This facet of bicycle invention was very important because not only did it improve the current model but those inventions were carried forward and incorporated in later models and also to later general engineering design and practices.

Consumer Influences Upon Invention

The third perspective on bicycle invention will attempt to assess the effects of users' needs (or desires) upon bicycle invention. This will attempt to determine if bicycle design responded to consumers' desires as well as technological push.

Bicycle Patents

The fourth aspect of bicycle invention will be concerned with the information which bicycle patent data can give. This includes not only annual figures of the number of bicycle patents granted (and therefore an index of inventive activity for this product) but also the kinds of ideas patentees had and their dates.

4.1.2 Process Improvements

This aspect of bicycle invention will be concerned with manufacturing changes and process inventions and their broad trends of improvement as in Utterback and Abernathy's model.

4.1.3 Trend Of Bicycle Prices

In this section the trend of average prices for complete British bicycles will be traced as far as possible using census and export data.

4.1.4 Changes of Bicycle Output

In this section the main concern will be with the growth of output of the and later decline. Attention will be concentrated upon the output of complete bicycles though a note will be made of the output of bicycle components and also of the relative importance of the bicycle industry exports.

4.1.5 Demand for Bicycles

In this section an assessment will be made of the social and economic factors which affected home demand for bicycles and determine the relative importance of each throughout the life of the British bicycle industry.

4.1.6 Invention and Growth

Having established the pattern of invention, then growth, it remains to compare both and establish whether or not invention appeared to be a cause of growth.

4.1.7 Chronological Table of Bicycle Development

The following table, based largely upon information from Caunter (1955) and Woodforde (1977) gives a conspectus of the main developments in bicycle invention and market features.

Conspectus of Bicycle Development

Period	Main Inventions	Market Features
Hobby Horse Era 1791-1860		
1791-1815	Stylistic Changes	Little Demand
1816-1820	Front Wheel Steering	Boom 1818/20
1821-1860	Experimental configurations	Demand died
Velocipede Era 1861-1869		
1861-1868	Early Velocipede	Rising interest to 1869 mainly secondary use
1868-1869	Many Product Improvements	Primary use began
Penny Farthing Era 1870-1884		
1870-1880	Simple & Effective Product Penny Farthing model	Better performance led to increased sales
	Many product & process ones	Specialist producers began to supply trade
	Other cycle types developed	Good demand for these
	Early Safety prototypes	Unsuccessful, little demand
1881-1884	Safer types of Penny Farthing	Better perf.> inc. sales
Modern Safety Era 1885-Present		
1885-1890	New Safety Product Design	Market appeal greatly widened
1890-1897	Many marginal product ones	Sales increase to boom 1896/7
	Major process changes	Arose because of high demand
1898-1914	Marginal Product ones;	Introduced to win buyer appeal
	Process improvements	Induced by low demand & prices
	& non-tech changes	also export drive
1919-1920	Little tech. change	Post war boom
1921-1928	Roadster model introduced	Steady home growth, & exports
1929-1938	Minor inventions	Record home sales and exports
1946-1950	Little change	High home sales, and exports
1950-1962	No basic change	Home sales and exports fall, switch to secondary use industry contracts
1962-now	Small Wheel model	Created new market segment
1962-now	Utility Bicycles	Market declined
	Leisure Bicycles	Market increased
	Incremental inventions	Often rejected
	Plastic model & components	Sales not high

4.2 Bicycle Product Invention

4.2.1 Theories of Bicycle Design

An early theory of cycle invention was given by Clarke (1870), who, ennunciated the "scientific principles" which should guide the construction of cycles. These principles were 'Safety', 'Simplicity', and 'Cheapness' and by today's standards would not be regarded as having any close connection with science, but simply described the intrinsic features of design. Clarke also stated the objectives of 'practical' engineering as practised in Victorian times. The aim of cycle design, Clarke said, was to produce a model which gave economy of time and power. Some specific engineering objectives included a need for lightness which had to be compromised with sufficient strength, friction had to be reduced to its lowest value and power had to be applied to the wheel as directly as possible. All complications had to be weeded out. Clarke also noted that some inventions had been suggested which were based on fallacious principles which presumed that mechanical parts themselves could create power.

Other similar theories were given by comtemporaries, for example Boys (1884) sought to explain the course of bicycle (product) development in similar terms to that of Clarke, believing that the principles had been Elaboration, Simplification and Perfection. This was based on the diversity of types of cycle (including tricycles etc.), though like other attempts this form of explanation did not give much insight into the reasons for the product changes he described. Boys said that the reason for such a variety of bicycle and cycle designs was that each model had some specific advantage which the rest did not possess and that as cycles were used for widely varying purposes no single model had an overall advantage, if it had done it would have rendered the others obsolete. The bicycle surpassed all others types for simplicity, lightness and speed.

Phillips (1885) presented an account which was similar to the two above accounts though of a more limited scope and gave a classification scheme rather than an illustration of the operation of principles. It was noted in the discussion which followed this account that "the principles of bicycles had not yet been sufficiently established" and that bicycles had been "rendered practical by a combination of subsidiary inventions over several years".

Sharp (1977, originally 1896) presented an account of cycle invention which was largely based upon design criteria. Sharp considered that the bicycle had evolved from early horse drawn carriages because a rider-powered model was wanted and models were tried with a cranked axle. It was soon found that this type of vehicle had profound problems especially that of excess weight and poor cornering characteristics and resulted in experiments with a two and three wheeled vehicles of reduced weight. Bicycle and tricycle developments sprang from these experiments.

The trend of development had not been straightforward and Sharp presented a historical chart of bicycle types (p.194) and another for tricycles. Sharp believed that cycles could be classified according to their main characteristics; tricycles and multi-wheeled types were Stable kinds, while bicycles, unicycles and certain di-cycles were Unstable. Sharp also classified bicycles according to their Method of Steering and their Method of Driving (front or rear wheel). He then gave a design-based account of development. The desire for speed meant that the most efficient driving design was needed, Weight was reduced by good design; Comfort and Efficiency was needed and had led to the use of rubber tyres; Safety from Falling required a stable design; Simplicity of design was needed to lower costs and give good performance; Reduced Power Wastage led to designs with reduced vibration, wind resistance etc. These various factors combined to produce an optimum design and, perhaps after a lag, sales of the best model would increase while sales of inferior models decreased so that the ´fittest survived´. Sharp considered that much bicycle invention had been wasted effort because of ignorance of the engineering principles which should have been taken into account. Like his predecessors, he implied that all technical progress in bicycle design sprang from "technological push", though, as the market rejection of his air sprung bicycle was to show, consumer acceptance was an equally important factor in progress. It is noteworthy that Sharp´s account described how product design was used to increase performance in various ways; by reducing weight, creating better driving mechanisms, by seeking stable configurations, by reducing vibration and wind resistance all of which underscores the notion that the prime function of product invention is to improve performance. But, as Sharp's description also shows, product design was used to reduce costs.

Bicycle Histories

Many others have given a descriptive history of bicycle development. These historians do not usually attempt to give an explanation of the reasons for the course of technological change and concentrate upon a chronological record of different models produced. Some give references to process changes too. Sharp has referred to some of the early histories. More recent descriptive histories have been given by Caunter (1955), Sumner (1966) who described the development of early bicycles, and Woodforde (1977).

4.3 The Bicycle: Product Invention and Design

Empirical Invention

Rosenberg (1976) noted that the bicycle was one of many new products which were developed largely by empirical inventions and without any direct reference to science. Even engineering principles had not been fully developed so that many ideas were tried and tested without the inventors having a clear idea of what was needed or the technical requirements of the proposed design. In this respect the bicycle did not differ from many other products though what was surprising was that once 'bicycling science' had been established by the mid-twentieth century, it showed that empirical methods had produced a very good design. Whitt and Wilson (1974) have given an account of scientific analyses of bicycles and physical performance characteristics of cyclists.

4.3.1 Overall Configuration

The word 'bicycle' implies that[1] the chief characteristic is that it has two wheels. The earliest cycle inventors tried various other configurations including models with one to four (or even more) wheels, and a few of the other cycle inventions were incorporated with bicycle design. The primary interest in this section is with the temporal development of the bicycle and its general features and the parallel development of cycles will not be detailed here as references to these developments may obtained from the works cited in the preceding section.

Ideas

Invention is often said to begin with ideas and the idea of a bicycle-like form of transport is very old. Pollington (1870) claimed that bicycle-like devices appeared in ancient Egyptian hieroglyphics, while Apperson (1898) considered that the first idea of a bicycle was suggested by John Evelyn in 1665. Doubtless many others had thought about such vehicles too.

4.3.2 Hobby Horse Era 1791-1860

The first bicycle ever produced was French. Sirvac's "Celerifere" of 1791, which had two heavy wooden wheels of equal diameter, one behind the other and joined together by a longitudinal wooden beam. The rider sat astride this beam and propelled the Hobby Horse by pushing the ground with his feet as though walking. This type of bicycle was very heavy and an unsatisfactory means of transport. For this reason it was used as a plaything rather than a vehicle, as it was less tiring to walk than to "cycle". Other disadvantages of this design have been noted by Hillier (1884) who commented upon the great friction, the jarring (due to lack of springing), and the possibility of a fall. The positive experience which the Hobby Horse gave, was a thrilling sensation of speed when descending hills, though generally its was used in parks or indoor "gymnasia" with level wooden floors.[2] When used on roads the

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1 Some confusion can arise from the early practice of calling all cycles (having one or more wheels) "velocipedes". In this section the term "cycle" will refer to a rider-propelled vehicle having one, or three or more wheels. The term "bicycle" will refer to a two-wheeled vehicle having a single track (i.e. with its wheels in line); the term "Velocipede" will refer to the bicycle model used in the period 1861 to 1869.

2 This model was called the Dandy Horse in Britain because it was used by "dandies" (i.e. wealthy people).

Hobby Horse achieved an average speed of about six m.p.h though the rider had to dismount and push it up hills.
It is doubtful if any of the early Hobby Horse inventors could explain why they chose and stayed with the single track configuration, but as Sharp (1977) explained this gave many advantages over other configurations, especially longitudinal stability and a better ride over undulating surfaces.

<u>Hobby Horse Improvement Inventions</u>

The first improvements were little more than stylistic changes, Sirvac himself did this in 1793 while Drais in 1813 and Niepce in 1816 made small changes too. The most radical invention came in 1817 when Sauerbrun made the front wheel steerable and it was this model which is believed to have led to a fleeting popularity for Hobby Horses in France and Britain in 1818/1819. Hillier (1884) has given references to Hobby Horse articles in journals published between 1769 and 1819. Pollington (1870) and Caunter (1955) have described the improvements which occurred from 1820, the most noteworthy one being that by Gompertz (of Surrey) who added a manually operated lever and quadrant front wheel drive which would reduce the tiring leg effort needed by a Hobby Horse rider.

Another factor which affected configuration at this time (and which continued for many years) was a social factor decreeing a step-through frame for lady's models. An illustration is given in the article on 'Cycling' in <u>Encyclopeadia Britannica</u> (1910) of a lady's Hobby Horse.

<u>Other Configurations Of The Period</u>

Pollington has described the variety of unicycle designs which were produced in this period (some of which were weird, one design had the rider revolve with the wheel), and this solution would reduce both weight and friction though at the cost of considerably heightened instability. A crude di-cycle was also built in this period, with very large wheels which would reduce jarring, and experiments were made with water-cycles in this period which would give a smooth ride. Various types of tricycles and quadracycles were also developed during the 1820s but as the writer of an article on 'Tricycles' in <u>Encyclopeadia Britannica</u> (1888) observed these early models suffered from three major defects. They were almost impossible to ride uphill (due to their great weight and high friction); they had no brakes, so that descents were largely uncontrolled, and they were very liable to overturn when cornering. The main contribution which these trials of multi-wheeled designs made was the development of various driving mechanisms based on cranked axles, levers and treadles, which were used later on some bicycles.

Interest in the Hobby Horse apparently died during the 1820s and invention also appeared to stop.

Macmillan's 'Safety'

In 1839 Macmillan invented and used a revolutionary new configuration of bicycle. This had a rear driven wheel with a lever and crank driving mechanism and was thus a form of Safety bicycle which appeared to be a great improvement upon the Hobby Horse. Contemporary accounts indicate that Macmillan cycled long distances on this model which had many desirable features later to become standard. How Macmillan arrived at his design is not known, though it was obviously the result of considerable thought. The strange aspect of this invention was that apart from Dalzell, no one else adopted Macmillan's configuration at that time.[3] Fifty years later the inscription "He builded better than he knew" was written on his memorial, a striking illustration of Cardwell's 'precocious' invention. Macmillan's design must be regarded as one which was "ahead of its time".

4.3.3 The Velocipede Era 1861 to 1869

The early Velocipede model was simply a Hobby Horse fitted with front wheel pedals.[4] This simple change altered cycling by making it possible for the rider to propel the bicycle without his feet touching the ground and

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3 An "Improved Kilmarnock Velocipede" was offered for sale in 1869. This model had a better steering handle, a brake and gun metal bearings. It was heavy, weighing 58 pounds and said to be capable of travelling at 8-12 m.p.h. It sold at seven pounds. This model was illustrated and described in the English Mechanic 1869, June 11, p.271 by "Mechanical Hawk".

4 It is not certain who was first to equip a Hobby Horse with front wheel pedals, some believe that Dalzell did so, the writer in Chambers Journal (anon, 1869) said that a M. Riviere did so, Grimely (1973) suggested Fischer did so in 1852, while Pollington (1870) and Starley (1898) said that Lallement did so in 1866.

therefore required him to 'ride' (or balance) the machine. Micheaux is generally credited with the invention of the Velocipede and his design was to become one of the most popular of this type.

Velocipede Problems

This configuration suffered from all the disadvantages of the Hobby Horse such as excessive weight, high friction and jarring as well as further complications due to the addition of the pedals. Woodforde (1970) has illustrated these further complications by an extensive quotation from a sales pamphlet of 1868 which described how early Velocipedes tended to have rear wheel side-slip when cornering, reactive handlebar torque due to pedal pressure (which required a very tiring counter-torque to be exerted by the rider), and how the position of the rider's legs (due to the pedal location) made it impossible to pedal when cornering and and rendered him liable to be cut by the rim of the front wheel. These problems led to later inventions to solve them.

Velocipede Improvements

Caunter (1955) has noted that Velocipede improvements up to about 1868 originated mainly in France and America. These involved a change from a wooden frame to an iron one, a similar change from wooden wheels to iron (artillary) ones; a "spoon" or plunger brake; some form of springing; and solid rubber (or similar) material for tyres.

Pickering's Velocipede

In 1868 Pickering (an American) made a remarkable series of improvements to the Velocipede which made it simpler, lighter stronger, more durable and cheaper. This was described in the English Mechanic (1868, pp362-3). Pickering's model was light and strong as he used hydraulic tubing (i.e. hollow tubing) for the frame. It was "made by gauge" meaning that standardised interchangeable parts were used which allowed worn parts to be easily and cheaply replaced, had gun metal bushings in the hubs together with an oil bath, both contributing to much reduced friction. The rider's position was also improved by positioning the handlebars further back and at a height which allowed the rider to sit upright. Crank pedals were three-sided and revolved on their pins; which allowed the rider to use the front of his foot for pedalling. This was found to be better than the French custom of using the rear of the foot. A peculiar form of sprung seat incorporating a rear wheel brake was also included in Pickering's design, and although no mention was made of an elementary form of suspension wheel it is generally reckoned that Pickering's model also had this too.

No adequate explanation can be given of how Pickering arrived at his design but probably the 'craze' for cycling was a primary cause. Pickering had obviously taken much trouble to solve a variety of problems and used solutions or principles from other industries so that he employed technology transfer. The 'American System' of manufacturing also impinged upon Pickering's design with its standardisation and interchangeable components. which implied the ability to produce precision parts - a feature which was not adopted in Britain until the 1890s.

British Velocipede Ideas and Inventions

In Britain, from about 1865, the pages of the English Mechanic were filled with ideas and discussion for cycle improvements.

Many of these ideas were wholly impractical, for example the balloon Velocipede shown in the 1869 edition (July 16, p380). An enormous range of ideas about new Velocipede configurations were discussed including water - Velocipedes; 'manupedes' (hand driven models); 'fugepedes' (flying velocipede with wings); ice velocipedes;[5] a velocipede for two riders; tricycles which could be changed into Velocipedes when a lever was pulled; steam velocipedes, di-cycles and unicycles of various configurations and a design for a lady's Velocipede. The majority of these ideas came to nothing, but some continued to attract inventors' attention for many years. These exchanges in technical journals indicate that ideas can be refined and enlarged by discussion.

Renold & May's "Phantom"

In 1868 a radically new type of Velocipede was designed in Britain. This model had an articulated frame with the rider seated in front of the frame hinge. This eliminated all the specific Velocipede problems (inability to pedal

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5 An American model of an ice velocipede was illustrated in the English Mechanic 1869, March 26 p.7. This had two 'skates' in place of the small rear wheel; it was said to perform well.

while cornering, liability to cuts on the leg, possible entangelment in the case of a fall and poor cornering characteristics). The Phantom design achieved its objective by using both the front and rear wheels for steering. The design ensured that the axle-lines of both wheels intersected at the centre of the corner being turned. Understandably the Phantom was difficult to learn to ride and for this reason was not a commercial success. It incorporated several other novel features, solid rubber tyres ensured that this model had a good road grip, and it also had elementary suspension wheels. The Phantom represented another radically new configuration based on the solution to recognised Velocipede problems.
Another version of much the same idea was Wiseman's 'Safety' with rear wheel steering[6] Its design also overcame the specific Velocipede problems though in addition Wiseman pointed to the advantages of its low saddle which permitted the rider to mount the bicycle before it was in motion, and that its low centre of gravity made it safer in a fall.

Later Velocipede Inventions 1868-1869

By 1869 it had become apparent that the Velocipede had potential as a form of road transport rather than its previous use as a plaything in fields and gymnasia. An article in the English Mechanic (1869, June 11, p.268) dealt with the latest American Velocipedes and reported that the efforts of inventors were now being directed to making a bicycle which could be used on common roadways. This caused inventors to alter their designs to deal with the greater shocks and other problems met with in road use. One British model designed to suit these new condition was the "Scarborough" and it was noted (English Mechanic 1869, June 11, p269) that the common French Velocipede frame had a tendency to twist and vibrate when going at any considerable speed along a road. This model also made provision for sprung saddles and adjustable treadles to suit riders of differing heights. Environmental conditions therefore affect product design.

The key invention which was to transform the Velocipede was the enlargement of the front driving wheel which effectively increased its mechanical

6 This was illustrated and described in the English Mechanic 1869, July 16, p.386.

advantage. This improvement depended upon the ability to make a light strong wheel and the successive improvements to the Suspension wheel made this objective possible. (This illustrates the influence which a sub-unit invention can make to the improvement of the overall bicycle). An illustration and description of what was essentially a Penny Farthing appeared in the English Mechanic (1869, April 16, p79) under the heading "Soule's Simultaneous Movement Velocipede". This was described as being virtually a unicycle with the small rear wheel acting only as a truck or friction wheel. The driving wheel could be of a very great diameter. (This model had a further provision to advance or retract the front wheel relative to the rider. The advanced position was intended for rapid descents and aimed to prevent "headers", while the retracted position was intended to be used when ascending hills so that the pedals were almost vertically beneath him thus allowing full pedal pressure to be exerted).

Other soon adopted the large front front wheel and riders were able to undertake very long journeys such as London to Edinburgh or London to Liverpool. The best indication of increased speed of these improved Velocipedes afforded by the times needed to cycle from London to Brighton which was 16 hours in May 1869, and 7.5 hours in July 1869.

Falling from Velocipedes was a problem which led to experiments with 'safety' models with rear driven wheels. The earliest Safety configuration was Macmillan's model with its rear-driven wheel and throughout the Velocipede era a variety of similar configurations had been made or proposed, Shearing's sketch in the English Mechanic in 1869 July 30, p.242 being a rear wheel driven example. Wiseman's model has already been described though it had a front wheel drive.

By 1869 British production of Velocipedes had begun. In part, this was an echo of the American and French craze for Velocipedes which had started a year or two earlier. This commercial introduction was associated with a concerted effort to improve the Velocipede but the decisive invention - that of the increased diameter driving wheel - was apparently not based on prior calculation and therefore represents an unforseen benefit. However, as the

London to Brighton speeds show, this new feature was developed rapidly and was associated with a perception of the distinct advantage of the bicycle over walking or other rider-powered vehicles. At this stage of development the bicycle had market potential as a new kind of vehicle which had decided advantages over other types of vehicle and walking. This was clearly perceived by 1869 and led to preparations for manufacturing and selling these bicycles.

New Uses For Velocipede

Another trend of invention is shown by this quotation from an advertisement in English Mechanic (1869, April 9, p.iv) by A. Davis, an agent for The French Velocipede Co. London, which reveals how manufacturers anticipated new uses or applications of a modified product. "The Velocipede for children is especially constructed for safety. Three-wheeled velocipedes are made convertible into two-wheels. For ladies light & easy Velocipedes are made with luxurious couches. For night use, lanterns can be fitted; for travelling, valises; for muddy roads, special protectors are made; reckoners to calculate the distances and speed traversed; umbrella supporters. A special Velocipede is being constructed for artists, photographers, commercial travellers, and all riders having to carry luggage."

These variations of the basic Velocipede model appeared to emanate from the suppliers rather than consumers.

Velocipede configurations are still used in some designs of childrens' bicycles and tricycles.

Impractical and Other Facets of Cycle Invention

Impractical ideas and proposed inventions were a feature of bicycle history which lasted at least until the turn of the century and a brief note will be made here of several aspects of weird and eccentric bicycle inventions which Linley (1925) classified as "bogus" and "crank". Linley considered that bogus inventors aimed to delude the public usually by demonstrations of these inventions (which often contravened physical laws) by hiring fast riders to provide racing proof. The other type of inventor was the "crank" who was obsessed with some technical principle or mechanism to improve speed or power without additional energy. Quite often the "crank's" claims could neither be proved nor disproved at that time, though it often contained some element of plausibility. The controversies over elliptical chainwheels and linear or circular pedalling motion reflect the kinds of issues and inventions which attracted "cranks". This feature of bicycle invention was particularly active in the mid-1890s when company promoters used patents and inventions as a basis for gross over-valuations of the bicycle companies they launched. Linley also considered that bicycle manufacturers failed to make a proper engineering assessment of new ideas.

A related secondary problem concerning bicycle invention was the attitude to new inventions themselves. One common manifestation was a prejudice against all new things even if they were perfectly sound; both Starley and Dunlop encountered this when they introduced their pioneering inventions. A notable recent example was the reception given to Moulton's Small Wheel design.

Another obverse aspect of much the same attitude was the belief that no further improvement was possible and in the case of velocipedes this was expressed by one English Mechanic reader in 1869 (p.467).

Cases of re-invention were also experienced as early as the Velocipede period as shown in the case of one writer to the English Mechanic (1869, May 7, p.158) who told of an illustration in an earlier issue which contained a design which the writer had previously included in a patent application.

These secondary and curious aspects of invention have been observed in the history of other products, but apart from raising discussion and further ideas they did not usually affect technical progress.

Effects of Velocipede Inventions

The results of invention in this period were not apparent as changes to Velocipede configuration yet considerable improvements had taken place in such features as increased strength, friction reduction and better springing and these all made a big difference to the performance of the Velocipede. Perhaps the overall effect of these Velocipede inventions can be summed up in a phrase used in the English Mechanic (1869, Feb 19, p.485) which stated that "present machines glide". The Velocipede had begun as a plaything and ended as a practical vehicle.

4.3.4 Penny Farthing Era 1870 to 1884

The Penny Farthing[7] was a masterpiece of apparent design simplicity which involved many inter-locking inventions at all product levels. These developments formed two separate strands; one was the improvements to overall configuration which will be described below, the other concerned sub-units, components and accessories. Few histories of bicycle development adequately record the enormous range of sub-units and components which were developed and tried in the period 1870 to 1900. Two of these (the tension spoked wheel and ball bearings will be described in a later section) but here it may be noted that many other inventions were simultaneously developed, largely it seems because the Penny Farthing became popular. Some examples of sub-unit bicycle inventions are briefly described here to show the pattern of development, the range of designs of both sub-units and accessory invention. Hollow tube construction was based on earlier invention in structural engineering which demonstrated the principle, this was first applied in Britain to the front forks of Grout´s Penny Farthing and, as Starley (1898) noted its use spread gradually throughout the bicycle so that the frame, handle bars and even wheel rims were made of hollow construction in order to reduce weight and provide a strong structure. This ´outspreading´ of design use of a new principle is quite common and will be shown to have applied to the adoption of ball bearings in bicycles as well. An enormous variety of driving mechanisms were invented and tried; this had begun with the Velocipede direct drive but the desire for gearing and lower rider position led to other types being tested, many new lever-drives (hand and foot types), spur and bevel gear drives, and others which will be noted in the later section dealing with patents. Chain drive ultimately proved to be the most successful and this too emerged from a protracted period of development beginning with rope and belt types and proceeded through the ´block´ chain until the modern roller chain was perfected - the first patent for this being granted in 1864.

The satisfactory basic design of Penny Farthing can be said to have appeared in 1875 and soon after a large number of bicycle accessories were invented

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[7] The Penny Farthing was called the ´Ordinary´ in Britain, and the ´high wheeled´ cycle in America at its introduction.

and placed on the market. Caunter (1955) noted that these included many types of saddle (often with air or spring cushioning), bags, bells and other warning devices, lamps and cyclometers. Solid tyres were fitted and improved by using different materials for outer and inner tyres while sprung frames were developed as well and would have probably been a commercial success but for the later appearance of the pneumatic tyre which rendered sprung frames commercially obsolete (although motor cycle designs later built upon these bicycle inventions). In the 1870s early types of two speed gear systems were tried and this also was improved much later. All those sub-unit and component inventions were carried forward to later configurations so that they tended to have an independent existence.

Overall Configuration

The trend of overall configuration improvement of the Penny Farthing followed a two stage course. The first period up to about 1875 was one of the continuation of the initial trend of enlarging the front wheel of the Velocipede which reached it limit once its radius equalled the inside leg measurement of the rider (and meant that a variety of wheel sizes were made to suit different riders). The second stage was later improvements to the overall configuration of the Penny Farthing.

Basic Penny Farthing

The configuration of the Penny Farthing was a big improvement over the Velocipede, the rider was seated almost vertically above the front hub which allowed him to exert nearly his full force on the pedals. This position also reduced the reactive torque on the handlebars to a minimum. The use of the large diameter wheel reduced road vibration, and as the loading upon the rear wheel was small its relatively greater vibration was not excessive. Solid rubber tyres had become standard by the mid-1870s. There were still deficiencies in the gear-ratio, riding position and vibration but as a whole the early Penny Farthing synthesised and optimised a number of conflicting design requirements with the result that riders were able to achieve record speeds and distances. Concurrently a second strand had been to reduce the weight of this type of bicycle and this depended mainly upon the adoption of hollow tube construction and lighter materials; this resulted in a product diversification with very light racing models (weighing about half of the ordinary one) being made. Structures had been reduced to their simplest form and lowest weight. The frame had become simply a curved rod, and the rear wheel had been made as small as possible to save weight, at the ′technical cost′ of increased vibration - another example of trade-off.

Ariel

One of the earliest basic Penny Farthing models was the "Ariel" model of 1870 which had a 40 inch lever tension front wheel fitted with a solid rubber tyre. With this configuration it was found that speeds increased. This, as Woodforde (1977) noted, caused some technological obsolesence, as riders sold their old Velocipedes and bought the new Penny Farthing design.

Later Penny Farthing Design Improvements

The trend of later Penny Farthing improvement was guided by the need to overcome its chief defect - its tendency to throw the rider either over the handlebars (a "header") or to fall when mounting or dismounting. Headers had a variety of causes, they could be due to some small road obstacle, a sharp application of the brake, or even if the rider′s foot slipped from a pedal during a power stroke. Such falls could be serious because of the height of the saddle and rider.

Inventors sought to make a safer bicycle in three main ways. The first way was to modify the basic Penny Farthing design to make it safer. The second was to develop another configuration called here the Early Safety. The third way was to add an additional wheel making it into a tricycle which was very popular from the mid-1870s.

Safety Improvements to the Basic Penny Farthing

The fundamental aim of all inventions to make the basic Penny Farthing a safer bicycle, was to design a configuration which lowered the rider and placed him further back, and, at the same time to achieve this without sacrificing the performance of the basic Penny Farthing. The solution depended upon finding a way of extending the pedals (and therefore the saddle) downwards and backwards without reducing the size of the driving wheel. This was not achieved immediately but the trend is exemplified by three models: The Xtraordinary of 1878, The Facile of 1878 and The Kangaroo of 1884.

The Xtraordinary

In this configuration the rider was lowered and placed further back by two modifications. A smaller driving wheel was used and the pedals were altered by the addition of a more complex driving arrangement. Instead of the direct pedal crank a system of pendulum levers (one on each side of the front wheel) with curved pedal ends, was pivotted to a bracket near at the top of the front forks, and the crank linked to the centre portion of this pendulum lever. The pedals described an arc and, because of the reduced front wheel diameter one "revolution" of the pedals produced one revolution of the front wheel so that this model was not as fast as the basic Penny Farthing, and some complication had been introduced in the driving mechanism. It was safer and this feature led to increased sales.

The Facile

The Facile achieved the desired objective in a similar way the pedals being lowered and placed further back by means of a downward sloping extension to the base of the front fork, and the pedal lever was pivotted at this point. The centre of this lever was linked to the crank and the pedals reciprocated rather than revolved. A smaller diameter front wheel was used and a relative loss of speed entailed as with the Xtraordinary. Sharp (1977) said that this model was safer too and under some conditions easier to propel because the reduced height meant reduced resistance to the wind; in 1883 a road rider achieved an average speed of 10.1 m.p.h. over 242.5 miles on common roads.

The Kangaroo

This model also had a smaller driving wheel with the pedals lowered and set further back. Its distinguishing feature was that gearing was employed so that one revolution of the pedals caused the front wheel to revolve more than that. Although the Kangaroo's driving mechanism suffered from some defects which Sharp (1977) noted, riders achieved record speeds and distances with it in 1884. one rider travelled 100 road miles at an average speed of 14 m.p.h. - the fastest up to that time.

Other Safer Models

The search for safer cycles led to further experiments with various kinds of cycles; in this section some examples of safer bicycles will be described.

The ´Star´

The American "Star" ingeniously sought to make the Penny Farthing configuration safer simply by reversing it, with the small wheel in front (and made steerable) while the rider sat slightly in front of the centre of the large rear wheel. This model was also difficult to learn to ride and steer, but was safer and sold quite well for a number of years.

The Di-cycle

The di-cycle configuration was of two side-by-side wheels with the rider sitting between them. These types had the rider seated much lower than on the Penny Farthing but a number of difficulties became apparent. One was that cornering and steering was quite difficult, another concerned its balance in the fore-and aft plane. The di-cycle was not new, reference has been made to earlier types, but Otto´s di-cycle sold in considerable numbers from 1879, partly because the desire to cycle had extended to older people who could not consider riding a Penny Farthing.

Early Safety

The basic feature of this configuration was its rear drive and low seat. The idea of a safety dated from MacMillan´s design and this was continued during the Velocipede era. During the 1870s these efforts were continued notably by Lawson whose efforts culminated in his "Bicyclette" design of 1879 which had a chain driven rear wheel and a huge front wheel.[8] The basic objective which all Early Safety designers sought was to return to the Hobby Horse/Velocipede configuration with the rider seated low in the middle of a long frame and incorporating rear wheel drive which eliminated reactive handlebar torque and other specific Velocipede problems. Boys (1884) considered that the main drawback with these Early Safety models was their steering characteristics and he believed that the lack of commercial appeal was due to this deficiency.

8 The reason for the large front wheel has been explained by Phillips (1885) who noted that some safety models had had erratic steering and used large wheels to rectify this although inventors had attempted to solve this problem in other ways.

During the early 1880s the Early Safety configuration was changed by the belief that the wheelbase should be as short as possible. This led to a standard design for those years with the saddle being placed vertically above the front edge of the rear wheel and the pedal crank placed vertically below the saddle as near to the ground as possible. In most of these models the steering was made Direct by sloping the steering head (or front forks, or both) so that the rider could grasp the handlebars and steer directly. These later Early Safety models had a modified frame with a stout horizontal tube fitted, and were called Cross Frame Safeties. A variety of such models were produced but they did not meet with great commercial success.

The Tricycle

The lack of safety inherent in the basic Penny Farthing configuration led to a resurgence of interest in tricycles in the mid-1870s. Tricycles made before this date were essentially cart types but with the development of tension spoked wheels, ball bearings, solid rubber tyres and all the other bicycle advances, much lighter, stronger and better tricycles could be built by incorporating these improvements. The first tricycle which had a sizeable commercial appeal was "The Dublin" of 1876.

No attempt will be made here to trace the development of tricycles in this period, as Sharp (1977) has given copious details and references. One of the main problems was that the lack of a differential axle meant that doubly driven tricycle wheels dragged when cornering and this was cured by various inventions including Starley's re-invention of the differential axle (which was later used on motor cars). There were other design difficulties which affected tricycle characteristics and these were gradually overcome.

The tricycle soon became very popular with older riders or those who would never have considered attempting to ride a Penny Farthing and by the early 1880s the speeds reached by tricyclists were only marginally slower than those of Penny Farthing cyclists as Boys (1884) has shown. The tricycle also led to new uses and forms, it was ideally suited for carrying parcels and light goods, and its "sociable" form (two persons seated side by side) proved to be attractive. In the article on 'Tricycles' in Encyclopeadia Britannica (1888) Boys described how tricycles were further diversified into manually operated types for use as invalid carriages and other purposes.

4.3.5 Modern Safety Inventions and Designs up to 1900

The Modern Safety (then called the Safety Dwarf) evolved from the Early Safeties described in the preceeding section. The first Modern Safety configuration appeared in the form of Starley's modified "Rover" in 1885. Starley (1895,1898) has given a detailed account of how he arrived at this new configuration. His chief aim was to produce a safe bicycle which was to have a performance equal to the best Penny Farthing. The basic pre-requisites of a safe design had already been established and incorporated a small rear driven wheel with front steering with the rider seated as near to the ground as possible, and over the rear wheel with the pedals vertically beneath him.

Starley's crucial design element was the frame and in order to get the best specification for it he altered the conception of the bicycle as a machine and replaced this with the concept of a frame-plus-rider thus aiming to design the frame around the rider. Starley's 1885 frame was an open one with some curved members and did not have a seat tube.

This new design had five 'main principles'. These were 1) to place the rider at the proper distance from the ground 2) to connect the crank with the (rear) driven wheel so that gearing could be varied as desired 3) to place the seat in the correct position in relation to the pedals 4) to provide an adjustable mounting (vertical and lateral) of the saddle 5) to position the handlebars in correct relation to the seat so that the rider could exert the greatest force upon the pedals with the least fatigue.

This Modern Safety had eight advantages over previous bicycles; these were safety, absence of vibration, easy steering, no side-slipping, narrow tread, single chain, good luggage carrying capacity and speed.

His first model was not well received until Sept. 1885 when it broke the world record for the 100 miles race and from then on it met with increasing success rendering all other bicycles obsolete except the Bantam. Its performance was as good as the current Penny Farthings. Starley had achieved his design objectives of a safe bicycle which would not throw the rider over the handlebars under normal circumstances and whose performance was equal to current Penny Farthing models. By 1888 the Modern Safety made a further advance when it was found the Dunlop's pneumatic tyre made it about one third faster, Starley said, as less power was needed to propel this model than previous ones.

No sooner were the benefits of the Modern Safety demonstrated than other inventors sought to further improve it. Sharp (1977) noted that the Safety increased in popularity from 1886 and that there were numerous designs with many varieties of frames.

Later 'Safer' Penny Farthings

One response to the success of the Modern Safety was for manufacturers of Penny Farthing models to re-design that model to make it 'safer'. For example the 'Geared Facile' appeared which was a rear driven version of the earlier model of that name, having treadles and sun and planet gearing; the 'Rational Ordinary' was produced which had a sloping front fork, its seat placed well back and a larger rear wheel; the 'Geared Ordinary' was another safe version with a small front wheel with a geared hub. The 'Bantam' was a small wheeled Velocipede with a hub gear. These models catered for cyclists who doubted the claims made for Modern Safeties and who preferred the earlier types but yet desired safer machines.

Diamond Framed Safety

The last major step in the evolution of the Modern Safety configuration occurred with the development of the Diamond Frame. In 1890 Humber introduced this frame which required a slight alteration to Starley's "triangle". This involved placing the seat further back over the rear wheel and at the same time moving the pedal crank a few inches in front of the rear wheel. Thus the pedals were no longer vertically beneath the rider as in earlier models. (Humber had produced an Early Safety in 1885 in which the rider was seated very far back over the rear wheel). This new position of seat and crank axle meant that a straight tube could be fitted between saddle and crank thus triangulating the diamond of the frame and producing a very strong, light and low cost frame whose rigidity was established in practice and which soon became the standard. Another minor feature of this model was that its front forks were bent forward to produce a castor action on the steering and this too was soon generally adopted by all.

The Diamond Framed Modern Safety, Caunter (1955) noted, led to the extinction of most of the other types of bicycles which had flourished from 1875. This was due to the superiority of the diamond framed Modern Safety. This did not mean that other inventors ceased to consider even better designs or try to further improve the Modern Safety.

Other types of bicycle frames were suggested but these were not lasting successes. One example was the Dursley-Pederson bicycle invented in 1893; this model had a more complex but lighter frame. Complexity meant greater expense and its torsional rigidity was not as great as needed so that although it sold for a number of years it was not a lasting success. Evans (1979) has described the history of this design.

Another feature at this stage was the transition from largely empirical invention to rational engineering design based on engineering principles which had been built up by this time. This is shown by the publication of Sharp's book in 1896, though of course others had made earlier contributions to these principles. Other sources of design information included engineering magazines and journals published by engineering institutions.[9]

Large Demand

The technical success of the Modern Safety design was largely responsible for the huge surge in demand which occurred in the mid-1890s. This craze lasted to 1897 and died about as quickly as it arose, leading to a period of stagnation in home demand which had repercussions upon bicycle invention.

9 The Institution Of Mechanical Engineers published papers on cycle design, for example Phillips's 1885 paper was one; an institution of cycle engineers was formed in the late 1890s, by 1906 it encompassed automobile design then after that was incorporated with the Institution Of Mechanical Engineers.

Product Invention in Economic Depression

The earliest article this writer can trace dealing with the effect of economic depression on bicycle invention is one written in The Cycle Trades Patent Journal (1893 June pp.73-74) dealing with the difficulties which cycle inventors met. In the past (i.e. the 1880s) "novelty had succeeded novelty" and inventors had enjoyed some recompense. However in these days (i.e. 1893) of "cutting prices and severe competition there is nothing more difficult than to induce manufacturers to adopt anything new and more particularly to trade in any article which will necessitate making fresh patterns and possibly rendering obsolete that which they may be disposing of to their cycle agents. Now that patterns are in great measure universally adopted and monopolies rule the roost, the inventor finds it far more difficult to gain his first foothold.--- Eight years ago (i.e.1885) it was the custom to introduce yearly at the Stanley Show, the novelties for the ensuing season.--- Manufacturers had dictated to the public then, now (i.e.1893) the manufacturer is slave to the public, he must and will supply only those things which are ordered." This journal writer then clearly distinguished between a buyers' and sellers' market and suggests that early product diversification had been instigated by manufacturers and not consumers; that new product inventions were welcomed in prosperous times but not in times of depression if capital investment was needed.

Pennell (1900) noted that British bicycle manufacturers soon reduced their prices after the boom was over, and because of the very large production capacity created by the change to mechanised manufacturing methods which the boom caused, they adopted a more aggressive sales policy. Part of this sales effort depended upon giving the bicycle more consumer appeal and invention formed an element in this policy. Pennell noted that British manufacturers "universally" turned to the Free Wheel in order to attract more sales. The Free Wheel was not new, Pennell said that it dated from about 1875 and had first appeared in the form of the Cheylesmore Clutch used on tricycles and later used extensively in carrier tricycles, and fitted to bicycles when requested. In 1899 this mechanism was re-presented to the public with 'rational' demonstrations of its effectiveness which took the form of fitting two cyclometers to a bicycle, one to the wheels and one to the pedals. The difference between the readings was said to show the benefit of the free wheel, and Pennell reported that a journey of 40 miles had involved pedalling only the equivalent of 25 miles. Pennell did not like the free wheel because he said it reduced the simplicity of design and made it impossible to brake by back-pedalling. One consequence of the widespread use of the free wheel was that rim brakes were introduced, and in association with this, the Bowden cable an illustration of ´inner logic´ pressure.

Bicycle as ´Machine-plus-Rider´ Concept Again

The idea of designing the bicycle to suit the rider, was still influential. Crompton, the well known electrical engineer, had considered current gear ratios after reading a letter written by Blathy in 1896. Crompton had decided that current ratios were far too low and that if these were raised, cranks lengthened and bicycle wheelbases made longer, the bicycle would be much improved. Crompton has given fuller details of his ideas in the discussion section of Starley (1898). Pennell (1900) reported on the effects of Crompton´s changes to Pennell´s bicycle which were made after measuring Pennell. These changes increased the gear ratio, crank length and wheelbase and also involved fitting toe-caps so that Pennell could pull the pedals upward on their return. The results of these changes, Pennell said led to an experience of power, comfort and ease undreamed of by riders of conventional designs.

Bicycle Gearing

This discussion about bicycle gearing in the late 1890s led to the development of various types of multi-speed devices although as noted above experiments had begun much earlier. Grew (1921) said that the first really satisfactory one was a derailleur type brought out in 1900 though by 1903 the Sturmey-Archer three speed hub had been developed "and was produced at such a low cost that they had the market to themselves". Other types were produced after 1903 however the Sturmey-Archer proved to be very popular and remained unchanged for over fifty years; its good design was a factor in this long market life. The derailleur type was favoured in France from the early 1900s and only became popular in Britain during the 1960s.

Gearing and Wind Resistance

Higher gear ratios led to higher speeds which in turn revealed the importance of wind resistance at these higher speeds. This formed an inner logic link. The article on 'Cycling' in Encyclopeadia Britannica (1910) noted that in 1900 there was a vogue for setting speed (paced) records with riders following a swiftly moving vehicle which had baffle boards fitted. Under these conditions cyclists attained enormous speeds, which in turn led to the fuller appreciation of the power required to overcome wind resistance and in its turn led to Recumbent configurations and Enclosed (streamlined) models. These never proved practical for everyday use, Whitt & Wilson (1974) give a brief history and modern force analysis of these types of bicycle configuration. The main effect upon the design of racing bicycles was to position the rider in the most crouched posture (to reduce wind resistance) with a high seat nearly vertically above the pedals and low (or dropped) handlebars. Bicycle configurations had diversified again and from this time the market was broadly divided into bicycles for everyday use and special racing bicycles, in which product design aimed to squeeze the 'last ounce' of performance without regard to cost.

Bicycle Accessories

The other branch of invention which was stimulated by the depressed trade after 1898 was the Bicycle Accessory one, which Pratt (1904) said had become a "new" trade by 1901, although it was noted above by Phillips (1885), that bicycle accessories were popular earlier. These accessories involved invention but did not change the configuration of the bicycle, catering solely for the comfort and convenience of the riders and their desires.

External 'Invention'

Another change which considerably improved the smoothness of the ride was the provision of roads or special cycleways. In Britain cyclists have never had to pay road tax and use the ordinary roads; on the Continent however special cycleways have long been provided as cyclists paid road taxes. The article on 'Cycling' in Encyclopeadia Britannica (1910) has briefly dealt with this subject. In recent years in some new towns in Britain special cycleways have been provided.

Caunter (1955) considered that the British home market for bicycles remained depressed from 1900 to 1925.[10] Caunter said that three broad classes of bicycle were built (and designed) in this period and depended upon the type of manufacturer. One was the small local workshop which built bicycles using a large number of components and sub-units made by large component firms; another was the cheap but good quality machine made by large firms and the last type was the de luxe model which was built without regard to cost. At this time bicycle prices ranged from five pounds to over twenty pounds. In effect the market exerted its influence upon product design and a fourth category can be added, namely exports. Bicycles were thus designed for particular segments of the market and product invention was used (in conjunction with process invention and non-technological change) to suit demand by low income buyers, wealthy purchasers who wished the highest possible quality and foreign buyers who demanded minor changes to suit their special needs. Another effect was for some bicycle manufacturers either to cease business altogether or diversify into motor cycle or motor car production. G.C. Allen (1970) and Saul (1962) have described this final feature.

Product Invention and Cost Reduction

The need for reduced costs of bicycles was apparent from contemporary reports of bicycle manufacturers, for example The Times (1909, Aug 18, p.17) observed that poor sales were due to a number of factors including a lack of money "among the classes who mainly buy bicycles". This had led to some discussion among British bicycle manufacturers about a better design but had not led to any results as the manufacturers were unable to agree among themselves.

Product invention was a major tool in price reduction. At the Overall Configuration level product invention was used to determine the main features of design; if high quality was the objective then costs were not regarded as important as the example of de luxe models and racing designs showed, but if the design was for a low cost but good quality bicycle then simplicity was a key feature. Caunter (1955) has described how American cycle manufacturers

10 Rosenberg (1963) noted that in America the bicycle market there also collapsed from 1900. It appears that world wide social factors affected bicycle demand as each country appeared to more or less share bicycle crazes and s slumps in demand about the same time.

´virtually redesigned the bicycle´ so that it incorporated fewer and cheaper materials, required less machining of components, used pressings instead of more laborious methods of manufacturing these components and produced bicycles without mudguards, chainguards, brakes and footrests and shortened the frame and sometimes used wooden handlebars and wheel rims to save weight. Grew (1921) noted that about 1900 frame designs were changed to incorporate stamped lugs which made production easier and also reduced weight and cost.

Better Quality Products

In 1910 (Dec 16 p.8) The Times again reported on the cycle industry noting that low demand had continued and manufacturers had experienced losses. "The working men, who have become the main buyers of the ordinary bicycle, purchased only in small numbers comparatively ---but among the middle classes instances of a willingness to pay more for a high grade machine." (This latter feature was repeated in 1938 when Engineering (1939) noted that while low cost bicycle sales had fallen in 1938, the sales of better quality bicycles had not fallen to anything like the same extent). Some very high quality British bicycles were produced at this time, one example being the "Golden Sunbeam", which Woodforde (1977) noted had been introduced in 1902 and remained unchanged "as no one could see how it might be improved."

Exports

The design of bicycles for export had to suit the differing needs of various countries. Watling (1949) observed that bicycles exported to India had to be tall to accommodate the robes which riders wore there; Africans needed oversize ´cushion´ tyres to absorb the road shocks of the tracks there; Canadians preferred low saddles; and Middle East customers wanted bicycles fitted with stands to prevent chains and gears becoming clogged.

Interwar Bicycle Designs

During the 1920s and 1930s the basic configuration of the Modern Safety design remained unchanged. The lack of improvement may best be illustrated by the announcement in 1929 that the Cyclists Touring Club had decided that, for the first time, the annual award for the most meritorious invention or improvement in the construction of the bicycle would not be made. (The Times

1929, June 25, p.6). The Lightweight Tourer model had been introduced in the mid-1920s; PEP (1949) noted that this had largely been developed by small bicycle manufacturers. It did not represent any fundamental change in design but, Caunter (1955) said catered for the growing popularity of cycling which had then begun. Its chief feature was its lighter weight, of up to thirty pounds in place of the former 35 to 40 pounds weight.

By this time the British bicycle had attained a world wide reputation for quality and durability. Watling (1926) considered that the high quality of British bicycles was one of the main reasons for a growing export success against foreign competition. The life of a good British bicycle was almost infinite, PEP (1949) considered that this would be about 50 years. A series of letters in The Times in 1934[11] told of readers whose thirty or thirty five year old bicycle was still in daily use.

Incremental Product Improvements

An illustration of the nature of incremental product inventions was given by The Times[12] in its report of the 1937 Cycle Show described how new lightweight materials had led to lighter mudguards and saddles, and that advances in rubber technology had led to stronger bicycle tyres which gave a better grip of the road. New rustproofing processes were used before enamelling and stainless steel spokes were being fitted. Lighting had improved because dynamos of up to 7 watts were being sold and reflectors made night riding safer. In its 1938 report on the Cycle Show[13] it was noted that improvements in materials for the aircraft industry had been transferred to the bicycle with the result that bicycle weights had been reduced by 25%, that overall strength had been increased by 70% and propelling effort had been reduced by 40% all because of the use of these aircraft alloys. Watson and Gray (1978) noted that the new alloy '531' was first used on bicycles in 1935 and was soon followed by another type called '753'.

Post-1945 Designs

The Modern Safety configuration continued in its unchanged form after 1945.

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11 The Times 1934, Jan 2 p.6; Jan 4 p.6; Jan 12 p.8; Jan 22 p.8; Jan 23 p.8; Jan 24 p.6; Jan 27 p.15.

12 The Times 1937, Sept 23 p.6

13 The Times 1938 Nov 8, p.11 "Opening Of The Cycle Show".

Production catered for low cost utility models such as the "Norman", while the Raleigh "Superbe" was a high quality machine for discerning buyers at this time. These designs satisfied the large demand of the immediate post war years.

During the 1950s sales of bicycles in advanced countries declined because more people were able to afford motor cars or mopeds.[14]

In Britain declining home demand was compounded by previously importing countries beginning to produce their own bicycles. As a result both the home and export markets contracted severely. British manufacturers responded in the usual ways, one was a repeat of the events of 1900 to 1914 when bicycle manufacturers either diversified or went out of business. Another later trend was to move up market and offer higher quality bicycles (at higher prices) to middle income buyers for leisure use (in place of the previous utility use of lower income groups).

Some improvements up-dated old inventions, for example the derailleur gear (with its greater range of speeds) began to be fitted to British bicycles from 1961[15] though this type had been popular in France for many years previously.

4.3.6 Small Wheel Design

Utterback & Abernathy's model made provision for the introduction of some radically new inventions in the mature stage at times when sales were falling or competitive stresses were great. Their observations of typical patterns of innovation led them to believe that the effects of such inventions did not materially alter the long run sales trends though they boosted demand in the short run. In the case of the Small Wheeled bicycle the effect has been to create a permanent demand for this new type. Moulton (1979) has, on the other hand, told how 'invention-push' was primarily responsible for prompting him to fundamentally reconsider the design of bicycles. This was due to the petrol shortage during the Suez crisis.

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[14] Caunter (1955) has described the postwar popularity of motor-assisted pedal cycles with the 'clip-on' motor units. Thousands of these were sold by the early 1950s; these were the forerunners of the 'moped' (motor assisted pedal cycle).

[15] Noted by Britannica Book Of The Year (1961) in its section 'Motor Cycle and Cycle Industry'.

Bicycle Springing

Small wheel bicycles had been made since the "safety" Bantam of the 1890s. The problems associated with small wheels had been known since Penny Farthing days, the main one was vibration. Linley (1925) has described the many inventions which were made in an attempt to cure vibration and these included sprung forks, sprung hubs, sprung wheels as well as sprung frames. The Linley & Briggs "Whippet" model of sprung frame bicycle was a very satisfactory design and might have been permanent but for the invention of the pneumatic tyre a few years later. The design of bicycle springing devices and arrangements continued for many years. The Graphic (1896, Dec 12, p734) described the Hurlingham Balance Action bicycle which had two, two-wheeled bogies (i.e. four wheels in line) and which apparently gave a very smooth ride over obstacles. Later in the period 1904 to 1906 Sharp produced his air spring system which never caught the publics' imagination, Grew said, because of its increased weight and the average cyclists objection to complication. Grew also gave a description of the more limited inventions which sought to dampen shocks, these included sprung forks, spring hubs and similar arrangements.

The design of good sprung frames for two wheeled cycles had to await motor cycle design. The complexity of the problem and the practical solutions only became apparent at this time.

As far as pedal cycles were concerned the two major drawbacks of any kind of springing were that the system itself absorbed some of the limited energy needed to propel the bicycle, and that springing often led to unstable handling characteristics. In addition because of the highly variable weights of different riders and the wide speed range of pedal cycles, a good suspension system was almost impossible to design at low cost. Moulton (1979) has discussed this last point while Whitt and Wilson (1974) have given a more general account of the problem and illustrate a sprung fork which is said to be entirely satisfactory.

Background to Small Wheel Bicycles

During the second world war a special folding motor cycle with very small wheels was developed for military use. After the war this design was found to have some commercial appeal and a number of these were sold. Then an Italian aircraft designer produced an improved form with many unconventional features such as soft long-travel suspension and an offset engine which made the motor-scooter very popular although its vehicle characteristics were not as good as the orthodox motor cycle design.

In Britain an "outsider" to the bicycle industry who had had experience in aircraft and motor car design, turned his attention to bicycles when petrol was in short supply in 1956. He mused over bicycle forms while designing a suspension system for a new very small wheeled motor car. His idea was to design a technically superior all-purpose bicycle which would equal the Modern Safety in every respect. The objectives which Moulton had have been described in Engineering (1962, Nov 9, pp 598-9); the new design was to be highly efficient, suitable for use for all members of the family, and cheap to buy. These objectives led him to produce a prototype which had a "step through" (or open) frame thus ending the distinction between lady's and men's models and contributing to cheaper production; to make the bicycle from a pressed steel frame for cheapness again, to have a low configuration with better luggage-carrying facilities than the standard Modern Safety model, thus pointing to the use of small wheels and the problems of increased vibration. A suspension system was essential in such a configuration. Moulton's desire for high efficiency led him to initially consider the Recumbent configuration. All these features were incorporated in his first prototype.

Tests of Moulton's first prototype showed that some of these ideas were impractical. The Recumbent configuration was found to induce more fatigue than the usual configuration; the use of a pressed steel frame was unsatisfactory for two reasons, firstly the stresses at certain points were too high for this type of construction and secondly the frame produced a high level of road noise. He therefore redesigned this prototype using the classic "triangle" of handlebars, seat and pedals used in the Modern Safety, changed to an oval-tubed open frame and improved the suspension system. The result was a functional new model which used standard bicycle components such as saddle, cranks, chainwheel, pedals and brakes to achieve low cost. Tests showed that his idea for small wheels with a suitable suspension was entirely correct with a total comfort greater than that of the Modern Safety, yet with only a marginal increase in energy losses. Speeds equal to the Modern Safety could be achieved and maintained, while the safety, comfort and luggage capacity were superior. This approach, based as it was on the application of engineering principles and modern knowledge, would have gladdened Sharp's heart, but it is noteworthy that Moulton's findings endorsed the results of the early empirical bicycle designers.

Having produced a sound new design, Moulton experienced the innovation barrier which often afflicts the acceptance of new things and found that no established bicycle manufacturer would undertake production, so that Moulton himself had to introduce it to the market. The model achieved an immediate market success and forced other bicycle manufacturers to produce something similar. This was done by using balloon tyres in place of Moulton's suspension system, but the balloon tyres absorbed a great deal of energy and led to a later compromise, with the wheel diameter being increased from 16 to 20 inches. This model was then diversified as a folding bicycle (not an original idea), and these small wheeled models did capture a sizeable segement of the market for adult bicycles. The annual sales of adult small wheel models show that their share of the adult market gradually built up to about twenty five per cent of the total by the mid-1970s. How many small wheel owners would not have bought ordinary bicycles had the small wheel design not been invented, is a matter of conjecture.

Other Recent Inventions

Changes to childrens' and juvenile bicycles also occurred at this time; with the introduction of 'fun' bikes in the late 1960s. These had their origin in the American fashion for off-road motor cycles, and 'fun' pedal cycles were essentially an engineless version of such motor cycles. Some of these 'fun' designs could be regarded as technical retrogressions as some seated the rider too far back in order to allow the front wheel to be easily raised (for "wheelies"), though this has since been changed for safety reasons.

Incremental Invention Continues

Bicycle invention still continues as reference to newspaper indexes show.[16]

[16] For example the annual indexes to The Times

In general these "new" inventions are frequently modern versions of old ideas which apparently never seem to be commercial successes. An article on bicycle standards[17] noted that the bicycle world was noticeably conservative in the engineering sense perhaps because the standard wheels and trapezoidal frame gave a combination of lightness and strength which had been so developed and refined that it was difficult to improve upon. Yet many people still tried to improve the bicycle "TI Raleigh, the country's largest producer of bicycles, receives thousands of letters, telephone calls and visits every day from people who feel that a reciprocating crank and pedal assembly has advantages over the present rotary pattern or that it is time to give the oval chainwheel another lease of life." (p.7). The article continued by observing that about once every five years someone re-invented the oval chainwheel or suggested a flywheel design to release previously stored energy for uphill riding. All these ideas are very old and have been tried and rejected many times.

Four illustrations of recent incremental bicycle inventions are now given. One was a design for a bicycle saddle which could be raised or lowered while the bicycle was in motion. This idea was intended to allow the rider to raise his seat as high as possible while riding making for efficient pedalling power, while the low position was to be used when stopping or starting, so that the rider's feet could touch the ground. Nothing has been heard of this idea since its announcement.[18]

Another old favourite is the puncture-proof bicycle tyre; Wilcockson (1984)[19] has given a description of fairly recent attempts to produce this using modern materials and he noted the engineering trade-off involved as the ordinary tyre-plus-inner-tube arrangement traded a high puncture risk against lightweight and low rolling resistance. Inventions to reduce punctures were of two main types; one idea was for a shield between the inner tube and the tyre and recent versions of this used modern materials but found that the rolling resistance and weight was increased. The other idea was for an "airless" tyre which was usually of hollow construction and modern

17 B.S.I. News 1981, Nov. pp.7 to 8; "Safety On Two Wheels".
18 Financial Times 1979, June 18 p.11 "Bicycle Saddle Safety Device".
19 Sunday Times 1984 Jan 15, p.72

versions employed plastics. None of these had been successful because of increased weight, rolling resistance, increased vibration and a proneness to skid although a recent German version made of synthetic rubber was said to be promising.

Infinitely variable gearing has been another evergreen in cycle invention, some of the best ideas were tried on motor cycles at the turn of the century. Strutt (1985)[20] has reported that ´intensive´ efforts are being made to develop better bicycle gears - "a long unresolved mechanical engineering problem". Present gear systems had advantages and disadvantages, for example the three speed hub gear had a was long lasting and weather-proof but had too few gears, while derailleur gears were awkward to operate and wore quickly, partly because they were exposed. The "new" inventions were of three kinds, one was a five speed hub gear; two proposed new types were forms of expanding and contracting chainwheels (´a principle tried for decades with little commercial success´), and the third kind was a Lever Drive system with variable stroke length giving it variable gearing, (steam engine valve linkage systems of the nineteenth century developed this branch of kinematics to a fine art). Strutt noted that the adoption of one or any of these new inventions was a critical factor which in turn depended on the kind of cycling the rider wanted and it seemed that present gearing design was quite satisfactory for many riders. Thus the requirement for better gearing also involves a trade-off between technical possibility and user´s desires.

The final illustration of recently proposed bicycle inventions comes from the results of a design competition organised by The Sunday Times and reported in Design[21] The competitors were asked how they saw the bicycle´s future role and how its design would change to fit that role given various categories (such as working bicycles, leisure bicycles and bicycle accessories). The first three prizes were awarded for folding designs of working bicycles the majority of which specified plastic either in total or at least for wheels. Many competitors offered alternatives to chain drives with toothed belts

[20] M. Strutt "Bicycle Makers Peddling Better Gears" Financial Times 1985 Jan 4, p.10

[21] T. Osman and J.Woudhuysen "Are You Ready For The Shaft-Driven Plastic Pushbike"? Design 1979, May (365) pp.44-47.

being a common choice. Imaginative entries were said to be lacking in the Leisure class of bicycle design and no prizes were awarded in this section. Prizes were awarded for Components and Accessories, one idea was a giant clockspring in the rear wheel which was to be wound when braking and supply additional power when re-starting; a common concern was for a seat to carry a child, and the final category was Accessories which produced a crop of 'duplicate' inventions based on the recognition of similar needs and similar solutions. The first Accessory prize was shared by two inventors who proposed drag free magnetic speedometers while the second prize was split among three entrants who proposed independent designs to inform the rider if his rear lamp was lit and the third prize went to an inventor who proposed a reflective safety panel. The major feature of all these responses were that the ideas and inventions were very similar; the previous success of the Small Wheel model led competitors to develop such designs, the existence of new materials to their application to proposed designs while the recognition of bicycle problems led to similar solutions and some old ideas were revamped.
In spite of all these "new" bicycle inventions the mature Modern Safety design still continues to be sold in large numbers and superficially at least strongly resembles a turn of the century model.

Overall Product Improvement

The technical performance of a bicycle is multi-dimensional which makes it difficult to demonstrate the effects of product invention. Two major aspects can be illustrated to indicate the trends of product improvement.
Weight reduction was a primary aim of bicycle designers and Caunter (1955) has given some figures which show how this progressed.

Trend Of Bicycle Weight Reduction

1818	Hobby Horse weighed about	38lb.
1863	Velocipede weighed about	59lb.
1880	Penny Farthing about	50lb.
1884	Racing Penny Farthing	21.5lb.
1888	Facile (ungeared)	32lb.
1885	Modern Safety (Starley's)	37lb.
1890	Modern Safety	18 to 40lb.
1926	Light Roadster	33lb.
1949	Raleigh Superbe	42lb.
1949	Ultra light racer	24lb.

Thus a general downward trend is evident although some later bicycles were quite heavy.

The other main concern was with speed and here too some variablity enters into actual performance as the rider's ability changed, the type of road or track surface had a big effect, so that speeds on level prepared tracks were much higher and even higher still if paced. The following figures are taken mainly from descriptive histories for ordinary road conditions and distances reputed to be over fifty miles.

Trend Of Increased Speeds

Hobby Horse	said to be about 6 m.p.h.
Velocipede	about 7 m.p.h.
Penny Farthing (1873)	about 13 m.p.h.
Modern Safety	about 13 m.p.h.
Modern Safety (1890)	about 14 m.p.h.
Modern Safety (1929)	about 15 m.p.h.

The trend therefore was for a rapid rise once the bicycle began to be substantially improved from 1870 to 1890 and thereafter its speed only marginally improved as far as ordinary riders were concerned.

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4.4 Sub-Units and Components

The preceding section on Overall Configuration has shown that bicycle invention and improvement depended upon component improvements as well as overall configuration changes and, as the invention of the spoked wheel and pneumatic tyre showed, the contribution which component invention made could transform the overall performance.

In this section the concern is with the pattern of component invention and technical development. The term "component" designates parts or sub-assemblies or bicycle mechanisms which had a specific function such as a driving mechanism, or steering mechanism or ball bearing. The analysis will not be as extensive as in the previous section largely because it is not possible to trace the full history of the development of each bicycle component and partly because a full discussion would involve complex technical issues. The aim is to give a broad picture of the temporal course of invention noting the factors which caused the invention and the reasons and forces which affected subsequent improvement and see if the same broad pattern applied as in the Overall Configuration.

The main period of component development was between 1870 and 1900, so that invention at the component level went hand in hand with overall improvements, and like bicycle configurations, bicycle components were largely the results of British inventive effort. Few histories of the bicycle depict the huge variety of mechanisms and components which were tried, and the best illustration of this range is from the various patent sub-classes for specific functions, such as driving mechanisms. This will be sketched in the later section dealing with bicycle patents. Accounts of early cycle component inventions have been given by Phillips (1885) and Starley (1898).

Ideas

Utterback & Abernathy's model tends to play down the role of ideas and and bicycle component design shared the same feature as overall configuration inventions in that no one had a clear idea of what was needed so that many different ideas and designs to achieve the same function were put forward. Another feature which bicycle components shared perhaps to an even greater degree was the technical uncertainty which surrounded the outcome of any invention. This uncertainty can produce two main effects; one is for a prolonged effort by many inventors to try and achieve a desired goal such as an infinitely variable gear mechanism for bicycles, but not succeed and frequent ´re-inventions´ were made of these old ideas, as noted in the previous section.

The other effect of uncertainty is for an unexpected bonus or benefit to arise, which was not anticipated at the outset by the inventor, or for an invention to perform satisfactorily when the inventor did not fully appreciate (or mis-appreciated) the technological principles, as Cardwell (1972) described in his concept of ´precocious´ invention.

Practical Difficulties

Another feature which applied with particular reference to component invention was the need to cater for practical use so that mechanisms had to operate under many different conditions and suit a variety of cyclists ranging from elderly ladies to racing cyclists. Mechanisms also had to be reliable and be easy to maintain.

Bicycle component inventions were mainly guided by specific technical requirements. A component had to perform a specific technical function though very often this had to harmonise with other specific technical functions or trade-off to be generally satisfactory. These compound functions are illustrated by the need for a bicycle frame to be both lightweight and strong. Component inventions had to satisfy other non-technical conditions such as economic ones, so that the final form of component was the result of the influence of many factors. This partly explains why such a diversity of designs were produced and why this aspect of bicycle invention needed some time for experimental designs to reach full development.

The two sub-units chosen for analysis here are the Tension Spoked Wheel and Ball Bearings. Both made considerable improvements to bicycle performance when introduced and both stemmed from much earlier ideas often involving a combination of principles and having a course of technical development which was anything but linear and logical.

4.4.1 Suspension Wheel

Early Rigid Wheel

Grew (1921) has described how the first cycle wheels were wooden cart types whose design and method of manufacture was transferred from cart technology. These were fitted to the Hobby Horse and early Velocipedes and were too heavy and liable to disintegrate. The first improvement was to make the entire wheel from iron so that it was much stronger. This was done in the mid-1860s but another much more radical design was being considered and this emerged in the form of the suspension wheel in 1868. The bicycle wheel transmitted a great deal of vibration from the road surface and the earliest inventions to reduce this consisted of fitting a solid rubber tyre or using similar material. A bolder idea was to create a wheel which would deflect - the suspension wheel.

Idea of a Suspension Wheel

The basic concept of a suspension wheel was of a ´rotating shock absorber´. This was to be achieved by an ingenious design, instead of the axle load being transmitted vertically downwards through the rigid spokes (as was the case with cart wheels), the lower spokes of the suspension wheel were to buckle or deflect thus ensuring that the axle load was carried by the upper spokes. Such a design would theoretically allow the lower rim to deflect and absorb the road shocks. Woodforde (1977) noted that this idea had been patented by Bauer in 1802. In 1826 Theodore Jones had also taken out a patent for a similar design. In 1868 Cowper obtained a patent for a design of suspension wheel with wire spokes, intended so Starley (1898) said for bicycles. Between 1868 and 1874 the suspension wheel underwent rapid development emerging then in its mature form. This development was accompanied by much discussion about the merits and demerits of various designs, much of this took place in the pages of the English Mechanic.

In 1869 the English Mechanic published one of the many letters written by "The Harmonious Blacksmith", though the issue of May 28 (p.223-4) gave an interesting account of the history and objectives of the suspension wheel. He had observed that some ´manumotive´ and ´pedomotive´ carriages were used in London about 1850 and he continued "There was nothing remarkable about these machines excepting their wheels --- Instead of wooden spokes, chains capable of being tightened by screws were employed to suspend the naves (hubs) from the rims just as rods suspend the naves in Theodore Jones's patent wheels so common in London, only that the chain suspenders being very elastic, acted as most efficient springs, and insulated the carriages remarkably well". "The Harmonious Blacksmith" then described a wheel design he had produced for a Velocipede some years ago which had rubber buffers at the end of the spokes. "The Harmonious Blacksmith" had written this letter to give his reasons for his preference for wire spokes rather than the thicker rods used on the Phantom wheel. He claimed that the Phantom rods were too thick to buckle and he considered that the Spider design of 1868, with its wire spokes, was better.

Another description of the design objective of a suspension wheel came from Mays (of Renolds & Mays "Phantom" Velocipede) given in the English Mechanic (1870, May 6, p.163) who said that it was to lessen the degree of traction required on ordinary roads by keeping the axle or load as level as possible with the line of the road. The main feature of this wheel design was to ensure that the strain was as evenly distributed as possible over its circumference, and the wheel strong but sufficiently elastic to give when it encountered road surface irregularities but to be perfectly circular when the road was smooth. He then gave some constructional details of the "Phantom" suspension wheel.

It became apparent that the earliest radial type of spoked wheel had a shortcoming, namely that a driving (or braking) torque caused the rim to move relative to the axle. In a later letter to the English Mechanic (1870, Sept 16, p.616) "The Harmonious Blacksmith" gave further criticisms of the current design of suspension wheels claiming that these were not good driving wheels as the driving torque would tend to rotate the hub relative to the rim. He also gave a description of his solution. "The spokes were about seven inches asunder, in the direction of the axle, where they rested in the naves, and they could be brought closer together by screw bolts acting on two wrought iron plates which covered the ends of the mortices in which the spokes were received, thereby providing for any shortening which might occur from long use, and making all tight again if needed".

These ideas were taken up by others. "C.H.M." later wrote a letter to the English Mechanic (1871 July 14, p.412) giving an illustration and description of a bicycle suspension wheel built on the principle suggested by "The Harmonious Blacksmith" "a month or two previously".[22] but the critical feature of "C.H.M's" illustration is that it shows a wheel with alternating radial and tangential spokes. It also had provision for tightening each spoke by means of nuts embedded in the wheel rim. This paved the way for a wholly tangential spoke arrangement, although radial spoke arrangements were used on non-driving wheels for many years.

These descriptions show that inventors of this period had a clear idea of the design and the objectives for the suspension wheel, an example of 'projective' invention in which the idea or principle is is clearly envisaged before it is made.

Tensioning The Spokes

Another old idea was woven into the cycle wheel designs; the origin of this is obscure. Rolt (1977, originally 1970) said that Sir George Cayley had designed the first tensioned spoked wheel in 1808 for use on his aircraft undercarriage. This idea was applied to other products, Cardwell (1972) noted "The use of light iron spokes in tension (his italics) coupled with the technique of taking the drive (of the water wheel), not from the axle but from the rim of the wheel enabled a much lighter and more efficient structure to be built". In these early designs the spokes were tensioned by a lever and called lever tension wheels.

This wider use was reflected in a letter to the English Mechanic (1871, Nov 24, p.251) written by "Philom" concerning the new Ariel lever tension wheel. Philom described the principle of the lever tension wheel and said that the patentees contemplated applying the principle not only to wheels of every description for road traffic but also for large fly wheels and driving pulleys, and for paddle-wheels of steamers, for which lightness, strength and firm construction would befit it. "With such qualifications combined with

[22] This writer cannot trace any letter by "The Harmonious Blacksmith" on the topic of suspension wheels published between Sept 16th 1870 and July 14 1871 in the English Mechanic.

simplicity of construction and low cost, it is undoubtedly the wheel of the future". It wasn't and "The Harmonious Blacksmith" soon voiced his dissent; however the intention of the patentees to include these wider uses for lever tensioning suggests that such applications had been common in the past.[23]
The Ariel lever tension system rotated the hub relative to the rim, and as "The Harmonious Blacksmith" pointed out, this was no good if individual spoke lengths varied as each spoke would then be at different tension, and his solution (described above) was for individual adjustment as well as the tangential arrangement.

Starley (1898) has described how his uncle (J.Starley) developed the pre-tensioned tangential spoked wheel in 1874. This had begun with Cowper's 1868 wire-spoked Spider design with the later ideas of tensioning and tangential spokes. By 1874 the new type of bicycle wheel was very light, very strong and completely satisfactory.
Its basic design remains the same today. Further improvements were made using steel when that became plentiful and cheap, and the 'hollow tube' principle was applied to the construction of the rims. Other ideas were also tried, Phillips (1885) described how spokes which were crimped or corrugated over their entire length were tried in an attempt to make the wheel more elastic, and how this had apparently been successful.

The curious aspect of suspension wheel design was that the suspension function really evaporated and that the 1874 outcome was a rigid form of bicycle wheel which was very light and very strong. The original ideas anticipated a considerable deflection of the wheel rim, but in practice this was minimal.[24]

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23 Patent claims were made as wide as possible at this time, and it was common for patentees to specify many uses for their new invention. Often these "new" uses were old ones, hence the inference that lever tension wheels had been used in driving pulleys, water wheels etc.

24 The suspension wheel design was used in early motor cars and motor cycles, by the mid-1930s most motor cars had adopted the rigid steel wheel, relying on the pneumatic tyre to absorb the low amplitude vibration and the car's suspension system to absorb the large amplitude vibrations. Then motor cycle designers followed the car designs. This trend finally diffused into bicycles with single piece wheels being adopted for "fun" bikes and plastic bicycles only in the last few years. The suspension wheel is still fitted to many modern bicycles though if single piece wheels can be produced more cheaply, they may soon be displaced.

The technical development of the bicycle wheel depended upon the fusion of two distinct principles, namely the idea of the suspension wheel and also the tension-spoked wheel. The main factor behind both these developments was the idea and progress was due to technology push in the form of much discussion and experimenting. Technology transfer was also involved as was the discovery of new or unanticipated technical problems. The effect of the final form of bicycle wheel was to permit any size of wheel to be made. This, in turn, permitted a great increase in mechanical advantage which accelerated the change from the Velocipede to the Penny Farthing model.

4.4.2 Ball Bearings

Friction losses had been recognised as wasteful long before bicycles were built. Landes (1969) noted that engineers dealing with mill machinery and power transmission had devised methods of reducing friction. These essentially employed suitable metal bushings with oil or other lubricants. The first design of journal bearings on bicycles used this technique, and as Pickering's improvements showed, these were updated. Landes noted that new mineral oils were introduced in the 1850s.

The first use of ball bearings in bicycles is not clearly documented. Popular bicycle histories say that Hughes (or Bown) introduced the ball bearing in 1877 and this is only partly true.

Linley (1925) has given a clear summary of the actual course of events, which when supplemented by information from Starley (1898) clarifies the course of improvement. It has already been noted that Pickering's Velocipede had improved gun metal bearings in place of the plain journal bearings used until that time. The writer of the article in Leisure Hour (1886) said that many attempts had been made to reduce friction but these had only been partially successful until the "ball bearing invention of recent years" to which cyclists owed the biggest debt.

The "principle of spherical bearings" (as Landes phrased it), was as old as history. Cellini had demonstrated the advantages when using balls (globes) which proved that rolling friction losses were less than sliding friction. This principle could not be put into practice until hard, smooth and accurate balls could be made, and this did not take place until steel and some method of making precision balls and grooves developed.

The first ball bearings used on Penny Farthings came into use in the early 1870s. These were not proper ball bearings in the modern sense. They were an early form in which balls were seated in a groove in the front axle, and the balls were retained by an outer casing. This design was liable to result in a non-circular casing as the faces of each half were ground to effect adjustment. Starley (1898) has described how his uncle improved this early type by a single casing (instead of the previous two halves) and used a transverse key to accurately locate the whole bearing. He noted that there were many other ingenious equivalent improvements at this time, 1876, which achieved the same end.

Ball Bearing Proper

Linley (1925) has given an account of the development of the ball bearing proper. Bown was a manufacturer of balls for the early type of ball bearing used on bicycles (described above). His foreman Hughes thought of applying a known principle (the stuffing box principle) which located balls by means of conical ends which were adjustable. It was the lateral adjustability which was the feature of Hughes patent, and even this, Linley noted, was not original as Chinnock had earlier secured a patent for much the same thing. Starley also stressed the adjustability of the ball bearing as its essential feature and not the reduced friction or low wear which was a feature of bicycle ball bearings. Bown initiated manufacture of the new design of ball bearing though Starley said that its adoption was slow. Linley considered that this was partly due to the high royalties Bown charged. However with the development of the Modern Safety design, lateral adjustability was essential and Bown had more orders than he could fulfil, with the result that others attempted to design equivalent bearings or else infringed Hughes's patent. Linley observed that Hughes's patent was not for a new idea but only a new application of a known principle.

Ball bearings continued to be improved largely because of more precise methods of machining and better materials. These subsequent improvements were marginal. The use of ball bearings reduced friction considerably and a writer in Leisure Hour (anon, 1886) considered that cyclists of that time owed the biggest debt to friction reducing bearings as it meant that only a slight muscular effort was needed to maintain a good speed. The reason for the noticeable reduction in effort was that human power output was very low so that a considerable friction loss would make a big difference in loss of speed and extra effort needed.

Attempts to measure the human power required to propel a bicycle were begun quite early; Phillips (1885) reported the findings of one which showed that to propel a Penny Farthing at speeds of six to fourteen m.p.h required one seventh to one third of a horsepower. Modern research findings on the power needed to propel a bicycle are much more precise and details of this aspect can be obtained from Whitt and Wilson (1974).

Ball Bearing Application To Bicycles

Their application to various bicycle components was not direct as Starley (1898) stated that at first they were used only in the front axle of the Penny Farthing driving wheel, then later progressively applied to the back wheel, the pedals and the steering head. The writer of the article in Leisure Hour (1886) said that ball bearings were applied first where friction was greatest. Ball bearings were rapidly used in many other engineering fields illustrating a transfer of technology from the bicycle industry.

Summing Up

This description of invention of the Tension Spoked Wheel and Ball Bearings is only a fraction of the inventive effort at this level and could easily be expanded to cover frame design, driving mechanisms, pneumatic tyres, chain design and so on. However the two examples chosen show clearly how complex each development was and how the original ideas had long preceded the bicycle industry. The prime factor of progress was technology push and in both examples resulted in a very successful final design although a full account of bicycle inventions at this level should ideally include the many which were unsuccessful.

4.5 Consumer Influence Upon Product Design

It was noted in the literature review that Mowery and Rosenberg (1979) had criticised ´demand pull´ innovation models because they claimed that little evidence had been given to show that consumers had exerted a decisive influence upon innovation and that the consumer-invention link was even more obscure.

The history of bicycle product invention certainly lends support to the idea the consumers exerted only a minor influence upon bicycle invention and design. For example the 1869 advertisement for new varieties of Velocipede appeared to originate from the manufacturer while The Cycle Trades Patent Journal noted that until the 1880s ´manufacturers had dictated to the public´ and that they (or inventors) had largely been responsible for the profusion of new models at Cycle Shows. It is only in relatively recent years that market research has been taken seriously and while the consumer-inventor link may have been weak in the nineteenth century it does not mean that consumers exerted no influence at all. Consumer purchases of new models or variants or accessories in fact reinforced the feedback to the manufacturer and they acted as a filter in selecting from an over-supply of these models or devices. This aspect of course does not indicate a direct association between the consumer and the inventor or designer. However a few instances have been recorded and are noted here.

Consumers´ Desire For Good Performance

One of the earliest trends in bicycle invention was to reduce the main problems which cyclists found when riding their machines. The inventions to reduce weight, friction and road shocks sprang as much from consumers´ needs as from inventors.

Many theories of demand or accounts of consumer preferences imply that purchasers are a homogeneous group. The history of bicycle invention shows that this was not the case and that some sought machines with different characteristics. From the 1870s a clear distinction can be drawn between young cyclists who wished bicycles to be as fast as possible even if unsafe, while on the other hand a sizeable group were prepared to sacrifice speed for increased safety and the development of the Early Safety, Tricycle and Di-cycle indicate the effect upon product design. Racing bicycles were deliberately designed to squeeze the 'last ounce' of performance from the rider and did so by minimising the weight, friction, wind resistance and other impediments to speed at a technical cost of reduced durability, safety and comfort while touring bicycles and tricycles were designed in the opposite direction.

Yet this distinction between those who took a rather utilitarian view of a bicycle as a basic means of transport and those who were aware of the latest improvements has always been a feature of the bicycle market. Engineering (anon, 1939) illustrated this with reference to those who bought bicycles as a convenient form of transport and who would find that such purchases lasted a lifetime; while about ten per cent of all new purchasers of bicycles "are much more sensitive to changes in design and who may be expected to replace their machines more frequently"- about once every five years. This latter group of enthusiasts were sensitive to product attractiveness.

However the utilitarian bicycle purchasers were again not a homogeneous group as the differing trends of sales for low and quality bicycles showed in times of economic depression. It was noted above that in the early 1900s and again in the late 1930s sales of quality bicycles fell less rapidly than cheaper models in periods of economic depression.

In the foregoing accounts of invention it has been suggested that technological push factors were the primary determinant of improvements though equally the original stimulus may have come from the consumers themselves. Thus the change to variable gears (especially three speed hubs), free wheels and other devices which made cycling easier, or made maintenance simpler (as the repairable tyre inventions and patents illustrated) could have been prompted by consumer influence. No evidence can be given to support either view.

Social Factors and Bicycle Invention

There is evidence to show that social factors had a direct bearing upon some bicycle invention. The Sociable and Tandem configurations were developed because people liked to cycle in the company of others. During the 1890s a craze for multi-rider bicycles arose for say up to six riders on one machine, this like the lady's model again sprang from social forces.

Though it cannot be shown that the earliest booms of 1818/19 and 1868/69 were due to social factors alone, there can be no doubt that novelty was a powerful factor in consumer behaviour at that time. If the new "principle" of cycling was initially directed to land transport, why not extend the "principle" to water and air? The idea of ariel and water bicycles may have represented consumer desires as much as inventive imagination.

The influence of social characteristics upon the invention of accessories has been noted in the car and motor cycle industries. Grew (1921) pointed out that the function of bicycle accessories was to express ´individuality´ and make machines distinctive. White (1971) noted the U.S. automobile purchasers rarely bought the cheapest basic model but were prepared to pay a little more for extras which expressed this ´individuality´ or status symbol. Bicycle accessories then were invented not only for the added convenience they gave but also to impart some distinctiveness upon standardised bicycles. Manufacturers added to this by producing minor variations of a basic model and supplying these in different colours.

It does appear that consumers exert two distinct types of force upon product design; one is linked to economic factors, the other is social in nature. The economic aspect of product design is manifest in the Price-Performance-Quality dimensions and was the principal reason for manufacturers producing such a range of models from de luxe to racing machines where technical performance was the key element without regard to cost, or to cheap but good quality bicycles which generally used the simplest and cheapest form of construction and low cost materials.

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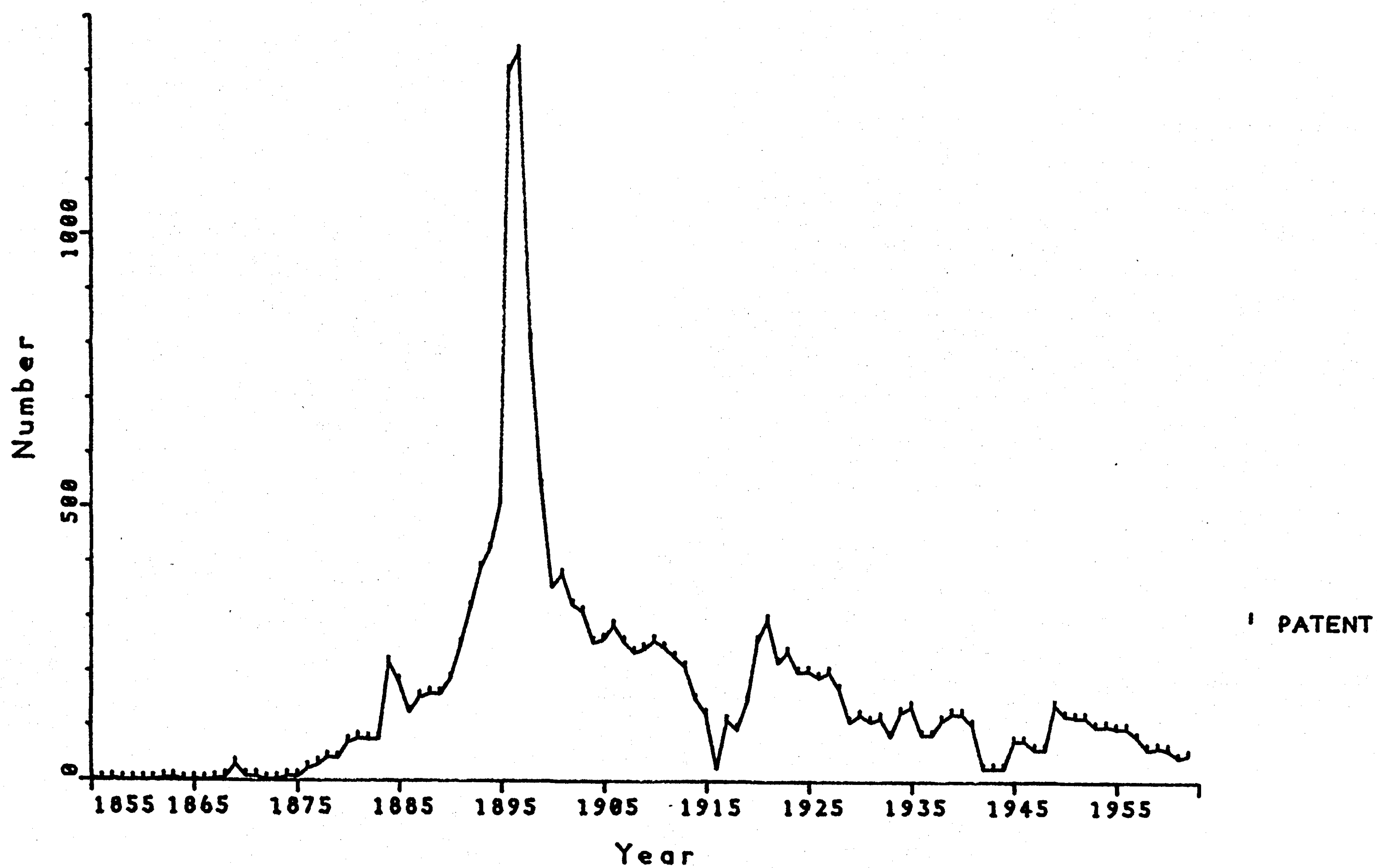
4.6 Bicycle Patents

A number of criticisms have been levelled at patents as a measure of inventive activity, as noted in the literature review. However patents are a valuable source of information about invention and in this section two aspects will be discussed; one is the temporal pattern of inventive activity, the other is the subject matter of cycle patents.

Temporal Pattern of Inventive Activity

The British Patent Class for cycle inventions was entitled "Velocipedes" Class 136. From 1855 to 1909 this patent class was undivided. From 1909 to 1930 Class 136 was subdivided as follows, Class 136(i) was for Brakes, Steering Mechanisms and Miscellaneous Accessories but excluded bags, bells, boxes, speed indicators, reflectors, and means of repairing punctures. Class 136(ii) was for Driving Mechanisms, and Class(iii) was for Kinds, Types and Structural Forms of cycles but excluded inventions such as enamelling or electro-plating these.(This sub-class included motor cycle frames and these rather than bicycle frame inventions swelled the figures from about 1910).
From 1931 to 1963 Cycle patents were reclassified from Class 136 to Class XXXl which also contained vehicle inventions (especially motor cars) but cycle patent sub-classification continued in its old form so that annual data was obtained consonant with Class 136 patent office publications, these data are tabulated in chapter eight.

These annual data give a reasonable index of inventive activity for the bicycle. One further point is noted (British) patents granted for a particular class (such as bicycles) include some foreign inventions and the number of these foreign patents cannot be assessed.
In spite of these limitations the analysis of patents is useful and in this section bicycle patent abridgements can show how the intensity of invention varied over the life of the industry, and the main factors which may have been associated with unusual increases or decreases in the rate of patenting. Graph 4.1 shows the annual number of cycle patents granted (up to 1904, thereafter the annual number of abridgements) for Velocipedes/Cycles.



PATENT ABRIDGEMENTS/GRANTED FOR VELOCIPEDES/CYCLES
CLASS 136/71: 1855-1963
Graph 4.1

Main Features Of Cycle Patents

Year(s)	Main Features
1855 - 1868	Low activity, never greater then 5 p.a.
1869	Marked peak (28); utility perceived, industry begun.
1870 - 1875	Low activity, never greater than 7 p.a.
1876 - 1883	Rapid increase, (21 to 75), sales increased
1884	New Patent Regulations caused increased numbers.
1885 - 1895	Rapid increase, (181 to 508 p.a.)
1896 - 1897	Boom in cycle patents (1300+ p.a.), sales boom.
1898 - 1899	Decreasing to more normal levels (811, and 542).
1900 - 1913	Declining trend, from 354 to 204 p.a.
1914 - 1920	War; low levels
1921 - 1925	Lower than pre-war;
1926 - 1930	Still declining;
1931 - 1938	Zero trend, fluctuating
1938 - 1946	War, low levels;
1947 - 1961	Sharp decline
1962 - 1963	Very low; less than 30 p.a.

The broad pattern is of a skewed curve with a sporadic start which rose rapidly once the industry began, rising to a peak quite early in the life of the industry then gradually declining.
This pattern for patenting rates for new consumer products had been observed by Merton (1935) and others noted in the literature review. The bicycle patenting pattern seen here is the same and indicates that inventive activity falls off as the industry ages and technical potential is exhausted.

The previous descriptions of actual product improvement in bicycle design make it possible to roughly compare the course of technical development with that of patent rates. From the descriptive histories it is known that by 1895-1900 the fundamental design of bicycle was fully established and that only marginal improvements were made after then. Some patents appear to have lagged behind technical development with little effect upon product improvement. This lag can partly be explained by the inventions created to by-pass master patents, or for secondary invention or for continuing inventive effort. The long run overall pattern of patenting activity does suggest that product improvement is roughly proportional to the patenting rate in the early years say up to 1900. This indicates that technical progress and invention are most intense and have their greatest effect in the early commercial stages of any industry and that in later stages only a decreasing return is obtained, or perhaps the limits of practical development are reached. One rough index of increased technical performance would be racing speeds, although this would also be affected by other factors. The 'average' speed of a Velocipede was about 6 m.p.h. while and 'ordinary' Modern Safety of 1900 could attain an 'average' speed of twice that.

The exceptional peak in patenting during the boom years 1896 and 1897 was limited to cycle patents only and coincided with the bicycle boom. This suggests that the promise of reward indeed promoted 'invention' although the technical history does not indicate any significant technical advance at this time so that probably these patents were intended to be used for other purposes, especially as an aid to company promotion or market defence mechanisms.

At the same time it was noted in the descriptive histories and in modern theories of innovation that some invention is defensive. This prompted inspection of patent data to ascertain whether any apparent increase in rates applies in times of declining bicycle sales as in the period 1900 to 1914 or again in from the 1950s to the 1960s but the rates indicate that this was not the case. Patenting activity does not reflect defensive invention.

Subject Matter of Cycle Patents

In this section an illustration is given of the enormous variety of bicycle inventions made for both Sub-Units and types of bicycles by reference to the patent sub-class descriptions.

Class 136(1) contains inventions for Brakes, and these are classified in terms of their mode of operation by hand, foot or hand and foot combined. The methods of operating these include by rod, by cable, by eccentric, by fluid pressure or by back-pedalling. This class also contains inventions for Accessories with sub-classes for windshields, awnings, hoods, capes; chain-protectors, gear cases, locks to prevent theft, props and supports for bicycles. Sails and kindred means for propelling bicycles, side-cars etc.

Class 136(2) contains inventions for Driving Mechanisms, and these are classified into Axles, Differential Gears, Hand, Foot and Combined Hand and Foot operated propulsion systems. Flywheels, Oscillating levers, Reciprocating chains and/or cords, Rotary Cranks. Gears: Free Wheel (from 1869), Sun & Planet gears, Variable Speed gears, Worm, Bevel. Chains, Belts, Ropes, Elliptical gears and drives. Fluid Pressure Transmission systems, Rack & Pinion gearing Treadle Mechanisms, Means for facilitating detachment of wheels and tyres.

Class 136(3) contains patents for Types, Kinds and Structural Details.

Only a few of the various types will be quoted here, the date in parenthesis being the date of the first patent application for such a type, although the descriptive histories given above show that Water bicycles (for example) were thought about in the 1820s and not 1867 as indicated here.

Year	Type
1877	Acrobatic & Gymnastic
1894	Ambulance
1869	Carrier cycles
1878	Folding & Collapsible
1862	Childrens'
1862	Railway
1876	Sledge
1863	Sociables
1869	Tandems & types to carry riders in file
1880	Unicycles
1867	Water Bicycles

This class also contains inventions for sprung frames etc., and from 1900 most of the patent applications in this group were for motor cycle frames.

An additional feature, brought to light in the course of inspection of bicycle patents was that these were mainly product inventions as inventions for manufacturing bicycles (and some bicycle components) fall into different patent classes.

This examination of bicycle patent data has revealed a characteristic life cycle pattern seen by others in other industries. It appears that up to the year 1900 or so there was a degree of association between patenting (inventive activity) and improvement in bicycle performance but after this time that degree of association weakened. However during the 1896/7 boom, when an intense burst of cycle patenting occurred, there was no corresponding advance in design as these boom patents were used by company promoters for financial ends. Cycle patent data give little evidence to show that invention was stimulated during periods of depressed trade in the cycle industry. One reason for the intense patenting between 1870 and 1900 was the exploration by inventors of every conceivable technical possibility or method of achieving a desired design and this was shown by the profuse inventions in various cycle patent sub-classes. They also revealed that much cycle invention was directed towards sub-mechanisms, components and accessories and that ´one idea often led to another´ - in other words that invention sequences were common until the ´fittest´ design was produced.

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4.7 Process Inventions And Improvements

This section deals with manufacturing inventions and process improvements in the bicycle industry. The level of analysis will follow model given by Utterback and Abernathy who considered that process invention was relatively slow in the early commercial years of any new industry, but that in their middle stage it reached a maximum rate because of the transition to mechanised production methods due to increasing volumes and stimulated by competitive pressures. In the late stage process invention reduced in intensity and became incremental in character combining with incremental product inventions and other non-technological changes.

Some features of Utterback & Abernathy's model will have no application to an old industry, for example automation was not developed at the turn of the century, but apart from such anachronisms it can be assessed whether or not the pattern of process improvement broadly followed their model.

Hobby Horse Era 1791-1860

The basic manufacturing techniques were transferred from general engineering practice as Grew (1921) noted with reference to wheels being supplied to cycle makers by hand cart manufacturers. As other cart technologies, such as their kind of brake were initially transferred from this industry, it is reasonable to assume that other aspects of manufacturing were also transferred. There is no indication of any process changes for this era.

Velocipede Era 1861-1869

The supply of Velocipedes up to 1868 appears to have been largely satisfied by imports. The few which were made would use existing technology and materials for the various iron and wooden components, so that process technology was transferred from existing practice.

Later Velocipede production techniques would require some specific developments to make the elementary suspension wheels, spring strips for saddles etc, and its is known that the first British bicycle factories employed men and techniques borrowed from other industries, in Coventry this began with sewing machine knowledge and general engineering.

The earliest manufacturing changes came from America, as Pickering's model illustrated. The use of the "American system" of manufacture with

interchangeable parts 'made by gauge' (noted in the English Mechanic 1868, p.362-3) was the use of interchangeable parts implies a high degree of precision as well as the existence of suitable machinery. This American development was not an isolated case as Burn (1931) has shown when he described the genesis of American production technology. Pickering had also used hollow tubes for his model which meant that he must have used techniques developed for the manufacture of gas and water pipes common at that time.
This American supremacy in production is noteworthy as it was to be further developed in 1890 as will be shown below.

Penny Farthing Era 1870-1885

By 1870 some specific British bicycle manufacturing techniques were beginning to be developed, for example the use of hollow tubes and wire spoked wheels. Here again the initial techniques would be transferred from other industries, Britain was able to manufacture wire ropes and wires for the electric telegraph and other purposes as indicated in Trade & Navigation Accounts which classified such exported articles at that time, while hollow tubing had been made by forming and brazing as with gas pipes.
The first major impetus to bicycle process invention came from the specialised bicycle component manufacturers. Grew (1921) noted that this sector of the British bicycle industry began in Birmingham because of the existence of skills and techniques in associated industries. The invention of ball bearings and bicycle chains required special machines and/or processes to manufacture them. The rise of such specialist suppliers changed the structure of the British bicycle industry as they supplied general bicycle manufacturers who fitted these components to their bicycle frames. Bown was one example of a specialised component manufacturer in this period who supplied balls for ball bearings. Other bicycle component suppliers, such as chain makers would be developing their own machinery and methods too.

Utterback & Abernathy considered that in the first commercial years of any new industry manufacturers used highly skilled labour, general purpose machinery and common materials, and that the efficiency of such production arrangements were low. This can be illustrated by reference to a description of two Coventry bicycle factories given in Leisure Hour (anon, 1886). These factories produced a variety of both tricycles and (Penny Farthing) bicycles, the former apparently being an important proportion of the total output. The description given of this 1886 British bicycle factory described how manufacturing operations began with the manufacture of bicycle components which were made using steel dies, some parts were formed by hot stamping. Spoked wheels were assembled using highly skilled labour and this task required much time to assemble and adjust these large wheels. The adjustment of the differential gear (for tricycles) was also said to be a lengthy process. Some parts of the cycles were nickel plated and others were enamelled both being highly skilled operations. The industry produced a highly diversified range of products which was indicated with reference to the 1886 Stanley Cycle show in which 100 exhibiters had displayed over 450 different models, and this indicates great model diversity.

Modern Safety Era 1885-1897

The key factor which influenced process improvements in bicycle production was extremely high demand which arose in the bicycle boom in the years 1896 and 1897

This boom had two main immediate effects. The first was for the price of bicycle to rise enormously, Duncan (1898) claimed that this rose from an average of sixteen pounds to twenty eight pounds. The direct consequence of this was large profits which in turn precipitated a flurry of new bicycle companies floated by company promoters who purchased small bicycle concerns and from them created large bicycle factories which used mechanised methods of production.

Sources of Process Inventions Used In Britain

The new machinery to make bicycles at this time, came mainly from America. Waldo (1897) described how this was developed using a "scientific" approach. The most suitable material for the construction of bicycles was determined by tests and high tensile steel was chosen. This approach also determined the method of assembly of the bicycle; fabrication using nuts and bolts was rejected because of the effect that racking of the frame would have upon the threads of these nuts and bolts, so the joints were brazed. The frames and completed bicycles were tested once built. This use of tests and experiments extended even to establishing the forces required for varying loads and speeds on the bicycle. This testing and experimenting illustrates the systematic nature of much "empirical" bicycle invention. Waldo also noted that working conditions in American factories were the best possible with up to date equipment and welfare provisions for all employees. Above all the American bicycle industry was quick to adopt machinery for production processes while England did not, Waldo said.

An article on "Cycling" in the tenth edition of Encyclopeadia Britannica noted that the Americans used dropped forgings and 'perfect' automatic machinery with interchangeable parts but that their dominance of the world bicycle trade ended because their (product) design of bicycle was not to European (and British) tastes although it was cheap.

Rosenberg (1963) in his description of the American Machine Tool industry 1840 - 1910 noted that the need for lightweight bicycle parts had led to new production techniques and new machine tools. Many bicycle components required high precision machining and hardening especially chainwheels and chains, and new machines were developed for these purposes.

Josephson (1900) said that the Americans led in the development of bicycle production technology in the years 1890 -1900 through American ingenuity, the use of automatic machinery and tools which led to a great reduction in the costs and "placed the bicycle within the reach of all classes". Process invention was therefore intended to reduce bicycle prices.

Floud (1976) in his history of the British machine tool industry 1850 to 1914, has shown how American process inventions spread to Britain in two ways. The first was by direct imports of American machine tools. This had begun slowly in the 1860s then with the bicycle boom of 1896/7, imports soared. A further complication in the midst of this boom was an engineering strike which caused British bicycle manufacturers to greatly increase their imports and learn of the great savings which could be made regardless of wage rates. The second way American technology spread to Britain was by leading machine tool manufacturers adopting American ideas. Floud described how the British machine makers Alfred Herbert, had begun in a small way to manufacture a variety of machines for the bicycle industry, including specialised turning, boring, drilling and tapping machines as well as more specialised ones such as hub tapping and lapping machines, and rim drilling machines. Another British company, Churchill, did the same thing. Floud said that Britain had initially been the leading machine tool country in the world but from the late 1860s both America and Germany had caught up. The trend of machine tool development had been for increasing specialisation and this was where Americans had advanced. Floud quoted part of a lecture given by a Mr Webb in 1898 who said that the bulk of the tools in the cycle trade had come from America. (p 72). He also quoted the comments of the editor of the American Machinist who said that the end of the 1897 engineering strike in Britain had led to new patterns of work which were free from the previous practices which had restricted output.

Caunter (1955) said that the pursuit of quality in the 1890s had affected production techniques and gave references to articles in the Cycle Manufacturer 1895 to 1898 for this.

Effects Of Mechanised Production

Grew (1921) has given a full account of the change from hand production to mechanised production in the bicycle industry. He noted that this transition depended upon a fixed product design. Reduced units cost were due to both a much reduced labour content but increased fixed costs, and that as high quantities spread these fixed costs the result was cheaper bicycles. The main technical change was the introduction of pressings which required a series of expensive dies. In some cases the re-design of bicycle components to suit mechanised production led not only to a cheaper part but also to a lighter and stronger bicycle, pressed lugs came into this category.

Process Invention in Depression

The bicycle boom ended in 1897, because the cycling craze died out. The immediate effect upon the bicycle industry was that demand declined, prices and profits were reduced. Harrison (1969) found that by 1901 the average price of a good (British) bicycle was about ten pounds and Grew (1921) said that by 1914 a first class bicycle could be bought for eight guineas. Pratt

(1904) in describing the "new" trade of bicycle accessory manufacturing noted that in 1901 the profits in this trade were so small that manufacturers were forced to use automatic machinery "similar to that employed in United States", and that this change was accelerated by the restrictive tactics of trade unions who desired the old fashioned rules and demands that were quite out of date. Harrison (1969) said that reductions in bicycle prices were not solely due to process improvements although these had had a pronounced effect during the 1890s and 1900s; for example the adoption of liquid brazing, steel pressing techniques, the use of automatic production machinery including some imported from America and further improved in Britain, all made a contribution to lower bicycle prices. Above all Harrison stressed the quality-price decisions made by British cyclemakers; there had been a considerable reluctance on the part of all to aim to produce a cheaper bicycle because all tended to stress ´quality´ and high prices were associated with high quality. In one way this stance had created long run growth as cheap imports during the 1896/7 boom had been of badly designed types of bicycles (mainly American) which had not satisfied the public and this virtually eliminated the threat of foreign competition from about 1900 and later was responsible for the leadership in world trade as other countries appreciated high quality British bicycles. Even within Britain the product range widened to provide luxury models (such as the Golden Sunbeam) and also cheaper utility models. Low prices induced cost reducing measures which included both process inventions and other non-technological changes in production.

This pattern was partially repeated during the 1920s and 1930s when the threat of cheap imports appeared again. Low cost Japanese bicycles appeared in the early 1930s but they were of such a poor design and quality that they soon acquired a bad reputation and consequently few were sold as The Economist reported.[25]

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[25] The Economist 1935, (pp.1059-1060) noted that British bicycle prices had fallen differentially from 1929; the most expensive kinds had only been reduced from 11 to 10 gns., the ´second´ grade types fell from just under eight pounds to six pounds ten shillings but the cheapest models had fallen most from five guineas to just under four pounds and these proved to be the most popular. In addition the increased demand for the cheapest models had "most favourably affected costs of production" (due to economies of scale) so that the trend became a reinforcing one.

Non-technological Process Improvements

Changes to bicycle manufacturing methods were accompanied by similar improvements in non-technological spheres. Grew (1921) said that in 1890 no female labour was employed in the British bicycle industry but by 1921 this formed a large proportion of the total employees. P.E.P (1949) considered that the seasonal nature of bicycle sales had been one factor which accounted for the employment of women in the bicycle industry.

Standardisation began in the depressed years at the turn of the century. Grew (1921) noted that this was greeted with reluctance at first, because one manufacturer did not see why he should design products which might be supplied by another. Caunter (1955) said that standardisation had begun in 1897 by the standardisation of chains and chainwheels and, from 1901 with the standardisation of cycle threads. Caunter also noted the various other non-technological changes which contributed to reduced production costs; these included the abandonment of excessive inspection, shift working, the use of more unskilled labour to operate the automatic machinery, piece work payments and these, together with falling prices of bicycle components led to lower bicycle prices. Standardisation had permitted local cycle builders to produce bicycles at as low or lower costs than factory ones. This trend to standardisation continued; Watling (1949) said it had reached a very high degree by 1946 and had been attained without loss of individuality for cycle manufacturers as the industry had a committee for standardisation. A writer in Chambers Journal (anon,1906) said that the profits were very low in the Coventry bicycle industry at that time, and that bicycle prices were very low too. this had led to "kaleidoscopic" business methods in the trade and gave an instance of an advertisement for a bicycle in which the prospective buyer was offered very low cost credit terms. The use of instalment plans for bicycle purchase had begun in the 1890s according to Rubenstein (1977).

The transition to mechanised bicycle production also required radical organisational changes with particular emphasis on co-ordinating the various production activities with respect to policy. In the new bicycle factories every activity was undertaken with design being done in the drawing office and applied not only to the products and processes but also to the tooling used. These activities could only be economically justified when high volumes were being produced, Grew observed.

Another non-technological development occurred in marketing methods and Grew pointed out that by 1921 the British bicycle industry was divided into two, one part was "public" in which bicycle firms made and sold their products to the public directly, the other was "private" and in this part a bicycle manufacturer made bicycles which were sold under the retailers name, this arrangement was based on very low priced bicycles using manufacturing methods which employed few and paid low wages.

Increased Production Capacity

The pattern of growth of British bicycle production capacity accorded with Utterback and Abernathy's model in which new small firms dominated at the start. The British bicycle industry followed this pattern until 1896 after which the number of firms declined though individual firms then expanded in size.

Phillips (1885) believed that 40,000 bicycles were produced in 1884, estimates of 750,000 to 800,000 have been given for 1896. The only other returns prior to 1920 are for the census years 1907 and 1912 (the latter published in 1924). Prest (1954) has estimated the quantities of bicycles sold in the period 1900 to 1919 although he stressed that these estimates were subject to a large margin of error. All these figures indicate that homesales of bicycle in Britain increased rapidly up to 1896 and declined somewhat after that date. Total production, of course, depended upon bicycle exports as well as homesales and exports appeared to grow after 1896/7. Harrison (1969) illustrated how the number of bicycle firms in certain towns had grown from about 1874 to 1896 and of the subsequent decline to 1914. The following table gives Harrison's figures.

Year	Coventry	Birmingham	Nottingham
1874	2		
1875		6	
1878			8
1880		43	
1882	14		
1886		54	13
1890	22		
1891		114	
1892	35		33
1897	75	309	
1898			80
1912	49		
1913		160	66

This shows the early surge in the number of bicycle making firms up to the 1896 boom and the subsequent decline in the number of firms. Growth was achieved by an increase in the number of cyclemaking firms before 1896, after this date highly mechanised factories were enlarged and increased output.

Later Process Improvements 1910 to 1939

The great increase in the volume of production which took place in the early 1930s did not lead to any considerable change in manufacturing methods, and, as Pratten (1971) later showed, a much greater increase in volume would have been needed to justify capital investment in more mechanised methods if this was to be economic. Bicycle production technology had reached its practical limit by the 1930s. Caunter (1955) said that during the 1930s and 1940s the were no fundamental changes in bicycle manufacturing techniques. PEP (1949) observed that the development of precision engineering during the Second World War had led to inventions in bicycles finishes, in gadgets and in methods of construction. "Whereas the standard practice has been to braze frame tubes into pressed steel joints or lugs, welding is now used for some racing cycles, particularly on the Continent. Welding is said by its exponents to reduce weight without loss of durability, but many people in the (British bicycle) industry consider that this advantage is more than offset by shortcomings."

Here then is a clear indication that inventions (technical improvements) had been made but that some manufacturers were rejecting them.

Limits to Economies of Scale

Pratten (1971), in his enquiry into economies of scale, examined the British bicycle industry (which comprised effectively of only one large firm at that time) sought to establish the savings that might be made by manufacturing bicycle hubs rather than purchasing them from an outside supplier. Pratten compared the costs for an output of 1,000 p.a. and 100,000 p.a. and found that the savings in labour and material at the higher volume, were almost offset by the increased overheads so that the high degree of mechanisation was not justified in this instance.

This implies that the volume of production is a key determinant of the means of production and that unless it is economically justified, no further changes will be made to production arrangements. The bicycle production techniques introduced after 1896 were sufficient to economically produce the required quantities, hence the neglect or rejection of many later process improvements. Process technology had reached a satisfactory level and there was no further inducement to change.

Plastic Manufacture

A recent development, the introduction of the (all) plastic bicycle has led to a product design which approaches that required for high volume economies. The new plastics allow single piece wheels and a single piece frame to be moulded with provision for fitting standard components directly. Thus great economies should theoretically accrue from the much reduced labour content and the savings in material, machining and finishing. The prices of plastic bicycles do not reflect this at the moment perhaps because the quantities sold are small. These techniques have been partially adopted for the production of plastic wheels on some models of childrens' "fun" bikes, but the majority of adult bicycles are constructed in the traditional manner. The recent Plastic bicycle represents the most logical product design and method of manufacture for very high volumes. Demand has not as yet risen sufficiently to secure the economic advantage of this new method of production.

4.7.1 Trend Of Bicycle Prices

The fundamental economic concept of (process) invention is that it is directed to cost reduction. If this is true then the long run trend of real costs should show a downward path. Not all price reduction is due to process invention as non-technological changes contribute as well. The cost of materials and components supplied to a factory are another element in costs, and Pratten (1971) has shown that these form a considerable portion of the total cost of bicycles. In addition manufacturers can alter their prices independent of material and production costs, raising them in booms and lowering them in slumps.

Early Bicycle Prices

The bicycle industry, like all others which make a variety of products, makes it difficult to specify an ´average´ price for a bicycle. A number of estimates have been given of British average bicycle prices; Priestley (1979) quoted the following prices.

Year	Price (Pounds)
1871/80	8
1881/90	7.5
1891/1900	10
1901/10	12
1910/14	12.5
1915/30	5
1945/50	12
1951/60	20
1961/70	30

Attitude to Bicycle Prices

The writer of the Leisure Hour article touched upon the price of cycles noting that they appeared to be expensive at first sight and said that once it was appreciated that the highest quality of materials had to be used in first class models, and that many of the ingenious patents used yielded a royalty - "in many cases the excellence of the machine is due to the patents and the use of superior materials" so that the high prices were not surprising. This shows that the main goal of British cycle manufacturers at

that time was on product quality and not low prices.
This attitude lasted until the 1896 boom as Rubenstein (1977) noted, during the 1890s the cycling press sometimes carried advertisements for cheap bicycles and "such advertisements were deplored by most cycling writers, who continually preached the gospel of high prices and high quality". (p.57) This indicates a relative lack of desire for low cost production.

Others have given examples of early British bicycle prices; Caunter (1955) noted that late Velocipedes sold in the price range 10 to 14 guineas, while the Ariel Penny Farthing sold for 8 pounds and an 1880 Penny Farthing sold for 6 to 12 pounds. An Early Safety retailed at about 9 guineas. Duncan (1898) considered that a Modern Safety cost an average of sixteen pounds before 1896, then during the boom the price rose to twenty eight pounds. After this British bicycle prices declined to around ten pounds (retail) about 1900, while by 1914 Grew (1921) said that a good model could be obtained for eight guineas. The tendency for British manufacturers to prefer high prices and high quality has already been noted; Caunter (1955) said that this involved a price-list system among bicycle manufacturers but this was abandoned after 1897.

There are two reliable sources of British bicycle prices. The first and most accurate one is the census (and I.D.A.) returns. This gives the ex-factory costs for the various years in which censuses were made. The following table gives the current average ex-factory price and the constant price (computed using the Retail Price Index given by Feinstein (1976) with 1913=100).

Trend of Census Bicycle Prices

The following table gives the average ex-factory price of complete (i.e. fully assembled) British bicycles for census years and these have also been converted to constant prices using the Retail Price Index from Feinstein (1976).

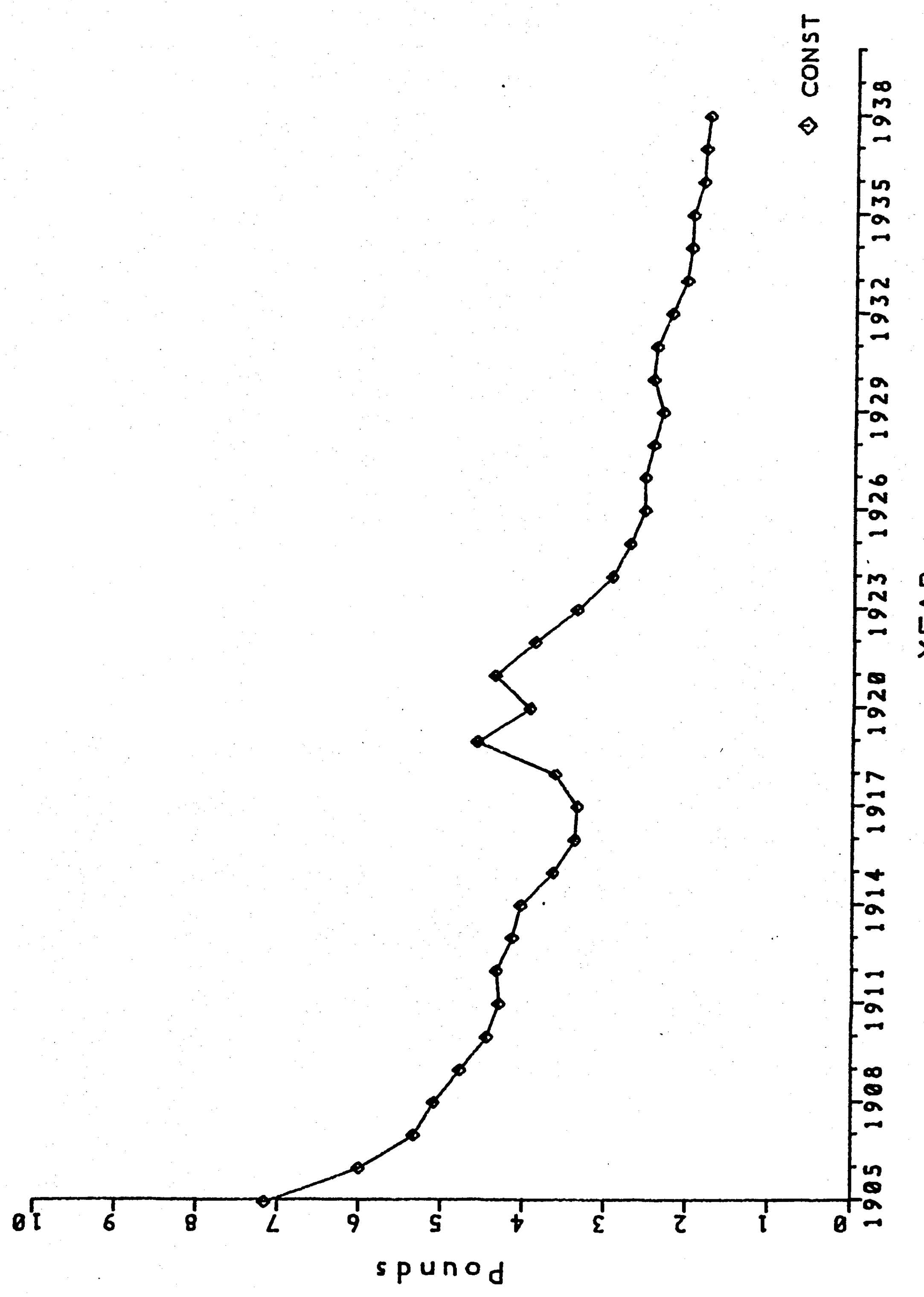
Year	Ex-Factory Cost (pounds)	Constant Cost (pounds)
1907	5.50	5.91
1912	4.55	4.64
1924	5.55	3.22
1930	3.40	2.19
1934	3.40	2.46
1935	3.32	2.37
1937	3.41	2.24
1948	7.28	2.71
1951	8.02	2.57
1954	8.92	2.51
1958	9.13	2.19
1963	9.04	1.94
1968	10.29	1.83

These Census constant prices show that the price of an average bicycle fell quite steeply from 1907 to 1930 and thereafter the rate of price reduction was much slower.

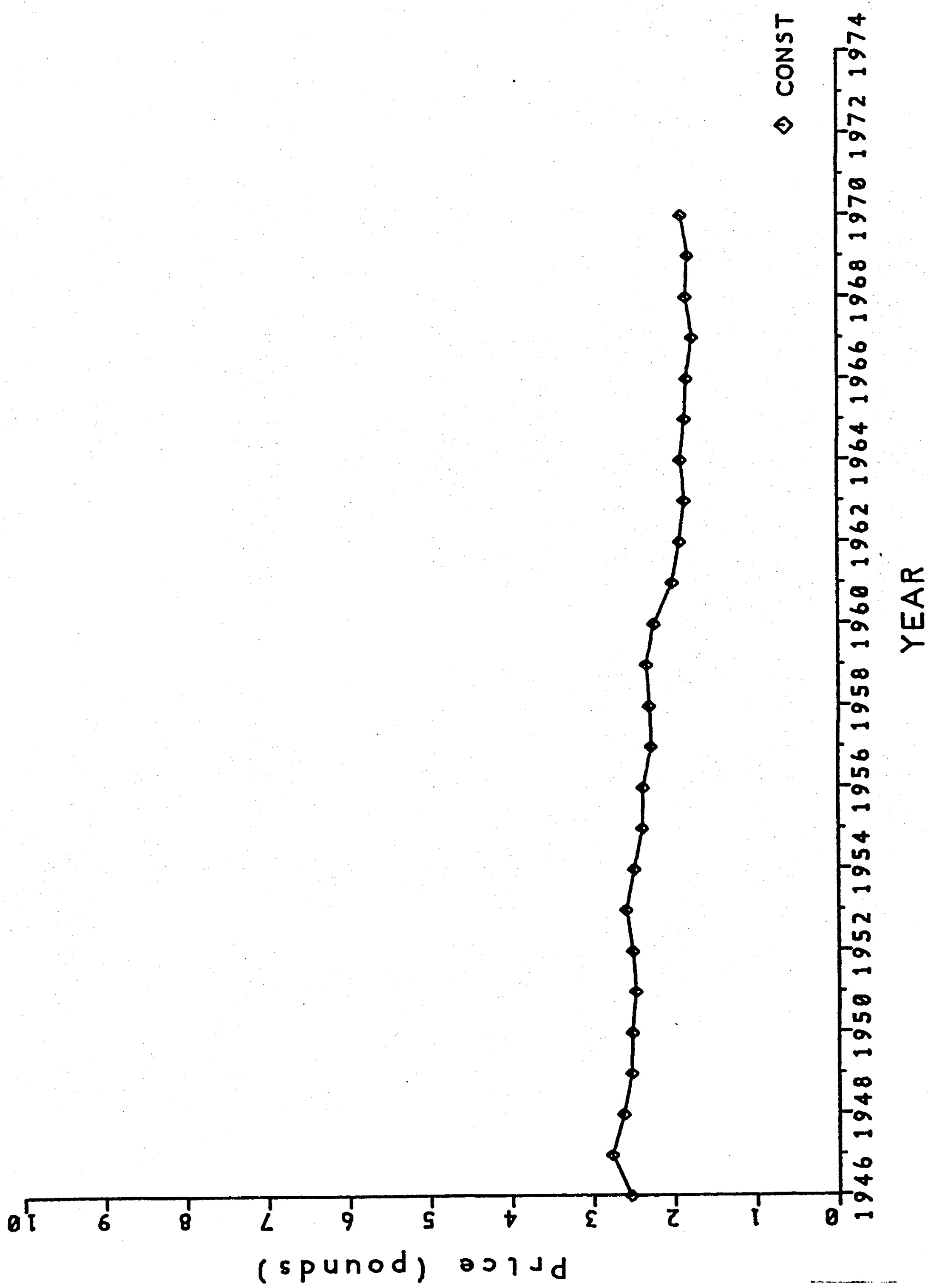
Trend Of Export Prices

The second reliable source of British bicycle prices comes from annual bicycle export data. The quantities and values of bicycles exported are available from 1905 to 1938 in the annual Trade and Navigation Accounts, although earlier returns did not separate complete bicycles and components. Graph 4.2 shows the trend of British (constant) export prices of bicycles for the years 1905 to 1938. 1905 was the first year in which complete bicycle values and quantities were separately recorded. This graph shows that a steady downward trend was interrupted during the last years of the first world war and that this lasted for a few years after 1918. Beyond that, the steady downward trend continued though at an ever decreasing rate so that by about 1930 the bottom had more or less been reached with little subsequent change.

Graph 4.3 shows the trend of export bicycle prices (constant) for the years 1946 to 1970. In this period the price changed very little showing that process improvements had no significant effect on unit costs after the war.



CONSTANT PRICES:BICYCLE
EXPORTS 1905-1938



BICYCLE EXPORT PRICES
(Constant): 1946-1970

Comment

These long run bicycle prices show a characteristic curve of falling prices, with relatively large falls in the years immediately following the adoption of mechanised production and thereafter tailing off. Process inventions and non-technological changes both contributed to this fall, (as well as product invention as noted earlier).

This characteristic pattern has been observed in many other product prices, one early time series being that of Ashton (1948) who gave the price of a grade of cotton yarn for a 100 year period; this too showed a rapid decline in the earliest years of mechanised production then tailed off with little change after 1830. It was noted in the literature review that Gold (1973) found a pattern of unchanged long run unit (constant) prices for established American industries. The secular trend of British bicycle prices thus accords with price patterns noted for other product industries and in general the factors and patterns of process changes accords well with Utterback and Abernathy's model. One or two minor points are noted here. Firstly the long run price changes appeared to be limited to a transient mechanisation effect; that is that mechanisation of production was indeed associated with markedly falling prices but only for a limited time after which subsequent process improvements had little effect on real costs. It appears that process invention (like product invention) reaches a practical limit, after which inventions (if adopted) have no real effect on product prices.

A second feature was the delay in manufacturers becoming 'price conscious'; the evidence showed that in the first commercial years of this new industry, manufacturers were more concerned about quality than prices. In addition the change to mechanised production was started by bicycle component manufacturers rather than those concerned with the final assembly of bicycles themselves. The decisive pressure to mechanise British bicycle production came through increased demand but 'price consciousness' only really developed after the post 1897 years and depressed economic conditions played a powerful role in forcing further production cost reductions. Even so British bicycle manufacturers continued to supply better quality bicycles which were more expensive than the low cost models intended for mass markets.

4.8 Growth Of Output

Bicycle Production Data

The 'output' of the British bicycle industry was not simply that of completed bicycles for sale in Britain. A considerable amount of British bicycle production was exported and in addition a large quantity of bicycle components were sold at home and abroad. This makes it difficult to specify the 'output' of the industry other than in terms of value.

The first real production began in 1869. Phillips (1885) noted that demand declined slightly in the early 1870s then began to increase after that. Many contemporary accounts suggested that the British bicycle industry really began in 1885, the articles in Encyclopeadia Britannica cited this date; in the ninth edition (of 1888) it said "bicycling has rapidly grown in favour during the past two years", while in the tenth edition (of 1910) that the cycle trade didn't really begin until the (Modern) Safety bicycle of Starley and Sutton was launched in 1885. Many general histories of the British bicycle industry consider that the true start was the 1896 boom, although Rubenstein (1977) noted that "the industry grew rapidly in the 1880s but suffered from inadequate demand between 1891 and 1894". (p.52). The output during the 1896 boom was, Rubenstein said, commonly accepted to be 750,000 bicycles.

Prest (1954) (p.138) has given annual estimates of the quantities and prices of bicycles sold in Britain for the period 1900 to 1919. He has stressed that apart from the census returns for the years 1907 and 1912, the is very little information for other years and that his estimates are "liable to a great margin of error". Prest constructed his annual price series beginning with the ex-factory costs given in the 1907 and 1912 census returns which he increased by 33.3% to arrive at a probable retail price for an 'average' bicycle. He then used export prices as the basis for other prices in other years. These data are shown in the following table.

Homesales Of Bicycles In Britain 1900-1919

Year	Price (Pounds)	Quantity (000s)	Consumer Expenditure (pounds, mil)
1900	10.0	350	3.5
1901	10.0	375	3.8
1902	10.0	400	4.0
1903	10.0	425	4.3
1904	10.0	450	4.5
1905	10.0	475	4.7
1906	8.6	500	4.3
1907	7.88	522	4.1
1908	7.34	420	3.1
1909	6.93	350	2.4
1910	6.58	350	2.3
1911	6.40	350	2.2
1912	6.61	385	2.6
1913	6.42	400	2.6
1914	6.34	400	2.6
1915	6.85	250	1.7
1916	7.54	50	0.4
1917	9.02	50	0.5
1918	11.20	100	1.1
1919	15.05	400	6.0

Homesales of Bicycles in Britain 1920-1938

Annual estimates of homesales for the years 1920 to 1938 have been given by Stone & Rowe (1966). These estimates for annual quantities and values for the years 1920 to 1930 are keyed on the 1924 and 1930 census returns and show that homesales of bicycles in Britain grew slowly. Their estimates for the 1930s are much more accurate due to the frequent censuses and I.D.A enquiries in that decade. (These are shown on graph 4.4 below). Their estimates were based on the output for the five census years (1924, 1930 1933, 1934, 1935) and a 1938 estimate from which exports were subtracted to give homesales using interpolation. Stone and Rowe computed retail prices of bicycles using census year data and increasing this by 50%; for other years they used 'average'

British bicycle export prices noting that "In later years exports (of bicycles) were less important and evidently represented a cheaper form of machine than was sold on the home market". (p.57).[26]

After 1946 official statistics were given in the Annual Abstracts of Statistics and Business Monitor(series PQ 382). These statistics are shown on graph 4.5 below.

Exports of Complete Bicycles

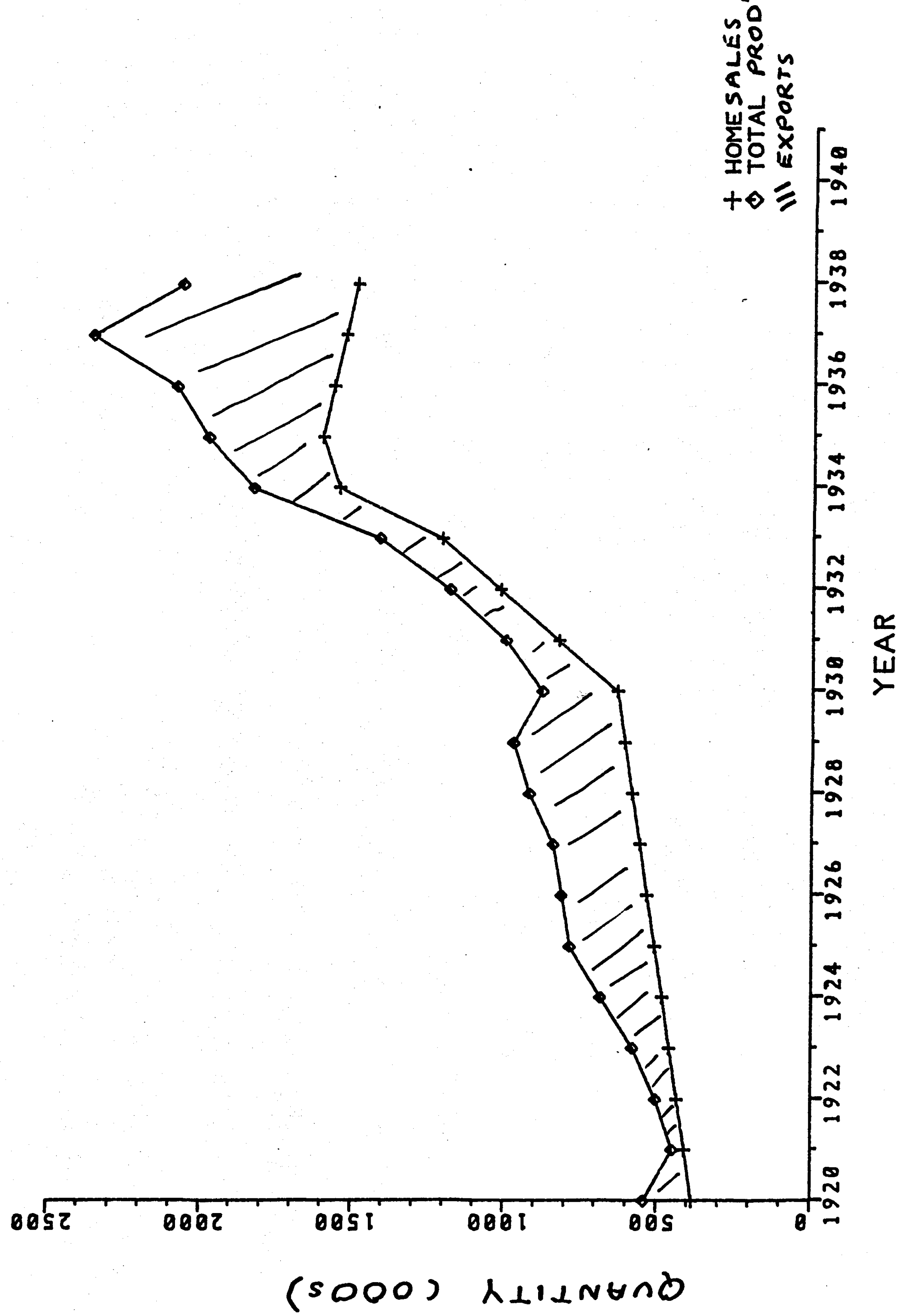
The export of British bicycles varied because international trading conditions. Britain had adopted free trade policies up to 1914 and the increasing exports to that date largely reflect the technical leadership in bicycle design and manufacture, a confirmation of the Product Life Cycle Hypothesis first suggested by Vernon (1966). The only accurate figures for exports of complete bicycles were first given in the Trade and Navigation Accounts from 1905 and yearly thereafter. During the 1930s world trade declined greatly especially in the depression years 1930 to 1932 but after this an increasing demand came from Empire countries and British exports of completed bicycles rose to 1938.

After 1946 international trade became much freer and British bicycle exports reached record levels until the 1950s because of foreign demand. But by the mid-1950s British exports declined rapidly; Maizels (1963) gave two reasons for this, one was that the previously importing countries had established their own bicycle factories, the other was the trend away from bicycles in the richer nations.

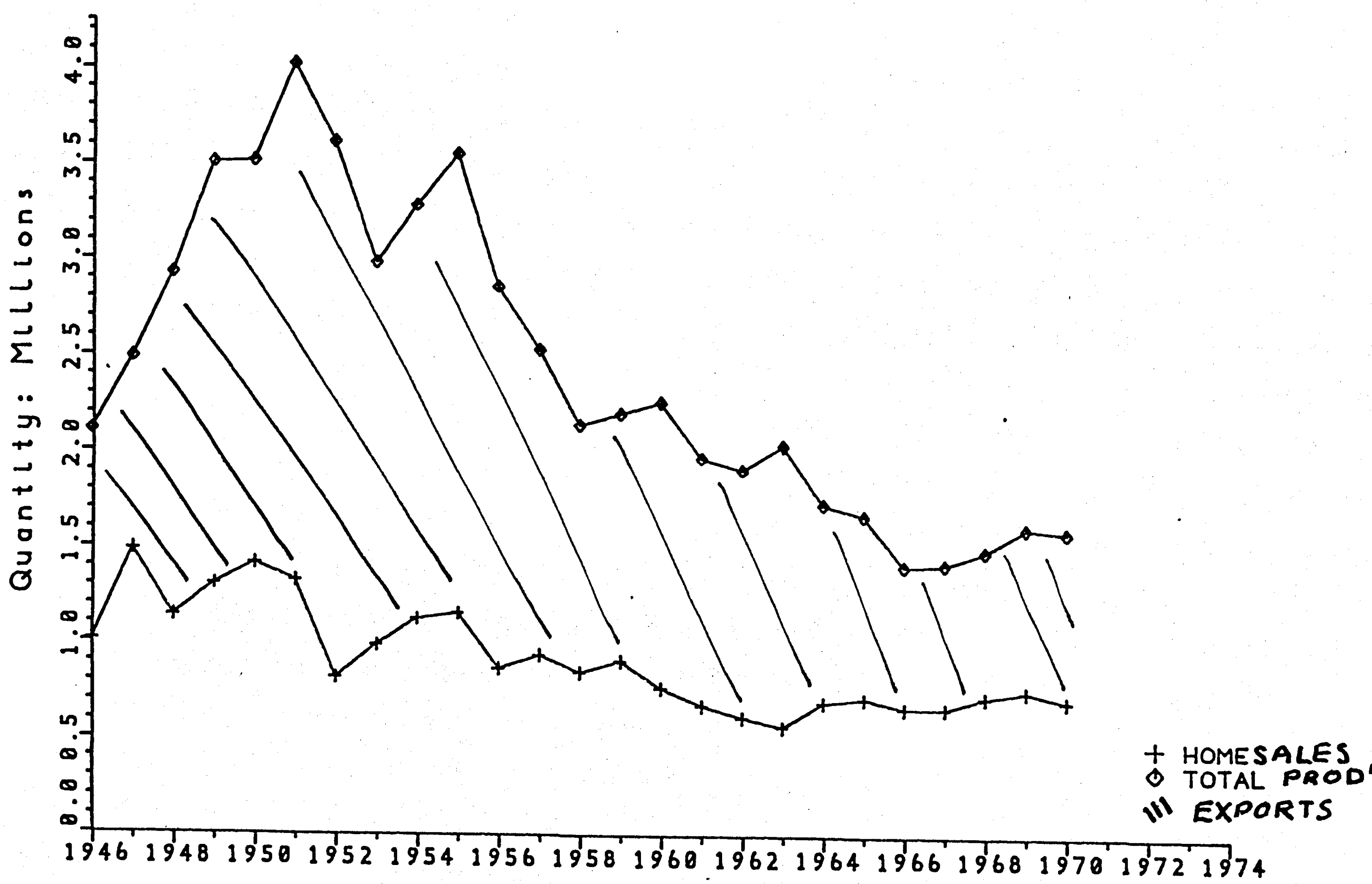
Exports played a very important part in determining the growth and decline of British bicycle production as the following graphs show.

The Total quantities of bicycles produced and the quantity of complete bicycles exported for each year in the period 1920 to 1938 are shown in graph 4.4; and the same information for the period 1946 to 1970 is shown on graph 4.5. The shaded area represents the quantities exported, and highlights the changing proportion of the total output and the relative importance in various periods.

26 Another estimate for the numbers of bicycles produced in Britain for the period 1928 to 1938, was given by Engineering (1939) and when these figures are compared with Stone and Rowe's data (with export quantities added to the latter) the trends are very similar and the quantities correspond quite closely.



BICYCLES: TOTAL AND EXPORT
QUANTITIES, 1920-1938



BICYCLES: TOTAL AND EXPORT
QUANTITIES, 1946-1970

Bicycle Components

The total output of any industry is not just the number of complete products it makes in any year, but these together with the additional parts, components and accessories. These additional parts and components are used for spares, replacements and exports. The British bicycle industry's output followed the general trend as the table of Census returns shows; for example in 1924 50% of the total output was components and parts, which were of value equal to that of complete cycles. This illustrates not only the commercial importance of the accessories, parts and components sector of the industry but also why product and process invention is so important at this level of the industry.

Year	Total Output Value (M-pounds)	Component Value (M-pounds)	Component Proportion (%) (per cent)
1924	7.514	3.751	50%
1930	5.976	2.566	43%
1934	10.823	4.573	42%
1935	11.367	4.854	42%
1937	11.854	4.821	40%
1948	31.640	12.508	40%
1951	47.650	17.270	36%
1954	43.202	16.281	38%
1958	33.461	13.232	40%
1963	25.700	6.133	24%
1968	20.910	5.279	25%

Component Exports

The proportion of components exported varied from period to period due mainly to the state of international trade, and the declining importance of bicycle components between 1924 and 1968 was partly due to falling foreign demand and partly because of the overall decline of the bicycle industry.

The values of components and parts are difficult to measure exactly. The only valid measure of components is their current value but they are an extremely heterogeneous mixture which change over time. Some attempts have been made to equate the quantity of components with that of complete (i.e. fully assembled) bicycles; PEP (1949) considered that 56 lbs of components equalled one

bicycle although noting that bicycles bicycles usually weighed less than that figure. Another difficulty is that of changing composition of components which is impossible to trace in the official statistics.
This discussion about bicycle components has illustrated some of the difficulties about defining the ´output´ of the British bicycle industry.

The converse side of this export trade was bicycle imports to Britain. Prior to 1914 these were of modest proportions, then from 1920 they substantially decreased and during the 1930s were so small that they were not recorded in the Trade and Navigation Accounts. From 1946 to 1970 bicycle imports were inconsequential, being only of the order of five or ten thousand per year in the last years of the 1960s. During the 1970s these imports rose to substantial levels of about 250,000 per year.

These output trends of the British bicycle industry accord well with patterns established for other industries. Kuznets (1930) and others had noted that physical volumes increased up to some ´saturation´ point after which they declined. The concept of product (or industry) life cycle is based on this pattern, though it is often observed that product invention can extend the post-saturation ´life´ of the industry by introducing improved models. However the explanation for the product life cycle pattern cannot be satisfactorily confined to Supply side variables; changes in demand factors appear to be a determining influence on output changes.

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4.9 Demand

In this section a broad analysis will be made of the market for bicycles as well as an attempt to assess the relative importance of the various factors involved in the home demand for new bicycles. The basic analytical framework will be Katona's two factor concept.[27] The first part of this whole section will deal with the social factors affecting demand for bicycles. The second part will deal with the economic factors affecting homesales of bicycles in Britain.

4.9.1 Social Factors and Bicycle Demand

One of the most difficult questions which market researchers ask is 'Why do consumers buy this particular product'?. The easiest answer is that consumers buy a product for its function, and in the 1870s a bicycle (and tricycle) was a new form of transport which offered considerable advantages over walking. Cradocke (1880) said that the early demand arose because the bicycle (and tricycle) was an individual means of transport which gave many the first freedom to travel where and when they liked, its only disadvantage being in the wet. Boys (1884) noted that various groups of cyclists demanded different types of machine according to their needs so that young athletic men invariably chose Penny Farthings in order to race while more elderly people chose tricycles to get about at leisure. Hillier (1883/84) said that the chief attraction of early bicycles was for racing and for those who wanted to get away from the city, or as a means of exercise or for summer holidays. The early Modern Safety bicycle has also been credited with an important social function, namely the 'emancipation' of Victorian ladies from their fettered social role; Rubenstein (1977) has briefly discussed this topic and given further references to it.

In modern language, it was soon observed that a bicycle had several functions and appeals and that almost from its introduction a segmented market existed. Its technical function (as a speedy means of transport) ensured that its

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27 It has already been noted in the section dealing with component exports that additional international factors affected foreign demand and this sector will not be dealt with here. The factors affecting demand for second hand bicycles will also be ignored as no long run data is available although the British second hand market is (or was) quite big; see EIU (Retail Business) (1977) for its estimated 1976 value.

technical development proceeded along that dimension of performance and the history of invention has illustrated that well. Its social function was important and any analysis of demand must attempt to explain that.

It is widely recognised that the 1896 bicycle boom was largely due to a craze for cycling which emanated from the middle and upper classes in Britain. Harrison (1969) said "The cycle buyers of the 1890s were middle class people pursuing the current fashion and demanded top quality machines".

Rubenstein (1977) has given an extensive account of the social factors behind the 1896 boom in Britain. He considered that social imitation was an important factor, and that the British public was greatly impressed by important people - such as the Prince of Wales (later King Edward the Seventh), the prime minister and writers such as G.B. Shaw and H.G.Wells - taking up bicycling which caused the public to follow suit.

Yet Rubenstein was at pains to point out that social factors alone did not solely determine the popularity of the bicycle at this time, but that economic and technological factors had contributed too. It was the technical excellence of the Modern Safety design (especially its safety) which enlarged demand from a previous narrow sector for racy athletic young men to a very much broader sector; male and female, young and old. Rubenstein dated the start of the boom earlier than most, "it was in 1894 that cycling first became widespread among both sexes in Britain and in 1895 that popularity became a passion". (p.49) He also noted that the middle and upper classes were not the only cyclists. "But there is plentiful evidence to show that many members of the lower middle and upper working classes of both sexes were among the cycling population". (p51) He noted that these lower class cyclists often had old machines and could obtain hire purchase facilities. Circumstantial evidence indicated that lower income groups bought a bicycle for its utility value especially for the journey to work; Woodforde (1970) has included early photographs of men cycling to work.

Like all social influences, changes can take place which entirely reverses the trend; Rubenstein (1977) illustrates how wealthier people turned to motor cars in the 1900s and were entertained by lampoons of the once popular song "Daisy Daisy" stressing that they could afford a carriage. From 1899 to 1914 the demand for bicycles was changeable and the contraction of the British bicycle industry from 1900-1914 has already been noted. This by itself does not explain the policy of that period though the following extract from The Times(1910, Nov 20 p.16) gives some insight. "---(There) was a period when cheap American bicycles were imported in large numbers, but that was repelled --- there are more pedal cycles being sold today than at any other previous period --- Production by large makers, of a soundly built machine at a low price brought the bicycle within the reach of the artisan class and they are the main buyers today". This shows that low priced imports had made British manufacturers lower theirs and the result was that lower income groups bought in greater quantities; this was partly helped by hire purchase as The Times (1910 Dec 16, p.15) noted. By at least 1910 the evidence points to a ´trickling down´ of demand for bicycles from the higher to lower social classes (and income groups) with a change from the predominantly leisure use to a utility one, and which involved product design. In 1919 there was another surge, usually attributed to pent up wartime demand and The Times (1919) noted that at this time the prices of bicycles increase by 30 to 40 per cent. Then during the 1920s home demand rose steadily, partly due to economic reasons and partly, as the ´invention´ of the Tourer showed, due to social pressures.

1930s Bicycle Boom

In the 1930s yet another surge in homesales of bicycles took place and although the quantities sold reached record levels, few bicycle histories comment on this demand. The Economist (1935, pp1059-60) considered that this boom was due to a number of factors "some of which are permanent". First there was the "outdoors" cult, secondly re-housing on new estates at some distance from work, thirdly public transport had lost to private transport in the early 1930s, fourthly the pedal cycle had a low capital cost and negligible running expenses which made it very attractive, fifthly the new regulations governing motor transport used for business purposes had prompted many firms to use pedal cycles, and motor cycles had not shared this 1930s boom; sixthly pedal cycle prices had been reduced. Wyatt (1966) said that the main 1930s market was for cheap sturdy bicycles although there was also some demand for expensive de luxe models too. The lightweight roadster sold well in this period. The Times (1935, Aug 24, p.13) also commented on the recent bicycle boom which it considered had begun only in the last two years "the acceleration being more rapid than in any other period", and pointed out that this was linked to a interest in outdoor pastimes which had increased in the 1920s and was reflected in the high and increasing membership figures for the Cyclists Touring Club. Erbes (1933) considered that the U.S. boom in bicycle sales in the opening years of the 1930s had been due to Hollywood influences. Social imitation also applies to "health" or exercise consciousness.

Social Demand Factors For Bicycles After 1945

Demand immediately after 1945 was high. Wyatt (1966) said that this was due to a number of factors, the main ones being that motor vehicles were costly and restricted in supply, cycle racing and touring had revived, and that the bicycle had become a status symbol to the young. In addition there was a large demand for exports due to European wartime dislocation and of greater importance, a physical fitness vogue in the U.S. where British pedal cycles had a good reputation. Post-1945 sales of bicycles continued to be influenced by social factors, among these were exercise-consciousness and "ecological consciousness" which became important once bicycling changed to being mainly a leisure activity.

Social factors also pre-determine who ride bicycles and who do not. Class differences have been important; a Hulton Readership Survey (1948) found a male-female class difference in British society, with bicycle ownership rates then increasing with decreases in class (as measured by income) for adult males, while female bicycle ownership was found to be greatest in middle classes. At this time the adult use of bicycles was largely confined to the age group 16 to 24 years and very few over the age of fifty cycled in the late 1940s.

Later Trend

By the middle of the 1950s demand for bicycles diminished when consumer purchasing power had increased enormously. It is not surprising to find that during the 1950s the bicycle had again acquired a 'down market' image, it became associated with people who had not been successful in life. In Britain and other advanced economies, the consumer changed to motor cars, and Maizels (1965) has illustrated this with reference to per capita rates for bicycle ownership and income, and he noted that increases in income had not been accompanied by increases in bicycle purchases. The home market then contracted and production was concentrated upon childrens' and juvenile models until the later 1960s when adult bicycle sales again began to rise and this time it was middle income group purchasers who sought better quality bicycles for leisure use, based on social desires for healthy exercise and environmental concern.

By 1960, Wyatt (1966) noted, there was clear evidence of a long term decline and the British bicycle industry contracted. Homesales then had fallen well below the million mark. Morley (1968) noted that in 1962 seventy five per cent of the British bicycle market was for children aged 16 years and under; this was at the time when adult bicycling had a downmarket image.

EIU (1977) reported that a reversal had occurred in the social class ownership pattern with the highest class(es) (A,B) having 52% of households with one or more bicycles, while only 42% of class (C2), and an even smaller proportion, 34% of class (D,E). Thus a marked change had occurred in the characteristics of British consumers in the postwar period and as noted this was intimately connected to the change to secondary use of bicycles. This led to a demand for higher quality bicycles for leisure use by middle income groups, although Critchley (1977) considered that the rising prices of petrol and public transport costs also influenced the return to cycling during the 1970s. This survey also established a male-female difference in that 90% of adult males had learned to ride a bicycle while only 68% of adult females had learned to ride.

Other quasi-social variables also have a direct influence on sales or potential sales and these include the changing age structure of the population which is determined by the birth rate, and the urban-rural distribution of the population. EIU (1977) noted that bicycle ownership in Britain was least in hilly areas and greatest in flat areas. Pratten (1971) found the British manufacturers had begun to make buyers fashion conscious by producing a diversity of models and changing them each year. This was done during the early 1960s when the industry was in a depressed condition.

All these social (non-economic) aspects of consumers' characteristics then affect both both demand and design, it is not possible to say which came first or acted as the cause but it showed that the home market was diverse as Critchley (1977) noted, saying that the structure of demand for bicycles in Britain in 1971 was as follows: 20% of adult purchases were for Sports type bicycles, 15% were for Conventional types and 14% for Small Wheel types, while Junior purchases were 14% for Conventional types and 37% were for Small Wheel types.

4.9.2 Economic Aspects Of Demand

Few economic studies of the demand for bicycles exist. Derksen and Rombouts (1937) have analysed changes in the structure of demand for bicycles in the Netherlands (where bicycles are taxed and therefore annual statistics are available). They found the New purchases were highest in boom years, while Replacement purchases were highest in depressed times due to low prices and increased purchasing power.

Maizels (1965) examined the long run trends in world trade for various commodities and goods and in his chapter twelve dealt with a variety of consumer durables including bicycles. He noted that in the period 1937 to 1958 there had been a very rapid increase in demand for consumer durables which rose faster than increases in income and that this demand was largely supplied by a few advanced countries. However he found that purchases of motor cycles and bicycles did not exhibit the generally close association between real income per head and ownership rates and that "the proportion of people owning these articles tends to fall after a certain level of income is reached " (p.315). He therefore concluded that the bicycle and motor cycle were 'inferior' goods (in the economic sense) and purchased mainly by those with lower incomes who, if they got richer, turned to other goods.

Regression Model

A detailed description of the purpose, form and data sources of the proposed regression model was given in the previous chapter and only a summary of that description will now be presented. The purpose of the model was twofold; one objective was to estimate the parameters of each independent variable and establish the contribution each independent variable made to the estimated homesales thus showing whether changes in product prices, income (earnings), or net saving were most important. A second objective was to observe whether or not this equation gave estimated values for homesales which were close to the ´actual´ homesales and a high coefficient of determination (R-square) and if so to show that growth of home demand could largely be attributed to ´trickling down´.

A simple and direct model was proposed, having the form

Homesales = f(Price, Income, Net Saving)

where product prices were annual average ones deflated by means of Feinstein´s Retail Price Index; Income was average annual earnings for manual employees again given by Feinstein and deflated to real values and Net Saving was the combined Post Office and Trustee Savings Bank figures deflated and reduced to a per depositor figure. The ´actual´ homesales were those quantities given by Stone and Rowe (1966) for the quantities of bicycles sold in Britain for the years 1920-1938 reduced to a per capita basis using Feinstein´s annual estimates of population in Britain. These regression data are tabulated in the statistical appendix, chapter eight.

Regression Results

The results obtained using the SPSS Regression program, described in the previous chapter, are now presented.

Regression Equation Parameters

$$H = -0.046C - 0.011P + 0.00055E + 0.0041NS$$

(0.0001)(0.0006) (0.00064)

Where H = Homesales

C = Constant

P = Product Prices

E = Average Manual Earnings

NS = Net Saving

Terms in parentheses below each independent variable indicate their standard error values. The coefficient of determination (R-squared) for simultaneous entry of all three independent variables in this equation was 0.96.

Relative Importance Of Each Independent Variable

It was possible to establish the contribution each independent variable (in the regression equation) made to homesales by means of the 'Enter' method on the SPSS regression program. This method allows each independent variable to be entered either singly or in combination and can therefore show the changes in the coefficient of determination (R-squared) and hence the relative importance of each as a determinant of homesales. The results using the cumulative entry were as follows:-

Variable Included In Equation	Corresponding R-squared Value	Proportion Of Demand Explained
Product **Price**	40.8%	40.8% (Price)
Price + **Earnings**	85.55%	44.74% (Earnings)
Price+Earnings +**Net Saving**	96.15%	10.58% (Net Saving)

These separate computations of the changes in R-squared due to each independent variable have shown that not surprisingly the combined effect of prices and earnings accounted for a great deal of the growth of demand but also that 10% or so was apparently due to net saving and this feature will be discussed below.

Trickling Down

This simple model of demand for bicycles can also shed light upon the importance of 'trickling down' of demand by indicating the likelihood that increased demand came mainly from lower income consumers. Three pieces of evidence lend strong support to the trickle down hypothesis; firstly the very high R-squared value (0.96) obtained in the above equation means that changes (growth) of homesales can, in the statistical sense, be almost wholly 'explained' by changes in the three chosen variables and indicates that in this period home demand was primarily economically determined between 1920 and 1938. Secondly the earnings and net saving variables were deliberately chosen to reflect changes experienced by lower income groups and finally the descriptive accounts of the bicycle market in the pre-1939 period have strongly indicated that the majority of purchases were made by lower income groups. It seems safe to infer that the primary source of home demand came through trickle down.

Discussion

A brief note is made here about the variables used in these regressions. Firstly changes in the average real price of bicycles was not particularly marked from the mid-1930s and the significance of this is that further price reductions (if possible) would not have had a great effect on growth. Secondly the main reason for growth of home demand in this period was due to macroeconomic changes. Real earnings rose principally because of falling prices in the pre-1939 period. The contribution made to demand by net saving can be fairly simply explained as a by-product of falling general prices which effectively increased the purchasing power of lower income families especially who increased their purchases of consumer durables and savings. This accounts for the huge increase in home demand for bicycles during the 1930s.

Some Comments On The Interwar Economy

British economic conditions of the interwar period, especially the 1930s have proved to be puzzling and only an outline will be given here to support the assumption that lower income groups experienced relative affluence, provided they were in employment. Aldcroft and Fearnon (1972) have provided a comprehensive summary of many studies of the British interwar domestic economy. They noted that one of the many paradoxes in this period was that the rise in unemployment did not affect Real Consumption. They illustrated this with reference to inter war economic statistics and in particular noted Radice's study of British saving in the period 1922 - 1935 and his finding that lower income groups with annual incomes of 250 pounds or less experienced an increase of Real Income, while those with incomes of 250 pounds per year or more, suffered a decrease in the period 1929 to 1932. The reason Radice gave for this strange trend was that the higher income group may have had some of their income from dividends, profits or other unearned sources, whereas the lower income groups did not. Aldcroft and Fearnon then went on to show that after 1933 the middle classes and others shared in a general prosperity; by that date 60% of new cars sold in Britain were of 10 horse power or less and 88% of new houses built had a rateable value of 26 pounds per year, the lowest rateable value group. These trends indicate that both lower and middle classes in interwar Britain were relatively prosperous during the 1930s, provided they were in employment.

Richardson (1967) has considered the possible causes of the 1932 to 1938 boom in the British domestic economy, and the possible role of such factors as cheap money, reduction of foreign investment, rearmament and the building boom. Though he does not claim that the prosperity was solely due to any one of these causes he did consider that falling world and commodity prices had led to much cheaper raw material and food imports thus reducing the cost of basic purchases and giving increased discretionary income to lower income groups especially.

The natural explanation is that lower income families especially experienced additional purchasing power due to falling general prices which allowed them to buy more consumer durable goods and also save more.

Implication For Bicycle Manufacturers

Another implication of this finding is that growth (of homesales) does not depend solely upon either manufacturers' prices or product but upon changes in macroeconomic variables over which the manufacturers have no control. The changed market for bicycles during the 1950s graphically showed how demand declined when incomes rose sharply and average real bicycle prices hardly changed. Bicycle manufacturers had to respond later to these new market conditions by catering for new 'up market' segments with higher priced, better quality new designs which did not totally recapture the earlier volume of homesales.

Conclusion About Demand and Growth

In this section the role of social and economic factors and their influence on home demand for bicycles have been examined. It was found that social factors were influential although they were complex, and that they could reverse in the long run. The main determinant of demand in the early years of the British bicycle industry appeared to be a social one of "receptivity" to the new product, which lasted to 1897. In this period there was no real emphasis upon price reduction of bicycles, rather a belief that high prices meant high quality.

After 1897, the British bicycle industry then entered an economically determined demand era which lasted to about 1938. In this period the main determinant of homesales was the demand by first time buyers from lower income groups and the home market became sensitive to changes in prices and income-related factors, causing cycle manufacturers to use product and process invention (as well as other non-technological factors) to suit these changed conditions.

After 1946 there was a brief period of high demand due to special postwar circumstances but by the 1950s the demand for bicycles was no longer economically determined as consumers then preferred substitutes (mopeds or motor cars) and sales of bicycles depended more upon consumer ´switching´ and social factors. Bicycle manufacturers then had to follow the market for higher quality leisure models so that cyclists had changed to secondary leisure uses instead of the previous primary use of the bicycle as a form of cheap transport, with design diversity, higher performance-quality and new (Small Wheel and Folding) models.

4.9.3 Invention And Growth

One objective of this analysis was to determine the relationship between invention and growth in the bicycle industry. The main finding has been that invention is not directly related to growth.

It has been shown that different factors affected the production of bicycles at different stages, and that different demand factors affected sales at different stages. These factors were a mixture of technical, social and economic influences.

Technical Factors

Invention was a very important element in technical change and could be usefully classified as either product or process invention.

Product Invention

Product invention was found to be complex. The broadest form of product change was a succession of different models which more or less superseded each other. As soon as each new model was introduced inventions were made to improve it. These product inventions could be classified as pioneer and incremental ones and the latter were found to have a marked effect on performance, although these were often transferred from other industries. Ultimately product design and performance reached a satisfactory level and though further inventions (or designs) were made which gave a superior performance they were not adopted or usually commercially successful because of economic or other constraints.

Product invention took place at different levels, for example at overall configuration, sub-unit, component, raw material and external and these tended to be independent although their basic function was to improve the technical performance of the product. The resultant effects were not easy to specify as a bicycle has a multi-dimensional performance.

Product invention had a variety of causes but three main factors seemed to be important; these were Technical factors, Economic factors and (non-economic) Consumer factors.

One important technical factor appeared to be ´inner logic´ action especially in the early years of product development. Problems gave rise to inventions to solve them and led to consideration of (technologically) related links. Thus product development proceeded by means of inner logic pressures or mechanisms such as self-sustaining sequences, ´backwards and forwards´ linkages or circularity (iterative sequences). Technical problems often gave rise to other technical problems and their solutions encountered trade-off requirements. Sometimes these solutions came from other industries, another instance of technological transfers.

Another important cause of invention was projected ideas, which established the technical objective and directed subsequent inventive effort. Chance or accidental inventions were not very important but did occur. Science was not involved in most bicycle invention but many empirical ideas and inventions were subjected to systematic tests or investigations.

One significant finding about the economic aspect of product invention has been that it was an important element in cost reduction. It had been noted that considerable efforts were made to simplify designs, use lower cost materials and other Value Analysis (or Value Engineering) techniques in order to reduce bicycle prices. It has not been possible to quantify the relative contribution which product invention made to cost reduction though it appears to have been about as great as process invention and non-technological process improvements.

Consumer influences were also shown to affect product design though these mainly came after invention-push had created a technically viable model.

<u>Process Invention</u>

Process invention was found to conform fairly closely to model suggested by Utterback and Abernathy (1975) although technological transfers from other industries (and other countries) was found to be important.

Economic Factors

Economic Factors acted upon both process and product invention. In the case of process inventions the usual requirement was for production at lower cost and the nature of this aspect has been widely described. This study has revealed how product invention is also used to reduce product costs or promoting growth; this can be done by creating variants of the basic design for new uses, by creating a variety of technical performances and hence a range of models to suit a spectrum of price-performance-quality criteria or to create a low cost model by simplifying its design.

Consumer Influences

Consumer influence affected product invention by requiring products which were easier to operate or use, or making servicing or repair easier and to make the product more attractive by the addition of accessories or even gimmicks especially at times of depressed trade. These technical, economic and consumer factors were of varying importance at different stages of the industry.

Demand

In the early stage of the British bicycle industry, growth of demand was primarily due to the diffusion of the bicycle, and price was apparently not important, neither were changes in income. Social and other factors were important. In the middle (or "economic") stage of the British bicycle industry, from 1900 to 1938, demand was principally determined by changes in discretionary income of lower income groups, and to a lesser extent by reduction in bicycle prices.

In the late stage of the British bicycle industry, from 1946 to 1970, bicycle homesales were not related to decreasing prices or increasing income. Therefore bicycle sales mainly depended upon consumer factors at this stage.

Theoretical Implications

This finding refutes the basic concept embodied in many theories of growth or innovation, that some direct and proportional association exists between invention (however measured) and growth.

This finding does not mean that invention was not an important factor in the British bicycle industry. The most crucial effect which product invention had was to create the bicycle (and other cycles) itself, this can be regarded as a once-and-for-all step. Later product inventions improved the product and these were linked to growth through "product attractiveness" making bicycles easier to ride, safer, more comfortable, and generally more appealing to consumers. Such improvements reached an effective saturation point after which the bicycle attained its mature product form. It is of interest to note that improved product ´performance´ appeared to be fairly closely linked to the patenting rate and that later inventions were frequently rejected. The role of product invention as a means of price reduction has been found to be important and this suggests that economic theories should be altered to take this into account.

Process invention in the case of the bicycle owed much to technology transfer. In the early stage, up to 1896, there was no evidence that bicycle manufacturers calculated ´technological possibilities´ of process changes or their associated labour-saving, or capital-saving properties, rather they concentrated on high quality and high prices. When the market changed from a sellers´ one to a buyers´ one, process invention was called (among other factors) to cheapen bicycle production, and it succeeded. Once again, a practical and effective limit was reached with a low price which, in constant terms, did not change much later, and yet the great growth occurred after this date.

In the post-1946 era, the growth of output soon changed into a decline, and this was not related to consumers´ discretionary income or bicycle prices but owed everything to a switch to alternatives. Bicycle sales in this period depended upon new leisure uses and social factors which forced bicycle manufacturers to use product invention again.

The current concepts of invention and growth are insufficient to explain the technological development of the bicycle and its pattern of demand.

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5. CHAPTER FIVE: THE DOMESTIC RADIO RECEIVER

5.1 Introduction

The reliability of the general pattern of product invention, technological change and associated demand factors observed in the Bicycle industry would be enhanced if the broad features could be shown to be repeated in another consumer good industry. For this reason the Domestic Radio Receiver has been selected for further examination.

The term "domestic radio receiver" refers to the earlier kind of valve "wireless set" (as it was then called) which was intended for family listening in the period from 1920 to about 1960. The most common type being a table model though radiogramophones, portable receivers and car radios were also produced.

Broad Pattern Of Development

The course of technological development of radio was a very complex affair, much more so than in the case of the bicycle. Pioneer radio inventions were not made with the intention for use in public broadcasting reception, they emerged from a series of experimental explorations which had their first limited commercial application in wireless telegraphy, then in military applications. These pioneer inventions owed much to earlier electrical knowledge especially of wired telegraphy and telephony. The recognition of the commercial potential of public broadcasting came after wireless telephony was successfully demonstrated. Broadcasting began in America and the Continent in 1920, and was delayed until 1922 in Britain. Public broadcasting revolutionised the market for radio from a previously small and specialised one to a mass market of consumer goods which created a new industry - or rather a series of new industries, as radio technology began to be applied to other spheres especially electronic controls which initiated the Electronics industry. During the second world war this new field expanded enormously to culminate in new kinds of "radio" (such as radar and other radio guidance systems) and also completely new fields such as computers.

Later still, new types of radio technology sprang from transistors and solid state devices which developed into Integrated Circuits and "microchips".

The technical development of the domestic radio receiver was very rapid after 1922 and by the late 1930s had attained a level of performance which has only marginally improved since. During the 1950s the market for domestic radio receivers changed profoundly because of later inventions; one was the widespread adoption of television which ousted the radio receiver as the main medium of home entertainment; the second was the change to transistorised receivers which was ideally suited for new miniature portable sets for individual use thereby creating a a new, big market especially for the young with new 'pop' programmes. Another technical development was the introduction of Frequency Modulation (FM) which gave virtually perfect reproduction though British consumers were slow to adopt this.

The prime concern in this chapter will be with the pattern of product invention of the Amplitude Modulated (AM) domestic valve radio receiver which was the main type of wireless set for about forty years.
The radio industry had some advantages and peculiarities which will now be briefly noted.

5.1.1 Advantages

Record of Invention

An enormous literature exists covering radio invention from its earliest stages. One of the most extensive sources of references and bibliographies of radio science and invention has been given in The Proceedings Of The Institute of Radio Engineers (U.S.), while in Britain the publications of the British Institution of Radio Engineers, and part of the publications of the Institution of Electrical Engineers have been devoted to radio research reports. At a less professional level the publications of Wireless Societies were intended for radio enthusiasts and in Britain the publications of The Radio Society of Great Britain (R.S.G.B.) and the many radio journals, such as Wireless World and Practical Wireless catered for these needs. All these accounts are primarily of product inventions.[1]

The radio industry is one of the few which has such a rich record of incremental changes at the Product level. These are contained in journals which gave annual reports of Radio Exhibitions. In America Radio News did this comprehensively while in Britain Wireless World and trade journals especially The Broadcaster (1932 to 1939) presented such reports. An example of the idea of the analyses of incremental invention may be illustrated by the following quotation given in Wireless World in 1930 in its review of Radio Shows.[2] "To the student of design therefore the show is a summary of the year's progress. It is from this point of view that a study of the radio exhibitions in chronological order is instructive. One might almost construct a graph, with time as a basis and each show as a point, showing not only the rise and fall in popularity of individual components and principles, such as the horn loudspeaker, the crystal set and the neutrodyne, but also fluctuations in the productivity of ideas in general. The latter would be practically flat between 1922 and 1923 with a prominent peak at 1926". Whilst this interpretation of incremental invention may be questioned, the method of analysis is sound.

The radio industry also offers the opportunity for an unusual insight into the consumer-inventor relationship. Radio receiver technology, like bicycle technology, became a matter of great interest to the general public who, in the early years followed each new development and were not slow to voice their complaints about any problems. In Britain a series of articles and letters to The Times and gave a very clear view of this consumer feedback as the problems, needs and complaints of the listeners were frequently published.

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1 This analysis will concentrate on British and American radio literature. Other countries, of course, have their own descriptions of radio inventions - a series of interesting French articles appeared in the 1920s and 1930s; references to these appear in the Public Affairs Information Service annual indexes.

2 "Radio Shows in Retrospect: Milestones of Technical Development in Broadcast Receiver Design". Wireless World 1930, Sept 24, pp301-4.

5.1.2 Disadvantages

The above advantages are offset by some peculiarities which made the Radio industry different from the Bicycle industry. The main points are noted here.

Transmitter Needed

A radio receiver could not operate without a transmitter, so that the receiver and transmitter had to be developed simultaneously in the early stages at least. It was a matter of luck that the earliest radio transmitters and receivers were very similar and that a receiver was a transmitter "in reverse" and inventions were transferred between them. The technical development of radio transmitters later became more specialised and will not be considered in this chapter; Pawley (1972) has given a comprehensive account of British radio transmitter improvements used in public broadcasting services from 1922 to 1972. There were associated propagation problems which affected receiver design, these will be briefly noted in the later analysis.

Radio Invention was International

A common assumption central to most models of invention and growth is that new product industries in any country are generally the result of new inventions in that country. Britain was in the vanguard of much radio invention up to 1900, thereafter though she led in thermionic valve developments and in high fidelity designs from the 1930s, the main improvements came from abroad especially America, though many continental countries were also active in various radio fields.

Radio Industry Had more than Economic Significance

The importance of radio for military and security reasons has influenced radio invention and the industry; Freeman (1974) (pp 112-114) has noted this feature with each country advancing radio technology by creating special research institutes or by financing research in existing institutes or through commercial firms. This continued (and continues) in peace-time, and, as the development of military radar and computers showed, can later affect the (commercial) electronics industry.

Radio Patents

Patents exerted a much more profound effect upon the radio industry and market than in the case of the bicycle. Patents for radio inventions were somewhat unsuccessfully used to control the rate of technological development and more successfully used to create price-fixing agreements based on "trade associations" formed by firms which shared or pooled technical information, and distribution arrangements which precluded new entrants to the radio industry from the use of established retail outlets. Radio imports and exports were also controlled by international cartel arrangements based on patent rights. The degree to which radio invention was said to be either hindered or promoted by radio patents is uncertain; some, such as Marriott (1917) and Dalton (1975) considered that invention was promoted by them, though Sturmey (1958) and Maclaurin (1949) thought that on balance patents did not materially affect the rate of technological development of radio. Sturmey (1958) devoted a whole chapter of his book to a discussion of the effects of radio patents on the British radio industry while Maclaurin (1949) has dealt similarly with the U.S. radio industry.

Domestic Receiver Not The Only Type

Finally the domestic receiver used only part of a much wider range of radio signalling systems. Other types of special receivers were used for commercial, security and radio amateur communications and these deal with signals which cannot be intelligibly received on a domestic receiver. A variety of modulation methods were developed including Single Side Band, Double Side Band With Suppressed Carrier and Pulse Code modulation (which have recently been further changed to ´digital´ form) but public broadcasting began with Double Side Band amplitude modulation which continues to this day, and, in Britain, Frequency Modulation (FM) broadcasting was started in 1955 which also continues to the present day.

5.1.3 Organisation Of This Chapter

Aim of This Investigation

The objectives of this analysis of radio will be very similar to that of the bicycle. Product invention will again be examined at four levels, namely the Overall Configuration, Sub-Unit, (and to a lesser extent) Component level.

However in an attempt to reduce the length of the chapter, the analyses of product invention of the Tuned Radio Frequency (TRF) domestic radio receiver will deal with Sub-Units, components, consumer influences and economic influences as well as engineering design.
The next section will contain a shorter analysis of technical developments at the overall configuration level for other types of domestic receivers.
The remainder of this chapter will then closely follow the format used in the previous one dealing with process changes, price trends, output trends and demand factors.

As the radio industry has been cited as a leading example of a science-based one, the role of science in product invention will be examined with special reference to loudspeaker invention.

The results of these various analyses will be used to form a judgement about the pattern of product invention and its relationship to economic and other factors, and if product invention can be regarded as the resultant of three factors, namely technical, economic and consumer influences, as in the case of the Bicycle.

Chapter Structure

5.1.4 Product Design: Types Of Domestic Receiver

The first basic domestic receiver was the TRF whose overall configuration did not change as improvements to this type were made at the sub-unit level. These developments really combined invention, engineering design, economic and consumer influences. The analyses will show how TRF product inventions responded to these forces; the first analysis will combine both technical and consumer influences while the second analysis will deal with engineering design and economic influences. The TRF receiver was not the only type tried in these early years and the next part of this analysis will briefly describe product invention for some other TRF based designs including the Crystal Set, the Neutrodyne, the Homodyne and the Super-Regenerator. A more extended account will then be given of Superheterodyne (Superhet) broadcast receiver which eventually made the TRF obsolete and became the standard type of domestic radio receiver. Later the Frequency Modulation receiver and system was developed which partly rendered the superhet obsolete, and a brief account of F.M. development will be given.

5.1.5 Component Invention

Because of the great importance attached to thermionic valve inventions which some regarded as the critical events in radio technology, an overview is given of the nature of this part of product invention and its subsequent change to transistor and solid state devices.

5.1.6 Patents

This section will portray inventive activity associated with the radio industry at the aggregate level and also for specific types of receivers.

5.1.7 Science And Radio Invention

In this section the concept of radio product invention as an example of science-push development will be critically examined in terms of pioneer and incremental inventions and illustrated with reference to the technical development of the loudspeaker.

5.1.8 Process Invention and Price Trends

In this section the broad trends of change will be noted together with Price trends of British valve domestic receivers.

5.1.9 Changes Of Output

In this section an account will be given of the changes of homesales of the British radio industry.

5.1.10 Demand For Domestic Radio Receivers

In this section the social and economic factors which affected homesales will be analysed in the form used in the bicycle industry.

5.1.11 Invention and Growth

This section will summarise the main pattern of product invention and growth of homesales to see if it is similar to that of the bicycle industry.

Chronological Development Of Domestic Radio Receiver

Period	Main Inventions	Market Features
Incubation Stage: 1830 - 1919		
1830 - 1890	Experiments -various methods (electrostatic, induction & ground current systems).	No market; initial curiousity & scientific interest.
1890 - 1921	Successful transmission with Hertzian wave system; Wireless Telegraphy improvements with new, fundamental inventions made; telephony success 1915	Market possibilities perceived, commercial start & slow growth of W. T. Public broadcasting possibilities forseen.
Early Growth Stage 1920 - 1934		
1920/22-1934	First crude TRF sets rapidly improved by many inventions. Many inner-logic, problem-induced sequences but also unrelated pioneer inventions for new kinds (neutrodyne, homodyne, superhet etc.)	Initial novelty appeal; consumers became more critical about performance wanted louder, more sensitive, selective sets with better tone & less interference.
	Economic pressure led to cheap, simple sets; low current valves, battery eliminator.	Consumers became cost conscious.
	Consumer pressure led to easy-to-use inventions (single knob tuning, automatic circuit actions)	Consumers desired sets with attractive features safe to use, easy tuning.
	Changed environment forced inventions for greater bandpass selectivity, good tone, even lower current consumption battery models.	Market diversifies: some cheap low perf. models, some for v.high perf.

Mature Stage: 1935 - Present

1935 - 1939	Technical design virtually perfected; superhet now standard. Golden Age designs cheap & simple sets, but standard domestic model now 3 or 4v superhet. Inventions now mainly incremental "tidying up".	Market saturated consumer wants now supreme. Sales features & gimmicks widespread. Car & portable sets now technically good and very popular.
1945 -1960	Standard set design more basic than pre-1939 one, All-dry portable Receiver reliability now stressed. Transistors introduced. Process invention (printed circuit board) & ferrite aerial are the main inventions, later radical FM system and its hi-fi performance virtually perfect.	Exceptional postwar demand huge, but sharp stop-go changes in homesales. Television became very attractive, radio homesales decline. Small transistor portables attract young buyers; FM sales sluggish.
1960 on.	Valve designs now become obsolete. FM stereo introduced. Many new hi-fi designs Gimmicks reappear, many for ´pop´ sets.	Transistorised sets now universal. Market diversifies again; Hi-fi market grows. Features mainly stylistic for ´pop´ buyers.

5.2 Theories of Radio Receiver Design

Various theories of radio receiver invention have been suggested though few of these have been developed to any great extent.

Heroic Theory

The 'heroic' theory and its emphasis upon geniuses and their pioneer inventions forms the subject of recurring series in radio journals. Usually these accounts are little more than biographical sketches of particular inventors with no explanation for the causes or reasons for the sequence of technological development. Hawks (1927) is one example of this school. Susskind (1968/70) however is one of the few who has attempted a critical appraisal of the contribution of each of the great radio inventors and his researches indicate that no single inventor 'invented' radio; radio technology emerged from cumulative efforts.

Demand-Induced Design

Jome (1925) presented an early theory of demand-induced product design for American radio receivers. He considered that the type and performance of radio receivers was principally the result of consumer preferences. In the first years of broadcasting consumers were content with cheap, low performance crystal sets but soon consumers became more demanding and wanted multi-valve sets with much greater volume. Later still American consumers needed greater selectivity and hence new designs were created to meet this need, especially the early type of superhet. (In Britain the public was led by the B.B.Co. to appreciate good tonal quality and this may partly explain why British hi-fi designers led in such developments in the 1930s and 1940s).

A. P. Harrison (1979) has given a demand-induced explanation for the development of single knob tuning inventions and described their development between 1924 and the mid-1930s. He considered that the efforts by inventors had begun earlier than 1924 but that the great increase in ganged tuning mechanisms and then other associated inventions were primarily due to demand-pull.

Science-Push Theory

For thirty years after 1945 the science-push theory of radio development was by far the most popular of all. The origins of the science-push theory stretch back to at least the 1920s but the dramatic radio and radio-related inventions of the second world war made the science-push theory a natural choice especially as it was coupled with appeals for greater government funding of scientific research. Maclaurin (1949) put forward a powerful science-push theory (coupled with a Schumpeterian emphasis on entrepreneurship) which was echoed by others, for example Sturmey (1958). These science-push theories were of the simple linear type in which it was postulated that 'science discovered, technology applied'. The role of science in radio invention will be examined in a later section in this chapter; here it may be noted that since the mid-1970s the simple science-push theory of invention, as noted in the literature review, has been questioned.

'Managed Technology' Theory

Aitken (1976, 1985) has given considerable thought to the history of the technical development of radio and a theory of radio invention. His first model was based on an interpretation of the history of radio inventions up to the year 1900 and depicted a model of creativity in which novelty was said to emerge from a recombination of given elements, especially the transfer of knowledge between three social spheres which Aitken called Science, Technology and the Economy. Aitken was at pains to avoid the heroic view of invention "that has afflicted so many popular histories" (Aitken, 1985, p.16) and employed the concepts of information and communication theories to depict pioneer inventors as 'translators' who, by exchanges of information and resources at the interfaces of the three spheres, controlled the rate and direction of technological development of radio.

Aitken (1985) modified his first model because its limitations were revealed by his later analysis of radio development for the period 1900 to 1932.
Aitken considered that one major weakness in his 1976 theory was that it presented a linear science-push model in which new knowledge was generated by science, converted into useful devices by technology and then put to use by the economic system. This view had been rejected by historians of technology

by the 1980s because "it left unexplained vast areas of technological development and seriously underestimated the extent to which scientific advance depended on technology rather than vice versa". (1985, p.17). Aitken also considered his first model had presented the three social spheres as real entities whereas he now felt these were highly abstract categories and his first theory had encouraged a "two dimensional view of reality and a linear theory of causation". (p.18). The pattern of development in the period 1900 - 1932 had shown that science and technology overlapped, that economic forces now played a major role in determining technological change and technological decision-making. Because research now involved high costs, great attention was paid to expected returns, costs and benefits and funding criteria which ran counter to ideas expressed in his first model. Aitken's third reason for dissatisfaction was that he had omitted any reference to the government sector in the first model; although this was not very important in the nineteenth century it had become very important by the twentieth century as the government not only controlled the funding of research but was also the main consumer of the results of that expenditure. In general Aitken considered that his first model had presented an oversimplified view of interactions between the spheres, had overemphasised the separateness and distinctness of the spheres and had been logically too neat and tidy with his classifications.

In his second model Aitken (1985) retained his view of society as a system of interactive networks in which points of high inventive activity were regarded as points of confluence of information flows and the locus of 'translators'. The earlier emphasis on individuals and the biographical approach had given way to the concept of 'managed' technology which depended upon the policies of large organisations and the mixture of their own interests, new technology and market power. 'Managed' technology implied that large organisations used their decision-making power or policy to create and control new technology over its life span for both the national interest and the market; however control was not easy because often new technology produced results which could not have been predicted, for example when developments for one purpose were found to have ready application for other uses which turned out to have 'explosive' market growth which disrupted organisations and strategies. The history of radio developments in the first decades of the twentieth century fitted into this unpredictable category.

5.3 Radio Invention: Incubation Stage To 1919

Radio invention is a particularly complex affair and the analysis made in this chapter does not pretend to approach an Engineering History either in its scope or detail. Ideally one would wish to describe not only the development of successful radio receiver inventions but also the unsuccessful inventions. Dalton (1975) set out with a similar idea but found that it was too ambitious therefore in this section attention will be limited to the major successful valve receiver inventions.

The analysis of the bicycle showed that the whole Product development life-cycle could be divided into three stages namely the Incubation stage, the Early Growth stage and the Mature stage.
Evidence that radio invention broadly conformed to this three stage sequence can be obtained from the literature which will be cited below. Here it is noted that the Incubation stage covered developments up to 1919. The rapid technological change which occurred in the early years lasted until about 1934 so that for Britain the Early Growth period will be designated 1922-1934. Thereafter mainly marginal changes occurred in domestic receivers (the transistor and F.M. were exceptions) so that the Mature stage will be dated from 1935.

5.3.1 Wireless Telegraphy Incubation Period 1795-1897

The earliest attempts at "wire-less" communication made by inventors were executed without a clear idea of the principle upon which the final form would function, and consequently invention at this stage was exploratory.
If invention begins with ideas then ideas for 'wireless communication' date from the eighteenth century belief that a magnetised bar could induce sympathetic motion in another similar unconnected bar, or by the early nineteenth century expressions that electricity would somehow be used to communicate with others at a distance. None of these ideas were based on any technical design, but by the end of the 1830s certain electrical principles -

induction, electrostatic attraction and 'earth leakage' (ground current) - had been observed in action usually over small distances in experimental laboratories, and these principles were the logical starting points for early inventors.

Bibliographies of radio literature have been given by Radio Research Board (Special Report No. 9, 1930); Shiers (1972) and McCavitt (1978). Historical accounts of radio development have been given by Michels (1894), Fahie (1901, originally 1899), Blake (1923), Dalton (1975), Dummer (1983), Swinyard (1962) and Buff (1962).

Strictly speaking visible signalling systems which depended on natural or artificial light, are "wire-less" signals though these will not be considered here as they did not use 'radio' (or Hertzian) waves. These light-communication methods soon became quite sophisticated for example Bell's design of the 1890s used a microphone to modulate the intensity of an electric lamp with reflector and used a selenium cell (with reflector) as the receiver.

Ideas

Ideas form one major starting point for new inventions and in the case of wireless communication the earliest one appears, according to Fahie (1901), to have been made in 1795 using the sea as a conductor of electrical currents. The idea of wireless communication was also suggested by "Corpusculum" in a letter to Mechanics Magazine dated 1837, Dec 30. (according to an English Mechanic (1899, May 19 p.311 correspondent). It is not certain who was the 'first' inventor of wireless telegraphy; American writers say that Loomis's idea and demonstration of 1866 was first, others suggest that a Dane, Sorenson was first, his demonstration also being made in 1866.
This uncertainty about the contribution and originality of wireless inventors becomes even more complex in the later years of the incubation stage. Susskind (1968/1970) has considered this question at some length and given references to earlier literature on this topic.

Ideas can be accepted or rejected. Ideas which are rejected are usually opposed because of prejudice or vested interest. In 1868 Wheatstone (of electric telegraph fame) was asked during the 1867/68 Electric Telegraph Bill enquiry (Cmnd 435 Questions 1075 &1076), if the idea mentioned by a previous witness for a form of telegraphy "which rendered wires unnecessary" posed any threat to the (wired) telegraph system. Wheatstone replied "Certainly not, not that any practical result should ever come from it".

Both Lodge (1923) and Dalton (1975) have described and discussed the negative influences of eminent scientists on ideas, proposals or experiments. These negative attitudes can temporarily inhibit inventors, a famous example being that of Hughes who considered publishing the results of his 1879 experiments claiming reception of electromagnetic wave signals. He was dissuaded by scientists from doing this as they considered that the results were due to induction. However when experimental proof was given of the existence of radio waves the previous negative influences were swept away, and Hughes published his results in 1899.

Early "Wire-less" Systems

Michels (1894) in a review of early wireless experiments (which did not include Hertzian wave devices) said that the various experiments could be classed into three categories. These were the Electrostatic systems, Ground Current systems and Induction systems. It has already been noted that these methods originated in laboratories where the effects were obtained over very short distances, usually a few inches, and experimenters sought to increase the range.

Electrostatic Systems

The principle of operation of this system was that a conductor with a high electrostatic charge induced a fairly high charge of the opposite polarity in a nearby conductor. This principle had been discovered in electrostatic experiments and was a logical choice for "wire-less" communication. Loomis's experiment of 1866 exemplifies the type; he used two kites, each with a vertical wire conductor (aerial) which each led to identical equipment consisting of an induction coil and galvanometer each placed on two mountain tops. High voltage collected by one of the kites was shown to deflect the galvanometer of the other "receiver".

In America, Dolbear later experimented along these lines. Dalton (1975) noted that such an experiment was repeated in 1909, but Jome (1925) said that this electrostatic principle had never been a satisfactory one for wireless communication.

Ground Current Systems

The principle of operation of this system rested upon the discovery that electric currents were conducted by the earth. Inventors considered that this principle might form the basis of a wire-less system of communication. Michels noted that Steinheil had experimented with wired telegraphy in Germany in in 1837, and in the following year had tried to send signals along railway lines. This was unsuccessful but led to the important discovery that the earth itself was a good conductor of electricity. Steinheil then directed his attention to further experiments with ground currents in order to find out the patterns of potential difference and established that these could be detected about fifty feet away from the primary circuit. Others, including Morse in the U.S. continued to experiment with ground current systems but no commercial ´wire-less´ device emerged from them. The main reason for their failure was the high signal losses and the lack of amplification, although Wheatstone used a more sensitive relay amplifier in 1845. The Ground Current principle was extensively used elsewhere in the nineteenth century; Bell´s first telephone network had an earth-return. Inventions continued to be made in this field as the figures for patents granted for "Leakage Telegraphy and Telephony" (old British Class 40) indicate.

Induction Systems

The basic principle of the induction system was that a changing current flowing in a primary circuit would give rise to a changing current in a secondary circuit not in direct contact with the primary one. This principle had been first demonstrated by Faraday in 1831.

Morse appears to have been the first to attempt inductive wireless communication. He used two long pieces of wire which ran parallel to each other, one wire forming the primary circuit and the other forming the secondary. Although technically successful the major weakness was that it would have been both cheaper and better to connect the wires directly (as for wired telegraphy or wired telephony). This idea was extended by trying underwater induction (in the belief that water was a better conductor than air) and although technically successful the same objections held, namely that it was far cheaper and better to signal through direct wires. Many others continued to experiment with similar arrangements; in Britain, Lindsay duplicated Morse's set-up. Spasmodic repetitions were made in Britain in the 1880s and 1890s, notably by Preece in response to a government request for an improved form of communication with lightships; these attempts never became of commercial value. Dalton (1975) has given an extensive account of these later experiments.

Interrupted Induction

A variation was the Interrupted Induction system. Faraday discovered that changes in field strength depended upon changes in current flow, and experimenters incorporated an interrupter in their circuit to accentuate these changes. The rate of interruption was about 400 per second. There is considerable difficulty in saying whether or not this gave rise to radio waves and the general opinion is that they did not.

The earliest interrupted system appears to have been that of Hughes who in 1879 demonstrated that he could receive signals, up to 500 yards but as noted earlier he was dissuaded from continuing his experiments.

Another sophisticated version of this system is illustrated in Edison's 1892 patent application[3] which looks very like a true wireless system with high aerials, an earth and a description of possible uses (signalling at great distances to prevent ships colliding in fog) and optimal construction (aerials to be as high as possible to reduce the induction-absorbing effects of houses, trees and hills). Reed and Welch (1976, originally 1959) considered that Edison's system was a true Hertzian wave one. This may be so, but Edison's patent claim stated it was an induction system.

Inventions continued to be made in this mode, British patents contain a specific sub-class "Inductive Telegraphy and Telephony and Signalling"

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[3] Shown and described in the English Mechanic 1892, Feb 5, pp 524-525

(Class 40). In more recent times this system has proved useful for confined transmissions using Induction Loops, especially for hearing aid reception and in other cases for broadcasting in very small areas such as student radio and TV in colleges.

5.3.2 Hertzian or Radio Waves

The critical factor which determined success in radio communication was the generation and reception of radio waves. Even today it is difficult to define these waves precisely and distinguish them from electric, or magnetic fields but radio waves could travel vast distances at the speed of light with little loss, and this ultimately proved to be the satisfactory principle for radio communication.

Hertz is acknowledged to be the first inventor of a radio system involving the generation and reception of electromagnetic waves (or electric fields as Hertz called them). Hertz however had no concern with the application of these waves to radio communication, as Hertz's objective was to give experimental proof of Maxwell's Electromagnetic theory, and indeed Hertz rejected the idea that his system might be applied to wireless communication when it was suggested to him.

Hertz's research comprised a series of extremely well designed experiments due to both Hertz's scientific ideas (to test Maxwell's theory), and his (Hertz's) development and adaptation of known electrical technology which permitted Hertz to create a novel combination of elements to make the Spark system. Hertz's transmitter was the Spark-gap type with an inductance-capacitance oscillating circuit designed to operate at about 50MHz and which propagated by means of the spark discharge.

Hertz's receiver was also based on prior knowledge and principles, it was an air-gap ring detector of three to seven feet in diameter with an air-gap of a few thousandths of an inch. Hertz made the air-gap adjustable because he observed that he obtained a bigger spark at the resonant frequency. Hertz's receiver emanated visible signals (sparks) and permitted him to demonstrate that radio waves possessed all the properties which ordinary light possessed thus indisputably confirming Maxwell's speculative theory. He detected radio waves up to distances of 20 feet from his transmitter.

Quite apart from the scientific contribution Hertz made by his experiments, he also made it 'respectable' for other scientists to pursue investigations as he had established that radio waves existed, and further, that others were encouraged to think about radio communication.

Later inventors built upon Hertz's system and sought to increase the distance across which the radio waves travelled. As no method then existed for amplifying radio signals[4] this increased range could only be achieved by creating more sensitive receivers.
One of the basic difficulties was that wireless waves could not be sensed directly by humans and so a "detector" was needed to indicate the presence or absence of radio waves. Lodge used existing electrostatic principles to devise a 'knob-coherer' detector. Later in France, Branly discovered that metallic filings cohered in an r.f. environment and made highly sensitive detectors. Lodge improved Branly's coherer and used it in his demonstrations of wireless telegraphy in 1894.

Perception of Utility

The study of the bicycle showed that at some time in the Incubation period the advantages and utility of the proposed new device was perceived. In the case of the bicycle this occurred in 1869 when it was shown that cycling was faster than walking.
A comparable event in the history of radio occurred when Crookes, a British scientist, who had been closely following scientific progress in Hertzian wave experiments, felt sure that success was imminent. In 1892 he[5] had an article published in which he forecast the success of wireless (telegraphy), and noted that the immediate requirements were for a simpler generator of radio waves which could be of any desired frequency (i.e. a tuned transmitter), a more sensitive receiver and a method of directing the

4 Although relays had been used from 1845 as 'amplifiers' for (wired) telegraphs.
5 Fortnightly Review 1892, Feb. pp.173-181 "Some Possibilities Of Electricity".

transmitter waves. He also suggested the best uses for radio such as signalling to ships and in foggy weather. Whether this article actually stimulated others to work upon wireless (as Lodge (1923) emphasised) is a moot point, what is beyond doubt is that radio invention narrowed in scope and intensified after Crooke's paper was published.

Eccles (1930) has given detailed accounts of Lodge's receiver improvements from then. In 1894 Lodge demonstrated wireless telegraphic signalling over very short distances using a receiver which had a Branly-type coherer and elementary "aerial" and "earth" plates.

Many other aspiring radio inventors were busy in this period, 1892 -1896 and mention has already been made of Susskind's attempts to specify what each contributed. Pawley (1972) has also described these efforts and given further references.

5.3.3 Wireless Telegraphy Improvements To 1919

Marconi's Developments

The importance of Marconi's inventions cannot be overstated as they effectively led developments, Baker (1970), in his history of the Marconi Company has given detailed accounts and circuit diagrams of Marconi's early equipment. The overarching aim of Marconi was to put radio to the most profitable use and invention was one element in this. Marconi used invention to achieve technical performance, as this was the key to high economic returns and required greater range and the elimination of later problems which came to light in use and which speeded reception of WT signals.

Marconi's actions were initially guided by his ideas; in Italy his experiments in association with Righi, had led Marconi to believe that electromagnetic waves could bend round obstacles such as mountains, a concept not shared by scientists and which was to prove to be crucial later. Marconi also saw clearly that increased range of wireless communication could be achieved by concentrating the transmitted signal into a narrow frequency spectrum by tuning although he did not originate this idea.

In 1896 he came to Britain, because he considered that Britain's large shipping fleet offered the best commercial prospect and also because of family connections.

Marconi's field was partly defined for him because of legislation; the British Post Office controlled wired telegraphy and allocation of radio frequencies, while military interests were concerned to control their own radio developments. This left international radio communication open and Marconi developed wireless telegraphy for shipping and international communication. Marconi's improvements in wireless telegraphy were therefore influenced by economic and legislative factors and not solely due to 'invention-push', although he did not hesitate to purchase skill and 'know how' from others, for example he employed Fleming to supervise the design of a high power transmitter.

The Trend of Marconi's Invention

Vyvyan (1933) has given a detailed account of Marconi's contribution to the development of wireless telegraphy which is summarised here to show the trend. Marconi's earliest radio experiments were conducted in Italy before 1896 and he claimed to have succeeded in sending and receiving signals over a distance of about one and half miles using the 'high' frequencies employed by Hertz and Righi and the basic Spark transmitter. Marconi's first modification to the basic transmitter was to connect one of its spheres to a plate buried in the ground and the other sphere to an aerial screen mounted on a wooden pole; this new aerial and earth arrangement produced a improvement in performance.

In Britain, Marconi pushed his aerial and earth developments to the limit and by 1898 he found that aerials higher than 200 feet did not produce commensurate gains in range and that higher aerials needed costly structures. Marconi's next step was to increase the aerial signal voltage in the tuning stage of the receiver by using an r.f. step-up transformer or 'jigger' as it was then called.[6] Baker (1970, pp.27-58) has given a series of circuit diagrams showing Marconi's early jigger arrangements which soon incorporated

6 It was customary in the period up to about 1939 to use "h.f." (high frequency) instead of the modern term "r.f." (radio frequency). Throughout this chapter the term r.f. will be used.

capacitors for tuning. It was later found that the degree of jigger coupling affected the selectivity of the tuning circuit; loose coupling did not dampen the tuning circuit and therefore did not reduce its selectivity. This feature became important in early broadcast receivers. Marconi then decided to develop an earlier idea[7] - that of tuning (syntony) - in order to increase the range by concentrating the radiated energy at as near to a specific frequency as was possible with Spark transmitters. He then resorted to the use of greater transmitter powers to increase the range.

Marconi then set out to increase the sensitivity of his receivers and this was initially achieved by the use of a modified form of Branly's coherer. Marconi then developed an old idea previously used in wired telegraphy - multiplex working - to send and receive simultaneously at lower cost; in order to do this he had to separate the transmitter and receiver, and found that this arrangement was liable to interference from local transmitters so that Marconi was forced to devise some method of counteracting this interference which he did by an ingenious arrangement of aerials. Marconi further increased the useful range of transmission by the invention of a more sensitive detector; here again he borrowed an old idea and developed it. Rutherford had discovered that oscillations in a coil around a magnetised core de-magnetised the core, and Marconi based his new detector upon this principle. This proved wholly satisfactory with an unexpected bonus in that the periodic signals it produced were heard as a tone of definite pitch which made it much easier for the listener to distinguish the signal from 'atmospherics'.

By this time, 1900, Marconi was able to communicate over distances of about

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7 Hertz's realisation of the benefits of tuning have already been noted. The English Mechanic 1894, Dec 7, pp359-360 described how two German researchers had found that the best performance of a gas-discharge light was obtained when the secondary circuit was tuned exactly to the primary circuit frequency. Some qualification must be added to the popular statement that Lodge 'invented' tuning, though as Eccles (1930) observed, Lodge's 1897 patent contained many sophisticated ideas including tuning by means of 'syntonic jars'. Many others in different countries were working on equivalent designs based on the same principle, namely that of passing the aerial current through a selective tuned circuit. In Britain Muirhead (as well as Lodge) proposed such a design, while in Germany Slaby, von Arco and Braun, and Stone in the U.S. were similarly engaged.

150 miles and he was convinced that it was feasible to extend this to any distance - even right round the world. This belief was not shared by those scientists who considered that wireless waves could only travel in straight lines and not bend, consequently when Marconi first claimed that he had sent a signal across the Atlantic many doubted the validity of his claim. Marconi was able to prove that a telegraphic receiver could print these messages which showed that his claim was true. The following four years, 1902 to 1906, Vyvyan said, were ones of a series of baffling problems which were the result of factors not understood at that time. For example it was not fully appreciated that wireless wave propagation differed in daylight compared with dark, or that different frequencies had different propagation characteristics. Marconi responded to these problems by devising new solutions, one of these was to concentrate the radiated energy even further by a spinning disc system in order to approach continuous wave signals though in turn this was not picked up by his magnetic detector so that Marconi reverted to partially damped waves. Another development was Marconi's adoption of 'long waves for long distances' - an empirical rule which remained until the advent of short wave transmissions in the early 1920s.

By 1906 or so Marconi's system of wireless telegraphy was reliable and commercially viable; it was most useful for ships and the benefits were recognised at times of disaster (such as the sinking of The Titanic)[8] and by 1911 international shipping regulations required large vessels to be fitted with wireless telegraphic apparatus. The biggest problem Marconi faced in this post-1906 period was trouble from atmospherics which frequently necessitated messages to be repeated and always to be sent at slow speeds; the invention of the Balanced Crystal Unit by Round proved to be a fairly satisfactory method of reducing such interference, and Marconi was able to concentrate upon the commercial aspects of his business from this time.

Marconi's efforts show clearly how he used invention to produce a technically satisfactory form of wireless telegraphy which had an economic value and how his inventions were directed to making this performance the most rewarding and economical for the limited market to which he had access. His inventions

8 The Titanic had radio telegraphy apparatus fitted.

were induced by a combination of ideas, technical problems and economic conditions and clearly show a trend pattern of 'inner logic' relatedness.

Other Inventions

It would be wrong to imagine that Marconi was the only improver of radio devices at this time. Many others in different countries but especially in America and Germany were very actively seeking leadership in wireless telegraphy. The governments of these countries (and Britain too) were interested in state and security aspects and for this reason gave their nationals every encouragement to develop their inventions.[9] All this effort was intensified during the first world war and by 1918 wireless telegraphy was if not a science then at least a practice conducted using established engineering principles, with transmission, reception, circuits and components being fully operational with formulae for their design.

American Developments

Marriott (1917) has given an account of the factors which affected American wireless telegraphy development up to 1916 which shows the inter-relations between technological and other factors as well as throwing light on the nature of invention. His paper is summarised here.

The novelty of Marriott's account lay in his use of charts to show the rise and fall of the importance of various technical inventions in different years. For example he portrayed the rise and fall of different types of detector throughout this period; the first of these was the Coherer begun in 1900 and peaked in 1903; the use of the 'Microphone' (microphonic detector) began in 1901 and peaked in 1904 and by 1906 had been phased out. The uses of the Electrolytic detector began in 1903, peaked in 1905 and was phased out before 1907; the Crystal detector was introduced in 1905 peaked in 1913 and slowly declined thereafter. The Audion (thermionic valve) began in 1906 had a very slow rise until 1913 and thereafter rose rapidly, while at this same time the Beat detector (heterodyne) began in 1909 was little used until 1913 and

[9] This was partly the reason for encouraging radio amateurs in all countries. In Britain radio amateurs were licensed from 1904. Dalton (1975) has given details.

thereafter rose rapidly in importance too. The overall pattern of detector invention and use was a series of transient curves in which earlier devices were made obsolete by later ones.
Marriott repeated this presentation for various types of interrupter, forms of aerials, measuring devices, types of power, and so on.

Marriott considered that one reason for the rapid improvement in radio technology had been the increasing numbers of radio inventors and this had partly been attained by the formation of Wireless Societies which led to increased knowledge and recruited radio enthusiasts.

Marriott then went on to chart some non-technical factors which he considered had been important in radio development. He considered that Standardisation had been important as a means of keeping down first costs and maintenance costs but that latterly it had obstructed improvement. Marriott then considered the influence of Stock Jobbing, share speculation, which he said depended initially upon assets and activity, assets could be either Patents or Capital Equipment and noted that "a patent was usually cheaper than a station which probably accounts for many radio patents". This Stock activity increased the use of marine radio and the development of science up to 1911, thereafter regulations were the chief determinant of use. Marriott then considered the attempts at to establish Overland Radio, in opposition to wired telegraphy systems, and these efforts begun in 1903 peaked in 1909 but rapidly declined due to technical problems especially summer atmospherics and mutual (radio station) interference. Marriott then considered Organisation, in the early days of radio there were a large number of small firms, later larger long-lived firms became important. At the start of the U.S. radio industry manufacturing was undertaken by the operating firms themselves, later specialised manufacturing companies arose largely because of government orders. The public had regarded radio as a scientific toy until it proved itself very useful when ships sank and regulations became a more important factor after 1911. Regulations also affected interference and power supply conditions.
Patent Litigation, Marriott said, had affected radio development in various ways, for example the Marconi case had led to the development of the Loop

Antenna while Fessenden's case concerning the Electrolytic detector had led to increased use of Crystal detectors. Patent Litigation also led to working agreements being established between companies.

No clear pattern existed among the groups of factors given by Marriott, although within each technical group the temporal succession pattern was clear. The overall technical trend was one of increasing range of communication in this period. The growth of the industry was reflected in the increasing number of transmitters, and Marriott implied that this depended largely upon non-technical factors, especially legislation.

Wireless Telegraphy: Sub-Assembly and Component Inventions

A great many other improvements were made to wireless telegraphy circuits and components in this period though no detailed account of this invention will be given here. Dummer (1956-1961) has given an extensive account of radio component invention. Dalton (1975) has shown how improvements to early wireless telegraphy components circuits made them much more efficient, smaller and cheaper. These improvements to established components were paralleled by exploratory inventions made at this time, for example Fleming's thermionic diode or Dunwoody's rectifying crystal - neither was sufficiently successful to make alternative devices obsolete then, but both were to profoundly influence radio technology many years later. All these wireless telegraphy inventions made cumulative improvements which were carried forward later to wireless telephony techniques and circuits.

Wireless Telegraphy Receivers

The earliest receivers for Wireless Telephony signals were simply the same designs which were used for wireless telegraphy provided they used a suitable detector and headphones. A number of receiver circuits had been devised by radio amateurs and of course by wireless telegraphy firms from about 1910 in Britain and other countries. Hill (1978) gave an illustration of the "Horophone" - a crystal set made in London in 1914 for the reception of Morse time signals from Paris (for watchmakers - hence the name) though it would have satisfactorily received wireless telephony without any alteration. A number of wireless telegraphy valve receivers were made in this period some of which were quite suitable for the reception of wireless telephony and these formed the basis of the first domestic TRF radio receivers used from 1920.

5.3.4 Wireless Telephony Incubation Period 1900 -1919

The success of wireless telegraphy led others to consider a similar method of wireless telephony. The basic requirement was to modulate a continuous carrier wave with an audio signal. The greatest initial difficulty was to produce a continuous carrier wave as opposed to the train of damped waves which the Spark transmitter produced - with its consequent "splatter" of frequencies. Fessenden (1908) has described the trends of development up to that time and of his first wireless telephony experiments in 1899/1900. These were unsuccessful for two reasons, firstly it sent out a train of damped waves which rendered speech and music unintelligible due to distortion, and secondly Fessenden's method of (transmitter) modulation had its special problems. The key requirement was for a better kind of transmitter to give an output nearer to continuous waves. Pawley (1972) has described the various experiments, made in many countries, up to 1914. In general the Poulsen Arc and High Speed Alternator transmitters were used in this period. Fessenden achieved the 'first' broadcast of wireless telephony in 1906 using a High Speed Alternator. From 1910 various inventions were tried to quench the spark so that the output of the spark transmitter would be nearer to a continuous wave.

Once the thermionic valve oscillator had been invented in 1913, it proved to be the ideal type giving completely continuous waves so solving the continuous wave problem. In 1915 an American company (A.T.T.) gave a very successful demonstration of long distance wireless telephony transmission and reception using hard valves in cascade. Further developments were undertaken once the war was over.

5.4 Early Growth Stage: Domestic Receiver Invention

5.4.1 Introduction: Background To Broadcasting

The special difficulties surrounding the introduction of public broadcasting in Britain have been noted by Sturmey (1958). Some of these difficulties sprang from the observation of earlier American experience. The hesitant commercial start of receiver sales in America has been described by Herron (1969) who recounted how manufacturers designed and produced valve receivers in anticipation of demand. Westinghouse's set was intended to retail at 125 dollars but the price was too high and the model was a market failure. Westinghouse then produced a kit of parts for the home constructor, to retail at 10 dollars, but this was too complicated for the ordinary listener. Westinghouse then introduced a range of crystal sets, priced from 12.5 to 47.5 dollars ready built and complete with headphones and aerial. The cheapest model, the Aeriola Junior, was a "smash success" and sold in thousands. However by 1922 radio had become a craze in America with much mutual interference by transmitters and an 'over crowded wavelength' which rendered crystal sets obsolete because of their lack of selectivity and resulted in later government control of frequency allocations.

These American events had not gone unobserved by the British government who decided that the B.B.Co. had to provide a national network of transmitters suited for crystal set reception.[10]

Another British stipulation was that all receivers to be sold to the public had to bear a stamp of approval to indicate that it did not re-radiate r.f. from its own aerial and that it was of British manufacture. This stipulation applied from Dec 1922 to Dec 1924 and meant that receivers for sale could not have Reaction, while home constructed models could. In early radio receivers "reaction" (positive feedback) was often used to enhance the receiver's performance, in skilled hands this posed no problem but when unskilled listeners used it they frequently set it to excessive levels which caused their set to go into 'self-oscillation' and which induced 'howls' in their own and their neighbours' sets.

These factors together with arguments about the provision of transmitters and control of public broadcasting accounted for the lengthy delay of the start of British broadcasting.

[10] Throughout this chapter the abbreviation 'B.B.Co.' refers to the British Broadcasting Company Ltd which existed between 1922 and Nov 1926; the abbreviation 'B.B.C.' refers to the British Broadcasting Corporation which existed from Dec 1926.

Pattern Of Product Invention

The analysis of Product invention in the Bicycle industry showed that the most intense effort and the major product changes occurred in the Early Growth stage. If this was a general pattern then it suggests that domestic radio receiver invention would peak, then decrease after the commercial start of the new industry. Evidence that this occurred was given in the B.B.C. Year-Book 1932 (p.377) "No outstanding or radical developments in the design of receivers during the year. Steady progress has been made in many directions but this progress has been in the nature of applying well-known principles more carefully, rather than in the discovery and adoption of new principles". while Nature 1931, (128 p. 553) stated "This (radio) exhibition supports the idea which was becoming evident last year, that the radio manufacturing industry has passed through its somewhat uncertain experimental stage to that of steady development along trustworthy and well established lines."

It follows that the most active period of product invention occurred in Britain in the first ten years of public broadcasting, say from 1922 to 1932 and that attention should be concentrated upon this period in order to establish the nature of major receiver product inventions and their causes.

5.4.2 The Tuned Radio Frequency (TRF) Receiver

A domestic TRF radio receiver can be regarded as a linear sequence of sub-units each of which has a specific technical function and comprised the following sub-units: the Aerial circuit, the Tuning stage, the Detector, the Audio Frequency (A.F.) Amplifier stage, and finally the Reproducer (headphones or loudspeaker). The development of the loudspeaker will be discussed later in the Science section of this chapter.

Technical performance is multi-dimensional but for a radio receiver the basic criteria are Selectivity, Sensitivity and Tone Purity; the first refers to the ability of the set to separate wanted from unwanted transmissions, the second refers to its ability to pick up weak signals and the last refers to its quality of reproduction.

Aerial and Associated Inventions

The prime function of the aerial and earth system was to ensure that as large a signal as possible was fed to the receiver, especially in the early years

when r.f. valve amplification was very poor. Boltz (1944) noted than in the early years there was a great deal of discussion in books and periodicals about the best types or forms of aerial.
Previous experience with wireless telegraphy had led to the empirical development and improvement of aerials and this was transferred to broadcast receivers when broadcasting began. This previous experience had shown that single line high aerials were best and that aerials composed of stranded wire were superior to thick solid aerial conductors. When public broadcasting began in Britain in 1922, the Postmaster General issued regulations which stipulated that domestic listeners could not have aerials longer than one hundred feet although there was much controversy about the best configuration for this line aerial.

In the first years of broadcasting the main discussion centred upon the best configuration for the aerial and every conceivable form was tried; these forms included rod, whip, L-shaped, T-shaped, dipole, umbrella, multi-line and frame types. It was also realised that good aerial insulators were necessary to prevent the collected signal from leaking. The National Physical Laboratory (NPL)/Radio Research Board tested various arrangements for domestic line aerial and earth configurations, and found that the L-shaped type was best for domestic receivers.[11]

However experience soon revealed that a well designed aerial by itself was not sufficient to ensure good reception and that a number of complicating factors were also involved. In the first years of broadcasting listeners believed that each receiver had a particular "range" limit, Burrows (1923) for example gave the range of a crystal set as 15 miles for headphone listening, while a 2-valve set supposedly had a range of 10 miles and a 5-valve set had a range of 80-miles. These ranges really reflected the r.f. amplification ability of each design but experience showed that signal strength did not conform to some constant square-law but was affected by other factors. It took some time to find out which factors affected signal

[11] The Times 1925, July 29, p.19 reported that the optimal configuration was 50 ft high and 50 ft long, the best earth arrangement was a "screen of wires" (counterpoise) under the aerial but insulated from the earth itself.

propagation from the transmitter; as far a ground wave patterns for medium or long wave stations was concerned it became appreciated that the field strength at the listener's aerial depended upon Ground Absorption (which was affected by the earth, the topography and especially any surrounding steel erection (such as bridges or gasometers). In addition propagation patterns differed for different signal frequencies, and usually higher frequencies met with greater difficulties.

Some indication of the propagation curiosities appeared in The Times 1923.[12]

The most important determinant of local station signal strength was the power radiated at the transmitter but in the first years of broadcasting in Britain this was ludicrously small, being only one and a half kilowatts. This power was gradually increased during the 1920s and 1930s in order to increase the "range" of each transmitter.

Night time propagation patterns were entirely different due to 'sky wave' reflection and skip distance effects made it common to receive some distant stations much louder than some nearer ones.

As r.f. amplification improved, due to more efficient valve designs, the need for efficient aerials declined. The aerial itself had capacitance and inductance and therefore r.f. characteristics including a natural frequency of operation. Methods of tuning aerials were developed, the most common being the inclusion of an aerial tuning capacitor in the receiver; a few sets (especially later crystal sets) had an aerial loading coil fitted for the same reason. Another aerial design had some kind of impedance-matching device (usually a transformer) interposed between the aerial and the receiver so that maximum energy would be transferred from the aerial to the set.

The most efficient aerial array was one which had separate aerials for Long, Medium (and later Short) waves with tuning and impedance matching, Camm (1941) has given a good description of these kinds in his section on Aerials.

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[12] The Times 1923, Jan 8, p9 in an article on Blind Spots described how some areas, such as Didcot, could hardly hear signals at all, while others reported a strange differential pattern of good local reception, very weak reception from transmitters about 200 miles away, and very loud reception from more distant transmitters about 400 miles from the receiver.

By the 1930s the technical necessity for large, efficient aerials had gone due to a combination of stronger transmission powers and much more efficient r.f. amplification in receivers. Indeed the rising amount of man-made interference from domestic, industrial and motor vehicle ignition systems meant that the more efficient the aerial the greater the interference signal. One consequence of this was the design of a variety of anti-interference aerials in which signal gathering was traded-off with interference reducing performance.

The most common design was some kind of differential (or balancing) amplifier with one input having as strong a signal as possible and the other input having as great an interfering signal as possible, the output with reduced interference being fed in to the receiver. In Britain in the 1930s one firm (Belling & Lee) created a large market for their type of anti-interference aerial. However the best solution came gradually as legislation was passed making it necessary for the offending equipment to be fitted with suppressors, but during the 1930s the cheapest and simplest solution was to use poor aerials hence the widespread adoption of picture-rail and "mains" aerials.

Consumer Influence on Aerial Invention

Not all listeners could use the optimal line aerials so further changes were made. There were various reasons for more compact aerials. Some considered that aerials disfigured their property, as the Sykes Report (1923) noted; others either could not or were not allowed to erect 100 foot aerials, for example flat dwellers often could not, while many tenants had leases which forbade erection of structures such as large aerials.

Frame Aerials

The frame aerial had been developed during the 1914-18 war largely because of its directional properties and was used for direction finding. An article in the B.B.C. Year-Book[13] explained the principle of the frame aerial.

The working principle was different from the ordinary line aerial. The incoming signal created a separate voltage in each plane of the frame aerial as it travelled so the current flowed when ever there was a temporal

[13] B.B.C. Year-Book 1932, pp 413-424

difference between the planes. Thus when the frame aerial was broadside (at right angles) to the desired signal path there was no temporal difference and no current, this was a null position. This bonus feature was used to increase selectivity by rotating the frame aerial to 'null out' an unwanted transmissions or 'atmospherics'. When the frame aerial was oriented in line with the signal path, a current difference existed between the planes and current flowed around the frame. The chief advantages of the Frame Aerial were its portability and directivity. Larger frame aerials gathered larger signals than small ones, though even the largest practical size was not as powerful as an ordinary line aerial.

The frame aerial had another bonus feature which was important in the early days of public broadcasting. It reduced the re-radiation due to Reaction and therefore reduced interference to neighbouring receivers. Thus the frame aerial allowed the listener to use a greater degree of reaction than was possible with the ordinary 100 foot aerial.

A further improvement which could be made to a frame aerial was to tune it by fitting a variable capacitor across its terminals thereby increasing selectivity. This was further enhanced if the frame aerial was made "active" (by reaction).[14]

Other Types of Domestic Aerials

Other kinds of more compact aerials were developed during the early 1920s. The Capacity aerial was very popular then, this consisted of two or more hoops, or a bundle of short wires like the end of a broom, and the proximity of these wires provided a capacity effect which enhanced its signal gathering property. A variant of this was a Plate aerial which was a sheet of metal having capacity. These capacity aerials were intended either for inside use or fixed to the top of windows or chimneys.

Another compact alternative was the Mains aerial which separated the r.f. signals picked up by the electricity supply wires. A filter was used to

[14] Radio amateurs still use this arrangement. A recent issue of Practical Wireless (1981, March) described various types of Active and Loop aerials for radio 'DXing' (distant listening) enthusiasts.

separate the r.f. from the mains currents. This aerial was very suitable in the late 1920s and 1930s when r.f. amplification had become much more efficient and many commercial receivers incorporated it internally.

The simplest kind of indoor aerial was simply a "picture-rail" wire strung around the room and this became very popular once high amplification r.f. valves had been developed.

The fear of an aerial being hit by lightning led to the invention of various types of anti-lightning devices which were fitted to aerials, most of these operated on the 'gap' principle so that any high voltage jumped across the gap and was earthed thus making the receiver safe.

Modern Receiver Aerials

The Ferrite aerial was introduced for domestic receivers in 1950. This was a very compact design of "frame" aerial which had directional properties. The ferrite aerial used special material which had been developed initially in the 1930s for "iron-cored" coils. Pawley (1972) noted that the relative inefficiency of the Ferrite rod aerial led to transmission powers being increased to compensate for this, and the ferrite rod aerial has remained the standard one for most types of domestic AM receivers until the present day.

5.4.3 Tuning Circuit

The principal function of the tuning circuit of any domestic receiver is to select only the desired transmission frequency and reject all others. The trend of tuning circuit invention and improvement was largely governed by technical factors which were complex and involved many secondary problems, though consumer influences also impinged upon tuning circuit design.

Early Tuning Circuits had very poor selectivity as this illustration from The Times 1925 showed.[15] The article was a plea for better design to give greater selectivity and noted that existing "modern" sets could separate 2LO (365 metres) "at two miles" from Aberdeen (495m), Birmingham (479m), Glasgow

[15] The Times 1925, Nov 5, p.8.

(422m), Newcastle (404m), and Belfast (440m) "if not Manchester (378m) Bournemouth (386m) and Cardiff (353m)". (Wavelengths added). This shows the selectivity of these early TRF sets was unsatisfactory as local London listeners, tuned to 2LO, were liable to hear Manchester or Bournemouth or Cardiff as well.

Tuning Circuit Improvements

In the early years of public broadcasting there was no pressing need for highly selective receivers because there were relatively few stations and most of these operated at low power. Quite often many of the early TRF sets dispensed with r.f. valves and used only a simple (valveless) tuned circuit. The detailed methods of improving selectivity are complicated and only an outline will be given of the nature of these selectivity inventions.

A variety of inventions were made to improve the selectivity of domestic receivers; additional tuning circuits were added, tuning circuits were 'neutralised', reaction was used, wavetraps and filters were fitted, transmitter frequencies were re-allocated to compensate for poor receiver selectivity and finally the lasting solution came from the development of selective bandpass tuning circuits.

Additional Tuning Circuits

The main idea of this type of improvement was to have a series of tunable circuits which, theoretically, should have increased selectivity. This often began by making the Aerial circuit tunable (as noted in the previous section), and in receivers which used r.f. valves, additional tunable circuits were added. The high inter-electrode capacity of early r.f. valves led to great instability which made a series of r.f. tuning circuits impractical and hence this type of improvement was not satisfactory. (It also led to decoupling circuits for each valve).

Neutralised Tuning Circuits

This form of improvement primarily referred to methods of neutralising the inter-electrode capacity of the early r.f. valves by the use of special components and other screening and layout improvements which reduced the stray r.f. currents and capacity effects around the tuning circuit. These will be discussed in a later section dealing with the Neutrodyne receiver.

Reaction

The simplest and most effective way of increasing selectivity in early domestic receivers was by the use of reaction and various methods of doing this had been invented by 1913 using either capactive or inductive or resistive circuits. Reaction was prohibited in manufactured (but not home constructed) sets. This requirement lasted until 1926 then with the invention of the screen grid valve in 1927 it became possible for TRF sets to employ Reaction without re-radiating through the aerial.

Improved Reaction Circuits

The first improvements to reaction circuits sought to reap the advantages of reaction without its disadvantages, and the primary aim was to limit the amount of feedback so that it would not make the set re-radiate. A variety of inventions were proposed to counter this, including Lodge's X-circuit but these were made obsolete by the invention of the screen-grid valve in 1927. From that time the efficiency of r.f. amplification meant that it was no longer necessary to use reaction to bring up weak signals but rather to incorporate a volume control to reduce strong signals and thus reduce valve overloading. In the early years the reaction control was regarded as the volume control.[16]

Reaction however was not always satisfactory as various kinds of interference had to be dealt with. "Shock excitation" or breakthrough was a common form of poor selectivity which manifest itself either as the continuous reception of a strong local transmission regardless of the position of the tuning knob on say the medium wave, or else the reception of this strong local station on the long wave. This was cured by good design which prevented the tuning circuit from being swamped by the strong local signal. It was noted[17] that in 1929 almost every radio receiver had adjustable (differential) reaction. This differential reaction capacitor kept the anode-capacitance value constant regardless of the level of feedback and made reaction control much more

16 According to The Times 1927 Sept 20 p.7
17 Wireless World 1930 p.367 "Lessons Of The Show".

stable and smooth; it was used in cheaper TRF sets until 1939. Yet by 1930 some receivers were without reaction due to better circuit design, screening and greater r.f. gain so that the need for high levels of reaction had been reduced and low fixed (non-variable) reaction circuits were used which would not 'howl'. Such design improvements, of course, increased both selectivity and sensitivity.

Wavetraps and Filters

The Wavetrap which increased selectivity had been developed during the 1914-18 war and consisted of a tunable circuit. Wavetraps could be of two types, one the Acceptor wavetrap absorbed all unwanted frequencies, while the other was the Rejector which rejected all unwanted frequencies. Wavetrap circuits were added at some stage before the basic tuning circuit and required considerable knowledge and skill for their proper adjustment. This circuit could be entirely within the set, or it could be an external small frame aerial for use in conjunction with a larger frame aerial. Its use was mainly to reject some adjacent powerful transmission close to the desired one, and a rejector wavetrap would be tuned to the undesired transmission frequency which was 'bled-off' thus reducing the interference.

Another accessory which effectively increased selectivity was the Heterodyne Filter. This device was fitted at the audio amplifier stage and consisted of a tuned filter which rejected the 9kHz whistle due to inter-station heterodyning.

Frequency Re-Allocation

Selectivity problems were also reduced by organisational changes and was an 'external' improvement similar to better roads to reduce bicycle vibration.

Wavelength Re-Allocation ensured that transmitters which were geographically close had carrier frequencies which were widely separated. This was an international problem and frequent conferences were held to make the best allocations possible. Two early ones were the Geneva Plan of 1926 and the Prague Plan of 1929. Both were characterised by tests before the final agreement. The increasing numbers of countries wishing their own wavelengths prompted the frequent re-allocations and this ultimately led to the use of higher frequencies beginning with Short Wave bands in the late 1920s and to

VHF frequencies after 1945.

Later Selectivity Improvements

By 1929 the increased numbers and powers of Continental transmitters caused much interference. It was noted[18] that the urgent need for much improved selectivity had led to a number of proposed new designs. One early American idea suggested by Carson of ATT, was to adopt Single Side Band transmission (which had been developed in 1915). Another idea was for the Stenode Radiostat transmission system which its inventor claimed could effectively broadcast the same signal using only one fiftieth of the bandwidth of the ordinary transmitter - a design which others thought impossible. Another suggestion was for the Stenode Radiostat receiver which had a very narrow "i.f" bandwidth and a piezo crystal and a tone corrected a.f. circuit. These improved selectivity circuits demonstrate again the designer's need to trade-off great selectivity against loss of high notes. The Stenode receiver had been demonstrated and The Times correspondent thought that some form of quenching might be needed as it did not follow rapidly varying signals too well. The Broadcaster Trade Annual of 1932 noted that 'congestion of the aether' had led to Broadcast Relay Systems (or wired wireless) being introduced as well; Sturmey (1958) has given a lengthy account of the different types of this system in his chapter 12.

By 1931 inter-station interference had become acute in Britain due to the recent wavelength re-allocations and it was considered that a more selective type of receiver was likely to be developed.[19]

Bandpass Tuning Circuits

The real improvement in selectivity was effected by the adoption of Bandpass Tuning and subsequent minor improvements to coils and coil-cores. The Bandpass design was a circuit with two (or more) highly selective tuned circuits each tuned to slightly different frequencies thus allowing a narrow band of frequencies to be passed and ideally these would correspond to the band width of the desired transmission. Bandpass circuits were further improved by detailed inventions such as low loss coil design and the

18 The Times 1929 Nov 29 p.11
19 The Times 1931 April 16 p.16

introduction of iron-cored coils. By 1933 TRF selectivity had reached a satisfactory level as far as the ordinary listener (who was interested only in good quality sound from a British transmission), as the test report of TRF receivers then showed. For example the Wireless World account of the 1931 radio exhibition dealing with TRF receivers noted that bandpass tuning was almost universal on these with ganging and the associated simplification of tuning operations which was accompanied by a trend to large dials with either the frequencies or actual station names marked on them.

By 1932, as the Wireless World test report on the Ecko Three valve TRF model M.23[20] noted, selectivity was very good with a sharp cut-off at 10kHz and freedom from M.W./L.W. breakthrough or local station interference. Bandpass tuning and good design had been responsible for this and this model was considered to give far above average performance in this respect.

By 1934 TRF design had reached a very high level and selectivity could be equal to current superhet standards. The Philips "Superinductance" (Model 636a) exemplified this as the test report[21] observed. This had been achieved by good design centred on bandpass tuning together with ´superinductance´ (iron-cored coils), tuned r.f. transformers, a.v.c., etc., and besides giving high selectivity, made the set easy to tune. Yet as Rust, Keall, Ramsay and Sturley (1941) noted, the average receiver of the late 1930s were excessively selective having a bandwidth of about +/- 5kc/s (p.87). This was a further illustration of trade-off as greater bandwidth highlighted other undesired effects especially atmospherics, sideband ´splash´ and inter-station heterodyne whistles each of which required further circuitry and therefore incorporated only in very expensive receivers.

Consumer Influence Upon Tuning Design

Inventors had not only to produce a technically satisfactory design, they also had to consider the needs of the consumer. Tuning was a skilled operation in the early sets, and inventors had to make receivers easier to tune accurately. This was achieved in two ways, one was consumer education, the other was easier single knob tuning.

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20 Wireless World 1932, 31, p.264

21 Wireless World 1934, 34, p.97; & 1934, 35, pp.256-257.

Consumer Education

Consumer education sought to teach listeners how to tune their early sets properly and to learn to recognise the different kinds of interference that existed. For example if two transmissions were on adjacent frequencies the listener heard a whistle of continuous pitch which did not vary as he altered the tuning knob. On the other hand a whistle which did change pitch as he turned the tuning knob would most likely be due to reaction from his own set.[22] This must have been very confusing for ordinary listeners. The main issue, of course was to try and reduce reaction howl, and at the same time tune to the desired (usually distant) station.

Inventions to Simplify Tuning

Early TRF sets had a great number of tuning controls which unskilled listeners found almost impossible to operate.[23] Such Tuning complexity led to the obvious objective of 'single knob' tuning which Wireless World noted in its 1930 Show Report, had become regarded as of paramount importance by unskilled listeners.

Ganging, to provide Single Knob tuning had developed from earlier inventions like Edgewise tuning which employed two separate knobs so that both circuits could be changed by nearly equal amounts and, if the listener was skilled, fine-tuned equivalent to Bandpass. Some other improvements contributed to simplification; The Times[24] noted that the introduction of Dull Emitter valves had eliminated rheostat controls as the coatings of dull emitters were not nearly as sensitive to current changes as the earlier Bright Filament valves. The introduction of matched r.f. components and compensating capacitors had led to identical r.f. characteristics of tuning circuits which

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22 The Times 1925, June 17, p 8 carried an article on Interference explaining how to distinguish the two types of whistle.

23 The Times 1926, Dec 14,p 21; Dec 16,p 5; & Dec 17,p 6 gave a series of articles on Tuning noting that until recently old 5 valve sets were likely to have 14 Tuning controls (Aerial condenser, First Grid condenser, Moving Coil, 2 Tuning Condensers, 3 Fine Adjustment condensers, 1 Potentiometer and 5 Rheostats). "Where there are three or four tuned circuits, it is a matter of the utmost difficulty -even with a wavemeter- to keep all together while searching". This was largely due to valve instability and an early solution was the Neutrodyne set which will be discussed below. The article of Dec 16 told readers how to modify their receivers to Neutrodyne operation.

24 The Times 1927 Jan 10 p.22

permitted simpler controls.

Harrison (1979) has given a detailed account of the development of single knob tuning in American receivers. He showed how the main efforts began from 1920 with inventions to rotate or mechanically alter a number of tuning capacitors together; these solutions were classified according to their method e.g. rack and pinion, four-bar mechanisms, collinear shafts etc., and also with the dates of these patents. In all some 72 solutions were proposed with peak inventive activity in the years 1925 and 1926. The next problem inventors tackled, Harrison said, was the tracking problem and again a variety of solutions were proposed the essence of each being some form of matching of components and some kind of compensation e.g. padder and trimmer capacitors. Harrison again tabulated the variety of suggested solutions and dates of patents which again peaked in the years 1925 and 1926.

Harrison then discussed the results of his analysis and concluded that Schmookler's demand-induced theory had been supported because the years of peak inventive activity had been ones of growing demand. However this endorsement was by no means without complication as Harrison noted that two early inventions for easier tuning had been made about 1910 for Wireless Telegraphy receivers; this together with the "step-wise incremental improvement" pattern lent some support to Gilfillan's social determinism which was further endorsed by evidence of equivalent easy tuning inventions, fashions in receiver design and post-1926 exhaustion of further technical possibilities for improvement evidenced by the rapid decline in patents after 1926.

Harrison's analysis may be criticised for its failure to stress the technological basis of these single knob tuning inventions (which required stable r.f. amplification stages) but his findings endorse the pattern observed in the development of bicycle sub-units with the enormous variety of inventive solutions which were due to exploration of every possible method of achieving the desired result.

Once easy Tuning arrangements had been developed, attention was turned to minor inventions in this field leading to easy-to-read dials marked in wavelengths or stations and illuminated dials.

Consumers' Desire For Fidelity and 'Distant Listening'

Tuning circuit design was yet another example where the designer had to contend with conflicting consumer requirements and exercise some form of compromise or trade-off.

High selectivity could be achieved at the cost of top-band cutting or failing to reproduce the high audio frequencies being broadcast. Due to self-cancelling errors the audio amplifier and horn loudspeakers of the early sets accentuated high audio notes and cut bass ones. Highly selective tuning circuits did the opposite so that the net result was not too bad. As amplifier qualities and tuning bandwidth increased the need for a balanced tone correction became more apparent and this began with treble cut controls at the a.f. amplifier stage; this was especially the case when the a.f. pentode valve was used. The real need was for high selectivity without top-band cutting and Bandpass tuning circuits gave this feature (though a.f. tone controls were used as well).

A second illustration of trade-off lay in the differing requirements of listeners. "Distant listening" meant a desire to hear faraway stations, and this needed high selectivity. Local listening required the opposite as low selectivity gave a better tone quality. This conflict was catered for in TRF (and superhets) by the development of Variable Selectivity circuits which the listener could adjust or select as desired. Variable Selectivity was a vogue of the 1930s and is not incorporated in most ordinary receivers today.

Short Wave TRF Selectivity

Short wave listening became popular in the 1930s and TRF receivers were not sufficiently selective at these higher frequencies partly because of TRF tracking problems and partly because of the differential r.f. amplification over the waveband. The screen grid valve was still a poor r.f. amplifier at high short wave frequencies. For this reason the Superhet receivers (and ultra-selective circuits such as the Stenode) were introduced, although TRF radio manufacturers began to produce "convertors" for Short wave listening on their sets. These were frequency changers which altered the short wave transmission frequency to a medium wave one and allowed the listener to hear it on his TRF set. A few manufacturers incorporated this frequency changer inside the TRF set and hence produced the hybrid models having TRF for Long and Medium wave and Convertor for Short waves. The Broadcaster Annual 1938 had a special category in its list for this type of receiver.

Consumer Influence Upon Component Design

Consumer influences also affected the design of tuning circuit Components as Dalton (1975) (Vol 3, Chap 1) has shown. The earliest tuning condensers were Straight Line Capacity ones which appeared to bunch all the stations at one end of the tuning dial, the Square Law condenser was then produced which made the stations appear to be more uniformly distributed over the dial, then finally the Straight Line Frequency design ensured that an equal rotation swept an equal frequency.

Slow Motion Tuners were also developed to assist fine tuning and "Vernier" condensers which originated in America, were widely introduced to British sets in 1925. Coil design was also continuously improved; the earliest Tuning circuits which were based on Moving Coils (usually coupled to Reaction) meant that any change of coil position altered the total inductance of the circuit so that if the degree of Reaction was altered it de-tuned the circuit. In addition the human body has effective r.f. capacitance so that tuning was altered when a hand was placed near the tuning circuit; and as no screening was used this feature was confounded by r.f. interaction. Good design and screening largely eliminated these problems.

A further illustration of a non-technical factor which influenced receiver design sprang from the broadcasting policy of the B.B.C itself. Reith (1924) had high aspirations for the new medium and considered that the cinema had become a vehicle for sensationalism. He insisted upon the highest moral standards in broadcasting to say nothing of Christian principles; these values were not shared by all the listeners and during the 1930s a number of English speaking programmes were transmitted from the Continent, Radio Luxemburg being the most popular. Satisfactory reception of Radio Luxemburg required not only a highly selective receiver but one which countered the severe fading it was prone to.

Sensitivity

Sensitivity is a measure of the ability of a receiver to amplify weak signals. The earliest way in which receiver sensitivity was apparently increased was by having the most powerful aerial possible. Later improvements depended almost wholly on better r.f. valves although in the early years alternative solutions took the form of new types of TRF receivers such as the Neutrodyne and Super-Regenerator whose main features were novel methods of achieving better r.f. amplification using the poor valves of that time. These other types of TRF sets are described in a later section.

Once the screen grid valve was introduced the selectivity improvements such as Reaction, bandpass tuning, better coils and so on, also contributed to better sensitivity as the test reports for the Ecko and Phillips sets noted above indicated.

Secondary Problems

Sensitivity was linked to other problems due to weak signals. Fading was one of the most important of these and had been encountered long before public broadcasting began. Before 1914 some inventions had been made to counter it, a useful one being Diversity reception which used two widely separated aerials placed miles apart.This was unsuitable for domestic listeners of course and other methods had to be devised.

The use of reaction gave a partial solution to fading as it differentially amplified the signal (although dealing badly with strong signals).

Automatic Volume Control

A pioneer invention, automatic volume control (AVC), was made by Wheeler in 1926.[25] The key feature of AVC was that it used control circuits to produce a constant signal output level to the detector stage. This involved 'boost and buck' and its success led to other forms of AVC notably 'delayed' AVC (which required the r.f. signal to reach some pre-determined threshold before it came into operation); and 'quiet' AVC ('squelch') which suppressed signals until

[25] This later became known as the Automatic Gain Control (AGC) circuit. Wheeler's invention of Automatic Volume Control was said to be the first instance of the use of negative feedback in radio circuits according to Electronics (International) 1980, April 17, 53(9), pp.438-439. The Times 1928 Jan 6 p.6 summarised Wheeler (1928).

strong ones were engaged, this was used to quieten noise between stations when tuning.

AVC proved to be the effective solution to fading, and like so many other radio inventions needed further improvements to associated circuits and brought problems to light. One further improvement was the invention of the Variable-Mu valve to provide the necessary means of automatic control of signal strength as it gave proportional amplification or sensitivity. AVC in its early form, was first demonstrated on the American Philco receiver in 1929. AVC made accurate tuning to the carrier wave frequency difficult as a slightly detuned signal was apparently as loud as a correctly tuned one, and this was overcome by fitting a signal strength meter, and later led to various indicators which became popular in the late 1930s. A second revealed problem of A.V.C. was that searching for stations led to blasting and much noisy hiss, Wireless World[26] noted " --- in all this year's (i.e.1935) sets the AVC is brought into operation in such a way that the ear-rending hiss and splash of sidebands is almost entirely eliminated". This was achieved by the delayed and quiet types of AVC on expensive sets. AVC was generally introduced in Britain in 1931 on more expensive sets as it needed an extra valve.

Noise

A further secondary problem which affected Sensitivity was Noise. Noise was most troublesome when signals were weak; tolerable listenting required signals to be greater than the noise. Noise arose from external and internal sources and has been one of the most difficult radio problems to solve. "Atmospherics" (as all noise was then called) constituted a considerable nuisance. and was the subject of extensive investigations by many researchers. No attempt will be made here to trace the history of these efforts or the particular circuits and radio components which were subsequently developed.[27] Reference to special articles on the historical development of radio components, such as that by Buff (1962) will show how low

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26 Wireless World 1935 Aug 16, p.163

27 In Britain the Radio Research Board published two surveys on this topic. One, Special Report No. 20 "Valve and Circuit Noise: A Survey Of Existing Knowledge And Outstanding Problems" was published by H.M.S.O. in 1950 and dealt with internal noise; the other was Special Report No. 15 "Survey Of Existing Information And Data On Radio Noise Over The Frequency Range 1-30 Mc/s" published by H.M.S.O. in 1947 and dealt with atmospheric and man-made external noises which affected radio reception.

noise components were developed. Here only the developments pertaining to external noise will be considered.

The problem of external noise led to various inventions to minimise their effect.[28]

Many inventors attempted to produce circuits and devices to eliminate atmospherics though these were never entirely successful. Many of these inventions dated from attempts to solve the problem wireless telegraphy receivers in the 1900s; a description of some of the early kinds proposed for broadcast receivers was given in Pitman's Radio Yearbook 1924 and included Weagent's X-stopper; Scott-Taggart's frequency multiplier; and Bolitho's twin differential amplifier. None of these were very satisfactory because 'atmospherics' were found to have a variety of signal characteristics, mostly aperiodic, yet each different form the other so that it was nearly impossible to neutralise them alone.

The Times[29] noted that some of these proposed inventions "were extremely plausible on paper" but not a single one had been successful. The reason for this was that 'atmospherics' covered a variety of natural and man-made interference signals and that different circuits were needed for each type of atmospheric noise.

Interference from Spark Transmitters was very troublesome during the 1920s. This came mainly from ships' transmitters and was a particular nuisance because it produced broadband noise. The solution largely came from legislation which specified that only continuous wave transmitters were to be used on ships.

Man made interference proved to be of increasing concern by the end of the 1920s, largely because of increased use of electrical equipment and motor vehicles. Inventors produced a variety of anti-interference circuits; one of the best being Lamb's Noise Blanker of 1936 which was developed specifically to reduce aperiodic interference (from ignition and pulse noise) in superhets by limiting the interfering signal to a level similar to that of the desired

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28 The Times 1923, Sept 20, p.6 in an article on Atmospherics described Scott-Taggart's invention for this problem.

29 The Times 1928, Feb 29, p10

signal and cutting out larger signals.[30] Generally the really effective solution again lay in the suppression of the man-made interference at source and this was achieved, over the years, by legislation.[31]

Detectors

The basic function of any A.M. detector is to demodulate the post-r.f. amplification signal which, in the early years was done by means of a triode valve and one of two possible methods of biasing the valve - the Grid Leak or Anode Bend.

Most early wireless telegraphy detectors were not suitable for the demodulation of broadcast signals as they could not deal with the continuous fluctuations of the a.f. frequencies although crystals, the heterodyne receiver and thermionic diodes or valves were suitable and formed the basis of detectors in early broadcast receivers. Phillips (1980) has described the development of early detectors in the period 1870 to 1914.

The chief problems with valve detectors on early domestic receivers were that they distorted the signal. This distortion arose because valve detectors utilised the non-linear characteristics of the valve and it was common for those early listeners who desired good tonal quality to use a crystal detector followed by a valve amplifier.

There were three main types of early valve detector; Grid Leak, Power Grid and Anode Bend.

Grid Leak Detector

The grid leak was by far the most popular in the early years of broadcasting The Times 1928 Dec 17, p.21 in an article on detectors considered that 90% of loudspeaking receivers used this method because it was simple to use, allowed Reaction to be employed and was ideally suited for TRF sets which had no prior r.f. amplification. Above all it was very sensitive and best for ´distant listening´. The grid leak detector did have a number of weaknesses; its worst feature was the distortion of large signals and this problem led to

[30] Electronics (International) 1980, April 17, 53(9), p.440

[31] An article in the B.B.C. Handbook 1932, pp 409-411, described the complaints procedure which listeners should use, and of the joint B.B.C and Post Office action that was taken to trace the source of man-made interference. Not all problems could be cured in those days.

modifications which reduced the r.f. gain, it also dampened the r.f. circuit and therefore reduced selectivity; it also induced distortion and as it required a transformer coupling in the following a.f stages, this compounded the frequency and amplitude distortion inherent in this arrangement.

In spite of these weaknesses the grid leak detector was by far the best type when dealing with weak signals and with reaction, the grid leak gave a level of performance unmatched by any other early type.

Power Grid

The Power Grid detector was later version of the Grid leak which used the higher voltages which were easily obtained in mains-powered sets. Mains operated sets were introduced once the mains-powered valve was developed in 1928 and Wireless World[32] noted that by 1931 the Power Grid detector was "now the rule rather than the exception".

Anode Bend

The Anode Bend detector was less popular but gave a far better performance provided a strong r.f. signal was present. The Anode Bend could be used when prior when local signals were strong, or when good r.f. amplification was available. The chief advantage of the anode bend was that it did not dampen the r.f. circuit and therefore did not reduced selectivity. A further advantage was that when properly adjusted its grid current was virtually zero. These good features were offset by its considerable distortion and low sensitivity.

Throughout the 1920s valve and other improvements had a beneficial influence on detector performance; the chief early troubles arose primarily because of the inability of the r.f. stage to amplify sufficiently and once improved valves became available, especially the screen grid, designers had a sufficiently strong signal to overcome many of the earlier problems which essentially derived from overdriving the detector stage.

Later Detectors

The weaknesses of early grid leak and anode bend detectors led to experiments with the Homodyne receiver which will be discussed below. The development of

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32 Wireless World 1931, 29 p.385

the mains-powered domestic receiver and better r.f. valves (especially the screen-grid and later the r.f. pentode) meant that higher voltages and currents could be used and to some extent this reduced the need to over-drive detectors therefore permitting detectors with linear characteristics. By 1934 Wireless World reported that the introduction of AVC had led to diode (valve) detectors and even HF metal detectors in multi-stage TRF sets because the r.f. signal was now sufficiently strong to operate non-amplifying detectors which had less distortion.

In cheaper sets triode detectors were almost universal although some designs employed an HF pentode for grid detection.

At this time some compound valves were introduced, notably the Diode-Triode which acted as an amplifying detector and provided an output for AVC.

After 1945 a very popular type of A. M. detector was the silicon or germanium crystal. Many other different types of detector were developed too, as Amos (1980) has shown in his recent survey of A.M. detectors.

Audio Amplifier and Reproducer

The final stage of the TRF set was the audio amplifier and its associated reproducer, the loudspeaker, unless headphones were used in which case the a.f. amplification did not need to be large. The amplifier's basic function was to amplify the weak output from the detector to a level sufficient to drive the loudspeaker and without distortion. This involved a design trade-off between amplification and battery economy as high a.f. outputs required large battery currents, many early designs overdrove the a.f. stage with consequent distortion. There are various kinds of distortion, amplitude distortion usually arises because the amplitude of the signal is beyond the valve's capability and leads to 'peak clipping' with a multiplicity of tones being added to the original signal. Harmonic distortion usually arises because of the non-linear characteristics of the valve(s), frequency distortion usually arises at transformers or inductors when the a.f. or r.f. spectrum is sizeable and differentially affected by the impedance of these components. Frequency distortion usually sprang from poorly designed a.f. coupling transformers used in the audio amplifier. These faults could not be rectified until the causes were understood, by 1924 the Marconiphone 'Ideal' transformer compensated for previous a.f. coupling deficiencies and with the introduction of the pentode valve (the a.f. equivalent of the screen grid) a sufficiently strong a.f. signal was available to satisfactorily drive the loudspeaker economically.[33] One advantage of the a.f. transformer coupling was that it could also act as a step-up transformer thus adding to the overall a.f. amplification.

The early Dull Emitter valve led to the emergence of ´microphonic noise´ due to the vibration of the finer filament by the sound waves from the loudspeaker. This was cured by making the filament stronger and more rigid and the use of sprung valve-holders.[34]

The prime concern of early receiver designers was to obtain sufficient loudspeaker volume from audio amplifiers which centred their attention upon valves and couplings. High volume meant high current consumption and encouraged the use of mains power. This began by using battery eliminators which supplied only High Tension voltage and trickle charging for the accumulator as mains current, when used for the filaments, produced a loud mains frequency hum from the loudspeaker. The invention of the Indirectly Heated Filament valve in 1927 largely reduced this mains hum and encouraged the development of the "all-mains" set. This encouraged receiver designers to develop circuits which employed greater voltages and currents - especially in a.f. stages thus making receivers more powerful. "All- mains" sets were more expensive, partly because the public electricity supply in Britain at that time had a wide variety of frequencies, voltages and even types (a.c./d.c.) in each district so that the mains circuits had to be adjustable.

Later a.f. amplifier designers concentrated on reducing distortion and achieving ´flat responses´ for the whole audio frequency spectrum. The development of the Pentode valve (an a.f. equivalent of the screen-grid), meant that a.f. amplification was no longer a major problem and so designers turned to the resistance-capacity coupling which did not step-up but gave less distortion.

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33 Many earlier "power" a.f. valves had been tried before 1928 and some of these were an improvement on earlier ordinary triodes.

34 The Times 1927 Feb 28 p.21

One fundamental amplifier invention was made at this time; this was the negative feedback amplifier circuit. Black (1977) has given an account of his development of negative feedback amplification which began as a quest for a solution to distortion in telephone transmission lines using methods which others had tried; then Black had the inspiration of using negative feedback and his suggestion met with disbelief. However his experimental results indicated that the principle worked though it only became really effective after Nyquist added a phase control in 1932, thereafter the benefits of low distortion amplifiers with stable gain based on negative feedback became widely appreciated and modern designs still employ it.

The negative feedback principle was later employed by Baxandall (1952) as the basis for his improved tone control circuit for amplifiers, a design which remains very popular as it gives independent control over treble and bass.

Another important amplifier development was the Push-Pull design which came into widespread use in the early 1930s. This amplified both the negative and positive parts of the a.f. signal and was also more economical on battery current. This experienced a slow introduction; Wireless World[35] considered that this was probably because of the patent situation, and that most manufacturers continued to use the single pentode a.f. valve. Later high fidelity amplifiers used push-pull circuits.
Greater efficiency was obtained by impedance matching between the a.f. amplifier and the loudspeaker, while more expensive sets in the late 1930s employed a compensated feedback circuit which dampened the specific resonant frequencies of the loudspeaker - the ´notch filter´ method.

Throughout the 1930s the Wireless World Show reports described how better and better tone quality was being achieved. As highly selective receivers tended (or were deliberately designed) to cut the side-bands, tone-correction circuits were incorporated to boost the audio frequencies. This added treble response led to the appreciation of hiss, interference, hum and other undesirable noises giving inner logic pressure to develop new counter measures for the new problems which included designing low-noise components,

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35 Wireless World 1930 27 pp.377-384

noise-reducing circuits, 9kHz ´notch´ filters (for the inter-station whistle), and anti-hum mains circuits (often an anti-phase field coil in the loudspeaker). All these developments led to greatly improved a.f. sections. By 1935 Wireless World[36] noted "Apart from a frequency range with amplitude distortion, there is also the question of response to transients. Resistance-Capacity coupling and the use of the high-slope pentode enabling the (a.f.) output valve to be fed directly from a diode detector has improved the reproduction of transients to such an extent that, on an average set, drums, castanets and even cymbals can be heard with something approaching recognisable realism". This is a further example of inner logic pressure leading to improvements in secondary aspects of audio quality.

Audio amplifier improvements were essentially based on incremental inventions. Britain led in this development and the main advances came from small independent radio designers such as Leak or Williamson.

High Fidelity Audio Amplifiers

There is some doubt about the origin of the desire for hi-fi. Most technical histories or accounts suggest that consumers became more critical and demanding.[37] At first sight hi-fi appears to be a splendid example of product invention in response to ´demand-pull´ but a closer examination shows that this is not the case. During the 1930s and 1940s a number of reports of psychophysical experiments apparently showed that the majority of listeners preferred ´medium-fi´ to hi-fi. Moir (1947) gave a the results of a British investigation of this; Langford-Smith (1954) gives further references to this topic in his section dealing with audio amplifiers. However Massa (1985) has told of other experiments conducted in America during the 1930s in which controlled amounts of distortion were introduced into radio tests and it was found that listeners preferred hi-fi when this was undistorted, but as distortion was introduced the preferred frequency range was reduced. It was found that if the audio spectrum of radio receivers of that time exceeded 8kHz the tonal quality "was generally judged to be very objectionable" (p.1298). This still supports the idea that consumers preferred hi-fi.

36 Wireless World 1935 Aug 16, p.162
37 For example Wireless World 1934 Aug 10, pp.94-99 took this view.

Evidence to the contrary came from actual sales. Some contemporary accounts of receiver performance about this time pointed to a marked decline in tone quality; in America Electronics[38] noted that domestic radio receivers had bandwidths of 2kHz to 6kHz narrower than transmitter bandwidths and that "the public apparently doesn't give a hoot"; and suggested that engineers wanted to improve fidelity but "sales departments decided that high quality sound was alright for engineers, but not for the public". The increasing sales of midget radios (introduced in America in 1928) whose tonal reproduction was very poor and was a new trend which was said to have led to a general lowering of receiver quality, prices and tonal reproduction. In Britain the trend to cheaper lower performance domestic receivers had also begun showing much the same trend. The accuracy of this market response is underscored by the large sales of cheap and poor tonal quality transistor sets in the 1950s and the sluggish use of F.M.

It appears that from about 1930 consumers became sharply divided in their desires; the majority were very satisfied with cheap low performance sets while on the other hand discriminating listeners were prepared to pay a great deal for hi-fi - a trend encouraged by the postwar B.B.C. 'better listening' campaign. In other words product invention was used to provide a range of goods which varied on the Price-Performance-Quality dimension; a feature noted in the bicycle industry.

The nature of product invention in later high quality amplifier design has been illustrated by Williamson (1947) who stated the desired objectives. This account revealed that hi-fi amplifiers had to satisfy multi-dimensional requirements so that not only did they need to have a 'flat' frequency response, low harmonic distortion, good transient reproduction, a large dynamic range freedom from inter-modulation products and so on, but all these objectives had to be satisfied at once. This illustrates the 'outspreading' objectives also noted in bicycle design. Hi-fi audio amplifier designs were mainly incremental inventions which optimised circuit performance by means of detailed changes. Hi-fi design has now become a specialism.
Loudspeaker inventions moved in sympathy with audio amplifier improvements

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[38] Electronics (International) 1980 April 17, 53(9) pp.100 & 103

and to a certain extent merged by matching; the trend of loudspeaker developments will be described in a later section dealing with science and radio invention.

5.4.4 Different Types of Basic TRF Receivers

The foregoing sections have mainly described the product inventions and product design changes at the sub-unit level for the basic TRF set. In fact product design also included various types of overall configuration of this basic TRF (not including the TRF derivatives such as the neutrodyne etc., which are to be described later).

The early basic TRF design was modified to suit consumers' desires; in those years it was customary to specify a set by its stages and the notation was of the form A-B-C where A was the number of r.f. valves, B was the number of detector valves, and C was the number of a.f. valves. Boltz (1944) (p.195-6) has described the varieties of early TRF set designs and their uses; in general sets for local listening were 0-1-1 or 0-1-2 while DXers had sets with good r.f. amplification stages say 2-1-2. Sets with good r.f. amplification were considerably more costly than the cheaper local listening sets, as the 1926 price list by Constable (1980) shows.

Different types of domestic receiver were launched, notably the Portable receiver (first offered by a British manufacturer in 1923), the Car radio, first offered in 1927 and the radiogram which was launched by a British manufacturer in 1929. U.S. models were slightly earlier. The limited sensitivity of the TRF design was most noticeable in the portable and car receiver types which only became successful in superhet form.

The battery operated receiver had been the sole type until the invention of the indirectly heated cathode valve which made mains-powered sets possible. Listeners could only use mains-powered sets if they were connected to the public electricity supply of course and during the 1930s the numbers of households being connected to the public electricity supply was rapidly increasing. The Broadcaster Annual gave annual figures of this. By the early 1930s, as Census returns show, the bulk of domestic receivers were mains powered although a large proportion of battery sets were still being sold. In the early 1930s a considerable amount of invention had been directed to

reducing the current consumption of battery sets and apart from better valves other measures were taken one of the most important of these being the Quiescent Push-Pull audio amplifier which permitted a volume and quality of output nearly equal to that of a mains-powered set while at the it greatly reduced current consumption. This was achieved by various means, one was the development of low current valves, another was the introduction of ´automatic grid bias´ circuits and high efficiency amplification also helped.
Towards the end of the 1930s a new ´cold´ valve was introduced; this had a low temperature filament and consumed very little filament current so that it could dispense with the accumulator battery and run from the high tension battery cells and led to the ´All-dry´ set. This innovation did not really enter the market until after 1945.

5.5 TRF Derivatives

The results of the analysis of the Bicycle industry showed that in the early commercial years of that industry a great variety of designs - such as di-cycles, tricycles and bicycles - were made often as exploratory exercises based on the apparent promise of a new idea or principle. The same feature applied to the radio receiver industry. During the 1920s a number of new or novel receivers were made or tried.

The examples which will be described here are the Neutrodyne, Super-Regenerator and the Homodyne. However the Crystal Set is really a TRF model which had a poorer performance but which was very cheap and commercially very important until 1927, the following account will show how inventors sought and succeeded in improving the Crystal Set and of its demise due to its technical limitations.

5.5.1 The Crystal Set

The crystal set was the most popular type of radio receiver in all countries when broadcasting began. This was due to its many advantages over other kinds of receivers available at that time. The crystal set was usually of very simple design, making it cheap to buy and even cheaper to build as home constructors did not need to pay royalties. Its running costs were zero. The

crystal set was relatively easy to operate, and could not 'howl'. It could receive a medium and long wave stations and its 'cat's whisker' detector gave a very good tone provided the receiver was fairly close to the transmitter. The main features and types of crystal set used in the period 1922 - 1927 have been described by Busby (1976).
One writer to The Times (1925, June 30,p 7) noted any school boy could build one at half the retail price. Another reason for the popularity of the crystal set was that many listeners were so afraid of causing reaction "howl" with valve sets that they would not have one; and if they wished loudspeaker signal strength, they used a.f. valve amplifiers to increase the crystal set volume.[39] The supreme technical virtue of all crystal detectors was their freedom from distortion in comparison to valve detectors of that time.[40]

It chief appeal was its low cost; Constable (1980) said it was all many could afford. It is not known exactly how many were used, Hill (1978) said that in the mid-1920s crystal users outnumbered valve users by four to one, a correspondent writing to The Times in 1925[41] said that 65% of listeners used a crystal set.

The crystal set also had some disadvantages; its low volume of sound output, poor selectivity and an inability to receive weak (distant) signals. It was also unable to drive a loudspeaker and could only power two pairs of headphones if close to a transmitter. These shortcomings, together with poor selectivity ultimately led to its rejection by consumers in favour of a better type.

The low volume of output led to the invention of the 'Microphonic' amplifier This type of amplifier originated from the telephone industry and for crystal set use fed the output from the crystal set to one single earpiece; this earpiece was placed in front of a telephone microphone; this microphone fed into a step up transformer and increased the volume of the sound. Johnson

39 The Times 1926, Oct 26,p 24
40 TheTimes 1925 June 9, p9 contains a letter describing the results of various configurations of pre and post crystal valve amplification. Another lady wrote (June 23 p12) to say that she considered the crystal to be the best of all detectors and used an a.f. amplifier with it.
41 The Times 1925, June 5, p10

(1923) described the principles of its operation. Hill (1978) has illustrated the various models which S.G. Brown supplied in the early years; these began as sub-units and ended as an integral part of a horn loudspeaker. Such Microphonic amplifiers needed only a small torch battery which lasted for a very long time. This type of amplifier needed a signal strength beyond the threshold of the crystal but like the crystal, it too had a threshold so that any weak interference was rejected - another instance of a 'bonus' effect. The Microphonic amplifier could be a very satisfactory solution to the low volume inherent in the crystal set provided the input signal was sufficiently strong.

Crystal Set Design

The basic design of crystal set had been established by 1914, as noted above. Its central component was the crystal detector (cat's whisker) which had evolved from Braun's observation in the 1870s that certain materials had "asymetrical action" meaning that they conducted little current in one direction and a relatively great amount in the other. Then in 1906 Dunwoody discovered that a crystal could rectify r.f. signals and this led others to experiment with a great variety of materials to see if they could do the same. Phillips (1980) has described many of the experiments with crystal detectors in the period up to 1914 and noted that trial and error was the guiding principle behind these efforts. The result was that cat's whisker detectors were found to demodulate broadcast signals and by 1917 were in use. The most popular material was "galena" (lead sulphide) as it was very sensitive, though many other types were tried some of which used a small biasing voltage to increase the output. In general these crystal surfaces presented only a single point of good contact which was not permanent so that the listener had to establish good contact each time he used the set. This delicate crystal contact could be broken by either a voltage surge (say from a flash of lightning) or by a physical knock; the contact had to be reset each time the receiver was used.[42]

Some kinds of crystal detectors were made more sensitive by use of a small

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42 One type of permanent crystal detector was invented, the "Perikon" but this was never commercially popular.

biasing voltage. The receiving range was largely governed by the sensitivity of the "cat's whisker" and for the basic crystal set was about 15 miles.

Crystal Set Tuning Circuits

The tuning circuit was the critical element in crystal set design. Harris (1922) has described a variety of crystal set circuits which were produced before public broadcasting began in Britain. The main differences among them was the tuning arrangement by the various ways of altering either inductance or capacitance. The cheapest arrangement was simply a crystal connected across the headphone leads, with one end connected to the aerial and the other to earth; no tuning was possible with this design but as in the early days no other local signals were broadcast, this arrangement was cheap and effective.

A more popular type was the Slide Coil circuit in which a slider was moved to alter the inductance, it was cheap but suffered from a 'dead end' effect due to energy being wasted at the unused end of the coil.

A better type of tuning circuit was the Tapped Induction Coil. This had a coil an inductance tapped at intervals and was tuned by selecting the tapping (or tapping and capacitor setting when a variable capacitor was fitted) which gave the loudest output.

The Variometer was long considered to be one of the best types of crystal sets as the 'Wireless Correspondent' noted[43] it gave the best form of control. The Variometer consisted of two series of windings, one of which rotated within the other thereby cancelling or reinforcing their mutual magnetic field, and a fixed capacitor was used in series with the aerial. As crystal sets could be provided with a range of different coils, a number of different values of capacitors could be fitted in the aerial circuit to suit each coil. The Variometer itself underwent some improvement becoming more efficient in the later designs, although the device itself was something of a vogue and 1923 was designated by Wireless World as "variometer year".

An obvious method of improving crystal set selectivity was to add another

[43] The Times 1925, June 15, p 8.

tuning circuit. This made the set much more expensive but quite a few were sold. Most of these designs employed the Loose Coupled tuning circuit in which the degree of coupling between the two coils could changed from ´loose´ to ´tight´ coupling. The great advantage of this circuit was that it minimised damping and therefore increased both selectivity and volume of output.

One factor which excited crystal set inventors in the early days were reports of freak reception and an article on this[44] noted that distant stations such as Frankfurt and Madrid had been received using the simplest types of crystal set. These astonishing reports led to investigation and in many cases it was found that a neighbour´s valve set was being used at the point of oscillation so enhancing the crystal set signal. In other cases though no explanation could be given for freak crystal set reception except in terms of unusual atmospheric or local conditions.

Later Crystal Sets

Jones (1925) wrote a book containing a number of designs for "loudspeaking" crystal sets, which implied that the output of these types was sufficient to drive a loudspeaker. However it became clear that loudspeaker operation could, in the majority of cases, only be attained by an additional amplifier. Nevertheless with "patience, practice and time" Jones said that these circuits could yield better results than the simplest crystal sets. The types described covered circuits suitable for an indoor aerial (Frame or picture rail), then a selection of designs based on the main types of tuning circuit described above (i.e. Slide and Tapped inductance, Variometer and loose coupled circuits, the majority having a double circuit often a mixture of types (e.g. variometer + tapped) and most with aerial loading coils. As long as the B.B.Co. pursued its "crystal set policy" (which it was obliged to do under the terms of its charter) and broadcast only one local medium wave programme, the set was quite satisfactory.

Then in 1925 a new high powered Long Wave transmitter came into operation and this led to M.W./L.W. sets (often with plug-in coils) which were quite satisfactory with poor selectivity (so long as "breakthrough" did not occur

[44] The Times 1926 Nov 24, p 20.

and plug-in coils largely eliminated this). In 1927, the B.B.C. brought a new high powered medium wave transmitter into operation at Daventry. This was the experimental forerunner of the Regional Scheme and soon reports were received of crystal set users listening to Daventry (5GB) hearing 2LO during quiet passages, especially those living close to 2LO (London). This illustrated the effects of poor selectivity on the medium wave and Wireless Correspondent noted that this indicated that crystal sets were not selective enough, the broad tuning characteristic being intended to give quality reproduction. The changes needed to make a crystal set more selective would be fairly elaborate either the addition of a coupled circuit or a wavetrap or perhaps a frame aerial, but the problem was likely to be more acute when the Regional Scheme began.[45]

Peak Crystal Set Design

The selectivity problem exercised the minds of inventors and the best design of domestic crystal set can be regarded as that provided by Wireless World in 1926/1927. In this circuit the objective (asked for by a reader), was for a simple but efficient design capable of receiving Daventry and a local programme yet to be free from local station interference and to be selective enough to separate two medium wave stations. The design given used a Split coil tuned circuit to minimise damping (with increased selectivity and volume), and employed a "auto-tapped" aerial coil with aerial capacitor to give both further increased selectivity plus a stepped-up voltage due to the auto-transformer principle. A later description[46] suggested a loose coupling arrangement with Carborundum crystals (with biasing).

The years 1927 and 1928 saw a widespread recognition that the crystal set had only limited possibilites for improvement. In Pitman's Radio Yearbook for 1927 it was noted that the cheapest crystal set cost about one pound and had a range of 12 to 15 miles, while a more expensive type would cost three or four pounds having a range of 15 miles on medium wavebands and about 100 miles on the Long Waveband. A "microphonic" amplifier then sold at six pounds and was said to be useful up to 5 miles from a medium wave transmitter and 25 miles

45 The Times 1928 Jan 27, p8
46 Wireless World 1927 July 15, p 53, & July 22, p73

from a long wave transmitter. Pitman's Radio Yearbook for 1928 carried an article by J.F. Carrigan (1928) dealing with ways of improving the crystal set, and he noted that this type of receiver was limited in its capabilities with severe limitations in sensitivity and volume which was not surprising as a typical operating signal was only 80 microamps. He suggested that variable inductance tuners (variometer or tapped inductance) were the best although both dampened the tuning circuit.

Crystal Set Decline

By 1929, the increased numbers and powers of European transmitters together with the spread of the Regional Scheme in Britain meant much greater inter-station interference on the medium waveband which ended the crystal set era because of the set's poor selectivity. This did not entirely end invention and interest in the crystal set although it never achieved the commercial importance of earlier years.

Revived Interest In Crystal Sets

The crystal set was one kind of receiver which experienced a renewed interest from inventors long after its commercial demise. At the outbreak of the second world war a sudden surge of demand arose for crystal sets. Hill (1978) has explained how fears of a cut in electricity supply, a shortage of valve receiver replacement parts and the wartime reduction to one national programme had led to the crystal set becoming practical again.
After 1945 the new silicon and germanium diodes became commercially available and this led to experimenters testing them on traditional crystal set circuits. Halket (1951) did this and after describing the experimental circuits he used, said that low-impedance tuning circuits were needed (unlike the 1920s crystal circuits) and he had found that a small biasing voltage made the new detectors much more sensitive. He believed that certain effects noted during these experiments held the prospect of even better performance in the future. However these new detectors did not fundamentally cure the basic weakness of this type of receiver.

The crystal set exerted a curious fascination for many; Constable (1980) noted that during the 1940s and 1950s a considerable number of 'toy' crystal sets were sold, which had the basic circuits in up-to-date plastic boxes which were replicas of 1940s and 1950s receiver cases.

5.5.2 Neutrodyne Receivers

The Neutrodyne represented a type of receiver which promised and gave a much better performance than the current TRF sets but which was made obsolete by the later invention of the screen grid valve. The principal aim of all inventors designing neutralised r.f. stages was to achieve stability in these stages which permitted better amplification of the transmitter signal. Success however led to an 'inner logic' sequence of consequent problems which needed to be solved before the original invention (neutralising) really worked; these consequent problems were mainly due to stray r.f. voltages affecting the r.f. stages and this was cured by 1) r.f. screening and 2) adjusting receiver component layout to reduce mutual interaction to a minimum.

The basic idea of the Neutrodyne receiver was the modification of a standard TRF design to give some form of negative Reaction or other measure to increase the stability of the r.f. stage(s). Strictly speaking the term 'Neutrodyne' should refer to Hazeltine's circuit as many early experiments had been directed towards stabilising the r.f. section from 1913. Dalton (1975) has given a brief account of these first efforts. "Various other attempts had been made to increase r.f. stability, for example by Loose Coupling, Lower R/C ratios for tuning circuits, Grid Current Damping and Lossing Resistors". Rice, in 1918, had patented the idea of screening in order to prevent r.f. currents straying to other parts of the receiver and causing instability. All these improvements were carried forward to later Neutrodynes and ultimately to all receivers.

Negative feedback could be achieved by many methods. Dalton (1975) has described some of the earliest of these; for example two which "were developed before their time" were Johnson's circuit and Phelps's circuit both of which fedback a negative signal voltage. This stabilised the r.f. stage and allowed r.f. valves to be used in cascade without instability giving greater sensitivity and also to allow (positive) Reaction to be used at the detector which was not re-radiated from the listener's aerial.

Hazeltine developed the Neutrodyne broadcast receiver circuit in America in 1918, and gave an account of his early idea, possible circuits which he could try and the early commercial form his receiver took in a paper Hazeltine (1923). Swinyard (1962) has given a more detailed technical account of Hazeltine's Neutrodyne circuit. Hazeltine had begun with the idea of reducing audio squeal in amplifiers in 1918. By 1922 he had worked out a design "on paper" which would neutralise the inter-electrode capacity in r.f. valves together with means of reducing magnetic r.f. coupling between r.f. transformers etc., by mounting them at a pre-determined angle. His ideas were proved sound by tests which showed that the neutralised receiver had greater sensitivity, and to a lesser extent better selectivity, and good r.f. amplification, no aerial re-radiation when a neutralised r.f. valve preceded the (reactive) detector valve, and above all the great r.f. stability which meant that particular stations always appeared at the same point on the tuning dial. Later neutralised receivers embodied improved layouts and additional screening, both features being a logical necessity because of good r.f. amplification. Dreyer and Manson (1926) have described the benefits of screened neutralised receiver designs.

Dalton (1975) noted that the Neutrodyne emerged in the U.S. because of the special needs and circumstances of that country. The early market for crystal sets and one-valve sets partly became obsolete because mass production had so cheapened multi-valve sets that consumers preferred them. In America where people were generally richer, and sets were cheaper, Herron (1969) observed, Neutrodyne sets were very popular because of their superior range.

In Britain the Neutrodyne was never the commercial success it was in America. The Times 1927,Aug 2, p.8 noted that at the 1926 (British) Radio show less than 10% of commercial sets had neutralising in spite of the improved performance. Constable (1980) gave a price list for all British receivers catalogued in 1926 and shows that the price of neutralised receivers in that year in Britain was about three times the price of an equivalent TRF. The high costs were due to more components, high royalty charges (based on the number of

valve holders) and higher running costs. In addition consumers may have been deterred by the number of tuning controls. The Times (1926 Dec 16, p.5) informed readers how they could modify their existing receiver to a neutralised one. In Britain the Neutrodyne was mainly built by amateurs because royalty charges did not apply, complicated tuning was welcomed and the improved performance desired. Technical journals readily supplied circuits for any number of valves, the Wireless World "Everyman Four" of 1926 was a famous example of the "Everyman" series which gave a performance beyond any commercial version of that time.
The real need was for increased selectivity and various improvements were made to the Neutrodyne to achieve this; Dalton has given some details and described the secondary problems which arose.

5.5.3 Super-Regenerator

The principal aim of all super-regenerator receiver designers was to make a set which had a far greater r.f. amplification than a TRF set with the equivalent number of valves. This was possible because of an ingenious idea; it had been found that an oscillating (i.e. regenerative) circuit required a certain amount of time (of the order of milliseconds) to build up to its full oscillating output and that this initial transient output was proportional to the input triggering signal, hence if it was possible to quench the output just when (or before) it reached its full level, the series of quenched outputs would form a highly amplified proportional r.f. signal. The quenching frequency was initially set at 40kHz because Helmholtz had suggested that the upper frequency limit for human ears was 20kHz and it was believed that twice that frequency was needed to convey the 20kHz signal in order to define its peaks and troughs.[47] A history of the super-regenerator receiver has been given by Whitehead (1950).

Various attempts had been made earlier with modified Reaction designs though Armstrong is considered to be the originator of the Super-Regenerator circuit in 1922, and its improved r.f. amplification was obvious.

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[47] The 40kHz intermediate frequency on early superhets was chosen for exactly the same reason.

Felix (1922) noted that it greatly increased the gain and that a three valve super-regenerator gave a performance equivalent to a ten valve superhet of that period and in addition had a good tone quality. It also reduced Spark Transmitter interference to a far greater degree than an ordinary TRF with reaction.

Early experiments with super-regenerator circuits showed that it was most efficient a high carrier frequencies so that Long Wave reception was not much improved, Medium Wave frequencies were better and Short Wave frequencies were best of all. It improved sensitivity but not selectivity.

Certain drawbacks were also apparent with these early models as Felix noted "utmost delicacy of adjustment and considerable patience" were needed when tuning it.

Croysdale (1923) also commented on this type of receiver noting that it appeared to offer great scope for inventors, largely because of its high amplification and because of the tuning difficulty due to the need to balance reaction and quenching.

The super-regenerator receiver was never a successful commercial design. It was the subject of much attention by inventors during the 1930s when Short Wave listening was popular, and indeed a commercial receiver was made then. Its chief application was for radio amateurs and communications equipment. In Britain in the late 1940s the super-regenerator was included in V.H.F. trials because it was known to be nearly immune to vehicle ignition interference.

5.5.4 Homodyne Receivers

The promise which the Homodyne receiver offered was undistorted detection. Roulston (1971) has described the essential feature of the Homodyne receiver which was its demodulator. This was effectively a heterodyne product detector but with the local oscillator frequency identical to that of the desired incoming transmission so that the "intermediate frequency" was zero and the output was a.f. theoretically without any inter-modulation frequencies. Tucker (1954) has given a fuller history of the Homodyne and its derivative, the Synchrodyne.

Colebrook (1924), the inventor of this type of receiver, has told how the idea of this novel application of the heterodyne detector principle appealed to him and of his prototype's performance whose linear detector characteristic ensured distortionless demodulation.
He confirmed this by comparing the tone of a broadcast programme with that using a grid leak detector in the same set. Colebrook's homodyne also proved to have great sensitivity. However "an apparently serious defect" was encountered, namely the acute distortion due to frequency drift of the local oscillator which made a "tenor solo sound like a discordant duet between a bass and a soprano". Later it was realised that the Homodyne detector was phase sensitive so that the slightest frequency change of the local oscillator would render the transmitted signal unintelligible. A friend of Colebrook's suggested that the problem might be cured by using a weaker local oscillator signal so that the incoming signal would synchronise the local oscillator; this was done and gave some improvement as Colebrook was only 12 miles from the London transmitter but was insufficient for a weak distant signal. Colebrook's friend had suggested the Synchrodyne, a Homodyne which used part of the incoming signal to control the local oscillator. Most of the subsequent experiments were to be based on this modification, but interest in the Homodyne (and Synchrodyne) died until until some private researches were undertaken in the mid-1930s and made public by Rust et al (1941). Then in 1942, Wireless World published a short article describing how the homodyne principle would improve tone quality by removing rectifier discrimination by increasing the strength of the carrier frequency alone and inventors renewed their interest in this set again.

The chief problem was to ensure that the local oscillator produced the exact frequency and later effort centred on Synchrodyne circuits. In Britain this approach was taken by Tucker (1947a, 1947b) and led to his Synchrodyne circuit which was far too complicated and costly for any commercial set. Tucker and Seymour (1950) developed another design which acted as a precision demodulator which was also unsuited as a commercial product.

By the later 1960s, Roulston (1971) noted, cheap phase control devices, integrated circuit Phase Locked Loops, had been developed which could ensure that the Homodyne local oscillator was at exactly the same frequency as the desired incoming signal and which had the bonus of a ´flywheel´ effect (or ´capture´ effect) so that the phase locked loop locked on to the incoming carrier wave frequency.

Then Herbert (1973) built a model which he tested and compared with TRF and Superhet circuits. His results indicated that the Homodyne detector was superior, but by then FM had been established in Britain giving an even better performance than the Homodyne so there was no real market for the improved homodyne.

The Synchronous detector has recently attracted the interest of some radio enthusiasts. Myers (1981) has described the comparative advantage of a synchronous detector over a diode detector. This advantage stems from the "capture effect" in which two nominally similar frequencies are presented to the detector and it accepts the stronger and rejects the weaker giving a virtual ´frequency lock´. The synchronous detector also offers enhanced sensitivity. This version of the Synchrônous detector is suited for special communications receivers.

The history of the Homodyne is really one of an idea which was ´ahead of its time´ and which apparently died only to to be the subject of further enquiry, later satisfactory development, yet ´too late´ for the market.

This brief account of derived TRF ´experimental´ receiver designs has shown that events parallel to those in the Bicycle industry 1870-1884 occurred in the early commercial years of radio as well. None of these became common domestic receivers although many of the design advances were incorporated into receiver technology though none displaced the TRF. Another design was being invented and modified which was eventually to prove successful; this was the superhet whose invention and development will be described in the next section.

5.5.5 Superheterodyne Receiver

The chief attractions of the fully developed supersonicheterodyne (superhet) receiver for AM broadcasts were its enhanced selectivity, good sensitivity, good tone quality, easy tuning and with a clear advantage for the reception of Short Waves.

This design originated in America and had a protracted period of development because of the need to solve specific superhet problems. Witts (1941, originally 1935) has given an extensive technical history of the development of the superhet receiver with emphasis on British inventions and improvements.

The key principle of the heterodyne receiver is that it changes the frequency of the transmitted signal to a lower one, called the intermediate frequency, which is then amplified and detected in the normal way. This heterodyne method of reception provided many advantages largely because early r.f. valves could only amplify satisfactorily low radio frequencies, and because the design of the fixed intermediate frequency stages could be peaked in terms of performance for that specific frequency thus allowing bandpass characteristics yet with sharp selectivity when staggered i.f. tuning was used.

Like some other radical inventions, the superhet was not invented as a logical response to technical needs but emerged 'sideways' from other applications of the heterodyne principle. Economic and consumer factors delayed its market acceptance because during this time the TRF was rapidly improved and cheapened. The superhet also benefitted from these general receiver improvements too but did not appear to consumers to offer a better price-performance-quality improvement over the TRF until about 1933.

Superhet Technical Problems

Boltz (1944) has described the nature of the problems of early superhets. "When it was first used the quality of reception was awful, there being a loud background of mixed noise, the tuning was erratic, and the set's performance unpredictable. Every person of any taste preferred the straight set. Since then, however, by careful attention to design, but especially by improvement to valves, the superhet has come into its own, though it is still faulty". (p.196). Another unkind remark was that the early superhet was "the radio which received every station at least twice."

The following account will deal with technical trends and other factors which led to consumer acceptance and the ´perfection´ of the superhet´s design by 1939.

The Heterodyne Receiver

The first heterodyne receiver was proposed by Fessenden in 1905. His aim was to make a more sensitive wireless telegraphy receiver than was possible with other detectors of that time. Fessenden (1908) has described how he conceived of the idea of two transmitters operating on two separate but close frequencies (usually only 1 kHz apart) were to send a common morse signal which he proposed to mix both at the receiver so that they would heterodyne (beat) together to give an audio signal.

This property of two different frequencies combining to give others (the most important being the Sum and Difference frequencies) had been known for a long time and Fessenden aimed to use it to provide an audible tone to morse signals. Later, Fessenden saw that he could make the system simpler by having only one transmitter and replacing the other transmitter signal with a local oscillator which provided the other (mixing) frequency.

There were many difficulties with this early circuit largely due to the type of local oscillator (Poulsen arc) and the idea lay dormant for a number of years. Then in 1910 it was accidentally discovered that when two ships were in close proximity, the reception of one was very greatly enhanced when the transmitter of the other (using a close frequency to the other´s receiver) was in operation. This was investigated and the improved reception found to be due to the additional r.f. in the receiver. In 1913 the thermionic valve oscillator emerged as a very satisfactory oscillator and led to interest in using it in heterodyne receiver circuits. This resulted in a number of valve heterodyne receivers, Round´s Autodyne of 1913 being a noteworthy example in which one valve was used to mix the incoming transmitter signal and at the same time generate a close frequency so giving a ´beat´ tone (heterodyne) output. This was fairly satisfactory for telegraphy signals but no good for telephony signals with their wide a.f. spectrum. The Autodyne tended to ´pull´ (merge) station and generated signal frequencies.

War Developments

The 1914-1918 war saw further developments of the heterodyne receiver for wireless telegraphy. One important use forseen by all military radio inventors was to use ´high´ frequencies (from 500kHz to 3MHz) offered greater security, and as the r.f. valves of that time could not deal with such high frequencies, it was necessary to lower the frequency in order to amplify it. Lowering such frequencies made greater r.f. amplification possible so that the heterodyne method offered the possibility of receiving weak high frequency signals.

Another application of the heterodyne method of reception was to separate a desired signal from undesired atmospheric noises; this was proposed by a Frenchman, Levy who used the heterodyne method to obtain a lower r.f. signal then added a filter which blocked the atmospheric noises leaving a purer signal. This illustrated the superhet´s potential for high selectivity.

Witts (1941) has described these efforts and associated problems in much greater detail. These accounts show that the heterodyne method had a number of desirable properties, all of which were eventually to be incorporated in the domestic superhet receiver. The actual construction of a reliable working model of a heterodyne receiver occurred in 1917 when the U.S. Expeditionary force had landed in France equipped with long wave receivers which were of no use as the Allies were using Medium Waves, and Armstrong decided to build a convertor so that these receivers could be used on higher (medium wave) frequencies.

After the war Armstrong decided to "push the heterodyne principle to the limit" and designed a heterodyne set for the reception of Spark transmitter signals which was demonstrated in 1920. This attracted the attention of radio amateurs at that time as they needed a radio receiver to deal with the high frequencies they had been allocated after the war, and the heterodyne receiver gave good results. This paved the way for its later application to the reception of wireless telegraphy signals used in public broadcasting.

Superheterodyne Receiver

The essential feature of the superhet broadcast receiver is that it converts the desired transmitter signal frequency to a lower frequency by mixing it with another ´local oscillator´ (within the receiver) to give an ´intermediate frequency´ (i. f.) of fixed value. Much of the success of the superhet design derives from the fact that the intermediate frequency is always the same, thus permitting the i.f. stage design to be ´peaked´ at that frequency.

Pioneer Superhet Invention

The initial incentive to develop the broadcast superhet receiver was not based on better amplification of higher frequencies or better selectivity. Armstrong (1924) stated the initial impetus came from another requirement "--- the superheterodyne began to take on a new importance - an importance which was based not on its superior sensitiveness not its selectivity, but on the great promise which the (superhet) method offered in Simplicity of Operation." (italics added).

Armstrong and his colleague Houk developed a superhet prototype based on earlier heterodyne designs and found that it was technically satisfactory. He than proceeded to simplify this design to make it easy for the listener to tune and made some improvements on his earlier model. Armstrong´s superhet had eight valves which meant that it was costly and had high current consumption making it commercially unattractive, so he decided to redesign the receiver to reduce the number of valves, and therefore the cost of the set, by making valves perform more than one function as with the reflex principle, using the first valve to amplify the i.f. and aerial signal. It was found that strong signals from a local station could swamp the r.f. circuit so Armstrong tried various ways of controlling i.f. amplification and found that the most practical method was by control of the filament temperature. All these modifications resulted in a superhet model which was highly satisfactory in the laboratory and which augured well for the commercial market. These prototypes were then passed to the Westinghouse Electric & Manufacturing Co. where Sarnoff "instantly visualised" its commercial appeal and development was begun. Armstrong considered that many important and radically new designs were made at this development stage while a further amplifying valve was added to deal with the weak signals encountered in steel buildings in American cities. A demonstration of the improvement which the superhet made was illustrated with reference to two lady listeners who, without technical knowledge, were able to receive the B.B.Co London transmission with this set in 1923, and Armstrong considered that receiver sensitivity had reached its limit with this design and that later improvements would be in selectivity and simplifying the construction.

Superhet Problems: Subsequent Developments And Inventions

Schottky (1926) has given a history of the origin and development of the superhet receiver up to 1925 while Witts (1941) has described how the superhet receiver remained of academic rather than practical interest in Britain until 1931 because of technical problems and cost.

Technical Difficulties

Perhaps the greatest superhet difficulties arose at the Mixing stage, where the incoming and local oscillator frequencies were combined. The methods of doing this were largely determined by valve technology; in the very earliest broadcast models made before 1927 designers could only had the triode valve and they normally inserted the local oscillator output to either the grid of the mixing triode or its cathode. These designs had two problems; aerial re-radiation and the tendency for the local oscillator to be "pulled" to another frequency nearer to the incoming signal, such superhets had poor selectivity.

These attempts led some designers to update the self-oscillating Autodyne circuit with some success but also with some of the same problems especially "pulling" and re-radiation.

The introduction of the screen-grid valve led to new possibilities and designers now put the local oscillator output to the screen grid but found that two problems arose, one because of the low common conductance and the other because of the inter-electrode capacity between the grid and the screen grid. When the tetrode valve was introduced the same problems appeared that had afflicted the screen grid mixer.

Then when the r.f. pentode was introduced about 1930 it was tried as the superhet mixer, the local oscillator input being fed to the suppressor grid and anode coupling with the self-oscillating mixer.

In 1933 the American pentagrid valve (and its later British equivalent the heptode) was introduced. These valves had multiple grids and one of these grids was constructed to give the variable-mu characteristic. This design was virtually a compound one with effectively two valves in one envelope the incoming signal being fed to a grid of ´one´ valve while the local oscillator was fed to the grid of the ´other´. This arrangement made a much better superhet mixer and allowed padding and trimming capacitors to be added to the local oscillator circuit for better tracking. These mixers were technically adequate for long and medium wave superhet receivers but not good enough for shortwave types because these valves had transit time limitations at the higher (short wave) frequencies. However the beam octode which was introduced in 1937 and was entirely satisfactory as a superhet mixer valve for all frequencies and proved to be the lasting circuit design for all valve superhets.

Other Superhet Problems and Inventions

These mixer inventions by no means exhausted all the superhet troubles; some idea of contemporary British problems with these earlier superhet sets are now given. Early superhet domestic receivers still had a large number of valves (usually 6 or 8) which made the type very costly to buy because patent royalties in Britain were based on the number of valve holders and of course valves were expensive in the early years of broadcasting; running costs were also high as these early valves consumed much current. The consumer was also suspicious about the local oscillator as he did not see what it did and he needed to be skilled in order to set it to the correct frequency. In addition ´crystal set´ policy of the B.B.Co. meant that neither high selectivity not high sensitivity were needed as the network of transmitters in Britain ensured that the bulk of the population were within ´crystal set range´ of either a Main or Relay B.B.Co. transmitter. It was hardly surprising that most of the superhet development between 1922 and 1931 was due to invention-push as their history of development shows.

In 1923 Wireless World published a superhet receiver circuit which attracted some attention but soon interest died. Witts has described the variety of other experimental were superhet receiver designs which were developed at this time, these included, some variants of Round's Autodyne, the Tropodyne and Infradyne. By 1925 British radio manufacturers considered that they could offer some superhet receivers to the public but they did not sell well.
Wireless World 1930, in its historical survey of past radio shows stated that 1925 was a superhet year and "All the principle manufacturers were showing examples of this type, which were discussed by everyone and purchased by the affluent few" (p.303)
The Times 1925, June 24, p.8 described the superhet noting that it was unsurpassed for the reception of frequencies of 600 metres or below but with "a tendency to instability". The next day The Times published a letter by W. Ayres who noted that superhets then required a minimum of six valves and "with very few exceptions are troublesome radiators". In 1926 The Times in its report on the radio show (Sept 4, p.11) considered that 1925 superhets were "hardly more than experimental" and went on to suggest that 1926 superhets were instruments of commerce. Ramsay (1928) has suggested that these early superhets were not popular in Britain because they had a poor reputation due to designers seeking too great a gain from each stage and also because listeners were content with local stations and the waveband was not particularly overcrowded then.

The invention of the Dull Emitter valve (which consumed only one quarter of the current of a Bright Emitter) prompted some of the 1926 superhet interest. Between 1926 and 1930 TRF receivers were considerably improved so that superhet types were not seriously considered until the pressing problem of inter-station interference in 1930 prompted a further search for a really selective receiver which forced designers to re-examine the superhet.

Between 1926 and 1931 many improvements had been made to the superhet, these largely originated in America where the superhet had been in considerable demand and use from about 1928. The majority of these improvements were solutions to second channel interference, inter-modulation and local oscillator problems. No attempt will be made here to describe these efforts in detail as both Cocking (1933) and Witts (1941) have done that though some examples are now given to show the nature of these efforts.

Second Channel Interference

Second channel interference was another problem which was specific to the superhet. This arose when two transmitter frequencies had an equal difference from the intermediate frequency; for example if the i.f. was 200kHz and the superhet tuning circuit was set to 1000kHz then it would have a heterodyne frequency of 200kHz but any transmitter broadcasting on 1200kHz would also produce a difference frequency of 200kHz and be treated the same as the desired transmission frequency.

The choice of the superhet's intermediate frequency involved a trade-off between Selectivity and Second Channel interference. Witts has described how the early superhets used a intermediate frequency of about 50kHz in order to obtain high selectivity and good stablility but it was very prone to second channel interference.

Mixing frequencies could also produce another common and troublesome problem in superhets due to the creation of unwanted inter-modulation products (by a.f.-i.f. interaction) and which were reduced by using filters or an antiphase signal of the same frequency.

The earliest i.f. was set at about 50kHz, as already noted, because it was believed that this was the lowest value which gave the highest notes a human could hear. By about 1928 the i.f. had been raised to around 125kHz in order to reduce second channel interference and improve selectivity once valves could adequately amplify at these frequencies.

At this time a further improvement was affected by the Double Superhet which had two different intermediate frequencies giving improved selectivity without much second channel interference; Ramsay (1928) has described his design for use on Short Waves. His model had 10 valves, two local oscillators and i.fs. of 600kHz and 150kHz. This principle was later expanded for use in communications receivers by having three intermediate frequencies - a design which continues to be used for these receivers to this day. Then about 1938 the new multi-grid valves and the listeners' desire to hear short wave frequencies led to a further increase in the i.f. to about 450kHz; a value which has remained to this day. This high i.f. was possible because there were no problems about r.f. amplification, selectivity was good due to bandpass circuits and therefore the real task was to reduce second channel interference which was particularly troublesome on short wave frequencies and raising the i.f. was a viable and good overall solution to the problem.

The local oscillator had two main problems associated with it, one was that in its early form it did not produce an output free from harmonics which, in turn, led to additional whistles being reproduced at the loudspeaker; another problem was that early local oscillators tended to suffer from frequency drift which markedly reduced the receiver's sensitivity.

The high selectivity of superhets led to top band cutting and the need for tone-compensating circuits. The tuning of these early superhets was very tricky as the listener had to set the local oscillator to that particular frequency which gave the desired intermediate frequency and problems with this led to superhet single knob tuning based on the local oscillator and having the main tuning control on a single shaft; this benefitted from general ganging inventions. Similarly bandpass tuning circuits were incorporated in superhet receivers and the principle extended to the i.f. section by adopting 'staggered' intermediate frequency stages to produce a flat overall response.

By 1931 all these improvements had been made and in Britain radio manufacturers sought to tempt the public once again. Market success was not immediate as the Show Reports in Wireless World reveal. Their introduction[48] was due to the increased need for high selectivity. In 1932[49] it was noted that there was still no real public interest in superhets although the latest models had been improved by reducing cross-modulation. 1933 was 'superhet' year[50] largely because radio manufacturers had redesigned the superhet using the new multi-grid r.f. valves making it possible to produce a superhet set having four or five valves at a price nearly equal to that of an equivalent

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48 Wireless World 1931 29 p.382
49 Wireless World 1932 31 pp.231-236
50 Wireless World 1933 33 pp.121-128

TRF. Even so this type of superhet still had specific superhet problems which, Wireless World noted, made the TRF still very attractive.

From 1933 to 1939 Wireless World noted that superhet design followed two main trends; the basic superhet receiver having five valves or less had a more or less uniform design regardless of the manufacturer. In this period the superhet table model was further improved by fitting noise suppressors (or sensitivity limiters), iron-cored coils, and a variable tone control. Wireless World[51] noted that in 1932 a three valve TRF costing fifteen to twenty pounds brought in only six or seven stations but by 1935 a small superhet costing from nine to eighteen pounds could bring in twenty five to forty stations. At this price and level of performance, the superhet rapidly became the the most popular type of domestic receiver which eclipsed all other types, once the consumer had been educated to appreciate the superhet's improved performance.

This basic mature superhet design became the fundamental configuration for the Frequency Modulation receiver and the modern television receiver, both of which have multiple intermediate frequencies.

Luxury Superhets

The success of the basic superhet design fired the imagination of radio designers and by 1939 these improved designs reached a pinnacle of near perfection - the 'golden age' of domestic receiver design.

A huge variety of different circuits were produced for these luxury sets because of the designer's desire for technical perfection as this extract from the Wireless World's 1934 description of new receivers[52] shows. "Nowadays the owner of an expensive receiver demands not only high quality reproduction but a high degree of selectivity, coupled with the ability to select the desired programme free from interference ---and expects his set to be equipped with visual tuning, delayed quiet volume control and tone control ---The keynote ---is sound design, and there is no doubt that it is of far greater importance than many more spectacular developments".

51 Wireless World 1935 Aug 16, pp.162-163
52 Wireless World 1934, Aug 10, pp.94-99

The nature of these new luxury designs can be illustrated by the description of the R.G.D Model 1202 which reproduced tones up to 10kHz necessitating a 9 kHz filter (to suppress adjacent channel whistle), a compound loudspeaker system (two cone type woofers and a horn tweeter), noise suppressors, two i.fs, and Short Waves. Wireless World concluded in its review of luxury sets for 1934 that there was no uniformity in circuits in these high performance sets "where technical merit is the ultimate aim in the design, in contradistinction to the more usual aim of obtaining a high performance for the lowest possible cost --- the one may present to the designer just as great problems as the other, but there is no doubt as to which is the more interesting scientifically".

The new circuits developed in this period were complex and improvements were inter-related, for example the Variable-Mu valve was a necessary pre-invention for the Quiet Automatic Volume Control which was developed and linked to the Automatic Frequency Control which came later still. The essential feature of the majority of these late 1930s developments were that they were extensions of existing principles which were more carefully designed to minimise or eliminate the problems or maximise the technical objective. Some of these developments bordered on "gadgetry" as the craze for push-button tuning in 1938/9 illustrated though in general the majority improved performance.

To a certain extent the rate of progress could be controlled as this abstract from Wireless World's 'Show Review" illustrates[53] "Some had expected radio receiver design to stagnate because of the introduction of television, but it did not and efforts have concentrated on improved receiver performance. Really solid work has been done on clearing background noise and tone improvement. Noise has been cleared by the use of valves designed to give more signal to noise ratio, automatic noise suppressors and no false economies to output stage and loudspeaker design. There is now keen competition to provide the finest possible quality of reproduction, large power output (up to 12 watts that year), reduced harmonic distortion and scientifically designed tone controls to give exactly the right frequency response".

These luxury circuits were used in expensive table models and radiograms.

[53] Wireless World 1939 Aug 31, pp.196-198

Post-1945 Superhet Inventions

Sturmey (1958) p.182 considered that the post-1945 receiver was more reliable that its pre-war counter-part but that higher post-1945 costs, the imposition of purchase tax and the competition of television had made it economically impossible to provide so many gadgets as in the pre-war luxury set. The reasons for this were not only economic as by 1945 the listeners' desire to search the wavebands, especially the short waves, had diminished. Press-button tuning and remote controls were also rarities after 1945 (they later became popular again in the 1960s). Sturmey observed "With the introduction of a satisfactory loudspeaker, of the all-mains set and of the superheterodyne, the radio receiver reached practically the form it retains to this day and progress during the 1930s and subsequently was mainly a matter of detail."(p.178). In other words the post-1945 British radio receiver market was primarily one of basic superhets.

Miller and Spreadbury (1966) have broadly described the changes to domestic superhet receivers from 1945. They noted that radio theory had not changed although some new developments especially the transistor, had caused theory to extend its scope.

From 1945 the cold-valve 'All-Dry' small portable set became extremely popular; this design used the traditional frame aerial (usually in the lid) and the standard superhet design.

Later post war design was largely concerned to incorporate the latest inventions (the transistor, ferrites and ceramic filters) and also with better design of problem parts of the superhet, and generally tidying up the whole design.

In the Aerial circuit the main feature had been the adoption of ferrite materials which had been reduced aerial dimensions and had largely prompted by the popularity of portable and car radios from 1946. The main aerial circuit design still had Bandpass tuning with a.g.c and r.f. amplification. Some sets had special tuning although the pre-war fad for tuning indicators had largely disappeared.

The Mixer stage still attracted designers' attention due to the complex problems at this stage though the pre-war problems with inter-modulation products had largely been eliminated. Many types of Mixer circuits had been proposed because of problems, especially tracking problems as single knob tuning in a superhet required excellent oscillator tracking and this was achieved by good detailed design.

Intermediate Frequency stage design was basically the same as pre-war ones with Bandpass staggered tuning with progressive i.f. amplification. Since 1945 variable selectivity had been dropped largely because there was no point in having a bandwidth greater than the 9 kHz broadcast from the transmitter. It was not worth the additional cost. One partial exception was Bandspread for Short Wave listening and this was quite popular and achieved by switching i.f. circuits.

Modern detection (demodulation) circuits mainly used a diode valve (or transistor) though some receivers used rectifiers. Such circuits employed Delayed A.G.C to counter fading although the pre-war popularity of Automatic Frequency Control (A.F.C), a variant of A.G.C., had declined.

The audio amplifier stage still had as its principal function the supply of a pure (undistorted) signal of sufficient strength to drive the loudspeaker. Inventions at this stage had largely been concerned with Couplings and problems with this had led to many possible designs. Distortion at the audio stage had largely been eliminated by good couplings and the use of Quiescent Push Pull. Tone Control design now included Active as well as Passive types.
As far as loudspeakers were concerned the Moving Coil type was the most popular, most had a permanent magnet though some still had an energised magnet. Mains hum was reduced but not entirely eliminated by anti-phase circuits. Better quality and more expensive receivers used compound speaker systems (woofer and tweeter).

From the mid-1950s the popularity of all transistor receivers increased and led to the virtual extinction of valve receivers by the early 1960s. The transistor superhet designs were based on earlier valve superhet circuits. Later 'hybrid' Superhet/F.M. receivers were produced so that listeners could receive both types of signal. The introduction of the transistor made it possible to eventually design and manufacture a wide range of radio-like products including tape-recorders and 'audio' units as well as different types of radio. This design flexibility meant that an even greater degree of market segmentation could take place and this led to market research which was used to specify the designs. By the late 1970s it was found that less sophisticated consumers would like hi-fi equipment without needing to understand the esoteric hi-fi language and simplified equipment was produced and found to capture new market segments. At the same time this market research revealed that consumers now wanted non-hi-fi equipment to have lots of 'features' such as more adjustments and even gimmicks which had no real effect upon technical performance; gimmicks such as a.f. controlled flashing lights or a.f. triggered 'sound meters' or graphic equalisers fell into this category. Fuller (1980), T.J. Gage (1981) and Yovovich (1981) have given reports of American market research in this field. These recent product design trends show clearly that it is market driven at this late mature stage.

The broad pattern of superhet product invention shows that by 1939 the modern form of this receiver had reached its mature level and thereafter was only marginally improved though its fundamental aspects, such as configuration and 450kHz i.f. remained unchanged. This pattern was similar to that of the post-1900 bicycle.

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5.6 Engineering Design

In this section the aim is to try and answer the question 'Why did radio receiver designers produce the designs that they did'? and to show how ideals, technical problems and economic influences affected the answers.

Design As The Application Of Knowledge

Engineering design had two functions; one was to create the best circuits possible and the other was to build a body of knowledge which could be applied by any engineer. This latter function was embodied in standard books (or magazine articles) for example Sturley (1965 originally 1943); and what is often regarded as the "bible" of radio designers, Langford-Smith (1954 originally 1937). These design books were revised frequently to incorporate the latest developments so that transistor circuits were included in later editions. These design books presented the fundamental principles (i.e. engineering science), the main circuits, formulae and calculations together with any further rules or conditions, for example Langford-Smith's section on tuning circuits gives the standard formula and typical LC component values with a further constraint based on past experience for optimal LC design.

Radio design books do not readily indicate how the knowledge was built up or the nature of the designer's task, they generally concentrate upon invention-push and the following illustration is intended to show how other factors influenced designers.

Problem - Oriented Radio Design in 1924

In 1924 a number of opinions on the main problems in radio were published in a series of articles.[54] The first article, edited by Campbell Swinton gave the views of some leading British radio engineers/inventors, beginning with Swinton himself who considered that better selectivity and distortion in amplifiers and loudspeakers were the most pressing problems.

Fortescue believed that valve performance needed to be improved, especially reduced anode-filament resistance and some method of countering inter-electrode capacity by fitting "two or more grids".

Marchant thought that the elimination of atmospherics was a major problem.

Mullard said that better coupling methods were needed, a more efficient use of valves with new designs based on valve characteristics, and loudspeaker distortion reduced by improved horn shapes.

Messner considered that there was a chain of unsolved problems but that the first requirement was to eliminate uncertainty about the solutions by establishing a ground work of theory so as to establish the principles.

McMichael believed that there were many problems to be solved; major ones such as Transmitting Power by radio,[55] Optical Transmission, and Directive

[54] Pitman's Radio Yearbook 1924 pp.135-140 "Wireless Wants - A Chance for Inventors", and pp.135-140 "Trends of Invention".

[55] Tesla's old idea

Transmission of Very Short Waves would involve costly expenditure and could only be undertaken by large commercial firms. The individual inventor had and could be considering new designs to eliminate unwanted signals (i.e. selectivity) and atmospherics.
The other article dealing with the trend of improvement described the variety of designs produced to solve a particular problem. For example the Prevention of Interference had led not just to one circuit but to many including Scott-Taggart's (Harmonic) Frequency Multiplier, Bolitho's twin differential receiver (similar to Weagent X-Stopper); Marrec's Periodic-Aperiodic limiting receiver and Beverage's long directional aerial.
Similar efforts in Directional Reception, Valve Capacity and Loudspeaker Distortion were described showing again a variety of proposed solutions.

These opinions reflected the primacy of technical problems at this stage of radio development. These problems mainly came to light from experience and led to investigations to determine their causes. Technological requirement was therefore a major dimension of invention and design, and suggests that much invention could be predicted at this stage.

Many of these inventions involved engineering trade-off, a feature noted in the case of bicycle design. In radio, for example, Sturmey (1958) (p.172) wrote "The design of a broadcasting receiving set is essentially a compromise between different aims. The ideal set would combine perfect fidelity of reception, great selectivity to enable stations near to each other to be separated and received without mutual interference and high sensitivity to enable any station, the transmission from which is loud enough to be heard above the static, to be received. Finally the ideal set, however, is impossible to obtain as the aims are conflicting and each designer has his own solution to the compromise."
That statement clearly expresses the trade-off aspect seen frequently in the foregoing analyses of receivers, and also illustrates the importance of the designer's ideal. Ideals can also specify a design to suit consumers.

'Ideal' Radio Inventions

Technical problems were not the only causes of radio receiver inventions. Quite often radio designers sought to provide consumers with an 'ideal' receiver. The term 'ideal' could be interpreted in various ways; one was an easy-to-operate set.

An article in The Times in 1925[56] suggested the features which a future radio receiver might have. The key point was that the proposed design would suit the listener (and was not intended for constructors). It would be easy to operate, have no external aerial, have its power from the mains, have a minimum number of controls, single knob tuning, a plate bearing the names of the radio stations, with a two-position switch for the two main programmes, and incorporate a single on/off-volume control with a loudspeaker embodied in the cabinet. This receiver would not be the most efficient design but it was considered that no technical difficulties stood in the way of producing it and that some manufacturers already had such types at the development stage. This ideal specification made in 1925 has proved to be a very accurate prediction of modern receiver design.

In 1927 Wireless Correspondent returned to the theme of the ideal receiver[57] and noted that the trend had been towards greater simplicity for some time. "The ideal that designers have before them is a set efficient enough to enable its owner to enjoy a considerable choice of programmes at full loudspeaker strength and yet so simple that it is operated as easily as a gramophone." The specified features were the same as in the earlier article with the exception of a reaction control which "altered the volume only" and a logarithmic variable condenser and single knob tuning based on coupled ganged circuits. The theme was restated shortly after[58] in a review of the trends of design but dealt with in more technical terms as selectivity was then a more pressing problem.

These articles show that ideas do establish design objectives and provide goals for inventors and designers in which technical performance may be sacrificed to some degree in order to suit consumer needs.

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56 The Times 1925, Sept 22, p.8
57 The Times 1927, Aug 2, p.8
58 The Times 1927, Dec 8, p.21

Engineering Knowledge Refined

It has been shown that technical problems and ideals formed the basis for investigations or trials which resulted in new knowledge. However, as the following examples show, the stock of knowledge can itself be refined.

Two fascinating statements about design were made in 1926 and 1927 which[59] dealt with design fallacies which were popular traditions but entirely wrong. These traditions had arisen in the early days when there was little literature and much uncertainty and later writers had repeated them without question so that they were now entrenched, used by amateur and professional designers alike and difficult to destroy. Among the illustrations given was the coil design criteria, a belief in the superiority of a two stage a.f transformer and the retention of the telephone condenser in the crystal set which, in most cases, served no useful purpose.
In the 1927 article it was noted that the early rapid technical progress in radio had led to uncritical acceptance of theories and practice, but as the rate of progress had slowed these were now being re-examined. "In wireless, obvious gains in one direction may be more than offset by unsuspected losses in another". The rest of the article gave illustrations of the refutation of some well established radio design practices and of design trade-offs. This indicates that technical knowledge is itself further refined by later re-examination.

5.6.1 Incremental Product Invention

The study of the Bicycle showed that once the basic product design had attained a satisfactory level, product inventors changed their objectives. These new objectives included incremental product improvements to "tidy up" the design, the creation of gadgets and accessories and to broaden the product range from high performance expensive models to simplified low cost utility models. In the period 1930 to 1939 much the same happened in domestic radio receiver design. By 1930 the basic (TRF) set had been well developed with good tuning, valves which amplified satisfactorily, loudspeakers which reproduced well and mains powered sets allowed sufficient volume.

59 The Times 1926, June 28, p.8 & The Times 1927 Aug 16 p.8

Rust, Keall, Ramsay and Sturley (1941) have given an extensive review of British radio receiver design for the period 1929 to 1939 covering the variety of circuits used in popular middle-range sets but excluding the simplified circuits of small receivers and also excluding the elaborate circuits of de luxe receivers. Their review is therefore a comprehensive treatment of incremental receiver design and the first part consists of a presentation of the variety of circuits (in circuit diagram form) of the most popular types of say band-pass tuners or tone control circuits, covering the entire receiver stages from aerial to a.f. amplifier. That part of their review revealed that there was no single design but that designers built up their overall set according to their judgements of both technical and economic aspects.

The second part of their review discussed the fundamental, mainly technical problems affecting receiver design and dealt with selectivity, fidelity, electrical interference (i.e. ´atmospherics´), the trend towards automatic functions (of volume, frequency, selectivity and remote control), attempts to specify receiver performance and concluded with the proposal for a new wavelength allocation in which transmitters for mainly musical programmes would have a wider spectrum than the +/- 9kHz allowed while speech programme frequencies would have a narrower band. In their discussion of the technical functions they noted that solutions frequently depended upon listeners´ criteria. They noted that the purpose of automatic circuits was twofold, one reason for their use was to make it easier for listeners to operate their sets, the other reason was to attain maximum performance from the circuit.

Designers also turned their attention to secondary technical objectives such as reliability and ease of servicing.
By about 1930 pioneer inventions and associated experiments had ended. A recent review[60] following the presentation of twelve ´classic circuits´ (most important inventions) stated "--- most of the important developments took place before 1940. Indeed, it should come as no surprise that today´s engineers by and large believe that the day of the pure circuit designer has long past and that the limits of circuit development had been reached. That

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[60] Electronics (International) 1980, April 17, 53(9), p.442

engineers have exhausted conventional development there can be little doubt." (p.442)

However designers turned their attention to minor improvements as Wireless World noted.[61] noted that once receiver design had reached "permanent stability" (i.e. maturity) manufacturers turned their attention to minor improvements such as better dials and similar gadgets, and above all that great attention was paid to the appearance of receivers even in the low price ranges. Manufacturers realised that customers were not too interested in the technical aspects of their set but were very impressed by its appearance and ´sales features´ (including gadgets).

After 1934 the TRF design became the basic one for low priced receivers, and designers deliberately sacrificed some technical performance in order to achieve low costs using product design to simplify TRF circuits. This was largely due to the commercial success of the low priced superhet.

5.6.2 Economic TRF Product Design

Wireless World[62] noted that TRF designs were being limited to "less ambitious" sets and that "so far as selectivity is concerned, the designs of this class (TRFs) have ceased to compete with the superheterodyne, in which relatively high selectivity is so easily and cheaply obtained. ---there is a distinct tendency to simplify straight (TRF) sets by the omission of bandpass tuning; most of the cheaper sets include only two tuned circuits ---one gets what one pays for, and the higher selectivity conferred by an extra circuit involves, in all cases, a slightly greater outlay." (p.97).

The design choices and criteria faced by radio designers in this area have been described in a series of articles on receiver design given in Wireless World in 1937/1938.[63] "Ideally the correct procedure in designing a receiver is to decide on the performance required and to work out on paper the type of circuit, number of valves and values of components needed to give that

61 Wireless World 1932, Sept 2, 31 pp.231-236
62 Wireless World 1934, Aug 10, 35, pp.94-99.
63 Wireless World 1937 Dec 30, pp 648-649 "How a Receiver is Designed" being the first of this series of articles.

performance. One then constructs the set and tries it out --- the experienced designer often overlooks something (because the set is complicated) which is revealed in the testing and remedied. It often happens also that there are several different ways of obtaining the same performance, and the best design is then the one which uses least material. --- There is one point in particular which is commonly met with in set design and which creates great difficulty to both amateur and professional alike. It may often happen that there are two or more different ways of achieving the same end and the difficulty is to decide which to adopt. Where the different methods lead to exactly the performance, of course, a decision is usually easy and one selects the cheapest if one is building a new set --- The real difficulties occur when the performances of various alternatives are slightly different. From the technical point of view a solution is straightforward. One has only to collect the necessary data on performance for each method, and a comparison will show that one system is perhaps slightly better than another from the point of view of quality, but another gives greater amplification or consumes less power. The solution than depends on the relative importance of the various factors. The problem gets really complicated, however, when cost must be taken into consideration --- the necessity for producing a set at a competitive price, and this affects not only the type of circuit adopted and the number and quality of the components employed but the mechanical arrangement of the parts. Complicated layouts increase the cost and through the greater time needed for assembly".

That extract illustrated the nature of commercial design in the mature stage of an industry. The design process began by a plan or decision about the performance desired and led to a design on paper which was worked out with reference to existing knowledge. When the technical objective could be achieved in a number of ways the choice depended upon Technical and Economic constraints. This is an example of the design "trade-off" met with in the Bicycle, and at this stage often involved Production economics as well as Product performance. Once the design has been finalised a prototype is built and tested to check the design.

In the eighth article in this series Wireless World[64] considered the design of the three valve TRF which had been the most popular domestic receiver until the mid-1930s and showed the aspects which needed most consideration. It was considered that this type of set needed more careful design than had often been the case a few years earlier because of the competitive pressure which a low cost highly selective superhet created.
As far as TRF design went there was no great difficulty with sensitivity and good quality of reproduction, the major design difficulty was to obtain combined sensitivity and adequate selectivity and this combined feature formed the core of the design article.

Experience (knowledge) had shown that adequate selectivity needed at least three tuned circuits, and for a single r.f. valve set, there were only two possible arrangements - a single tuned aerial circuit before the valve with a pair of coupled tuned circuits after the valve; or a coupled pair before the valve and a single after - the latter design being preferred because reaction was to be used and the application of reaction to a pair of coupled circuits usually led to serious difficulties. Selectivity was further affected by other technical factors, especially the accuracy of matched coils in ganged circuits as any deviation in a TRF would adversely affect selectivity. The rest of this design was relatively straightforward and in accord with established practice and will not be described here. The main concern had been with combined selectivity and good quality which was to be obtained by careful design especially of the tuning section of the set.

The main feature of TRF design, as already shown, was the tuning circuit and Wireless World[65] reported one manufacturer's comment that the manufacturing cost of a set was then largely determined by the number of tuned circuits it had. Lower costs would therefore follow if fewer tuned circuits were employed and the TRF receiver became less selective, in other words it performance was reduced. This is occurred and many TRF sets abandoned bandpass tuning in favour of a cheaper less selective form.

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64 Wireless World 1938, March 17, pp.232-4 "The Three Valve Straight Set"
65 Wireless World 1932, 31 p.233

Another trend was to move even further down the low price scale and produce two valve TRF sets. Although two valve sets had been produced before 1931 they were regarded as toys and not taken seriously. Wireless World[66] reported "The simple two valve set is at last being taken much more seriously and is no longer regarded as the Cinderella among wireless receivers". It described some of these models at the Show noting its reduced sensitivity and selectivity though they appeared to be fairly suitable for local listening and of course were the cheapest sets. These two valve receivers appeared to sell for a few years, and like the three valve one were very popular as Kit Sets for home construction.

These accounts of the design of low priced receivers give very strong evidence of the importance of economic influences upon product design. It was with some surprise that Wireless World[67] reported that Battery sets had diversified into two and three valve TRF types with reduced performance tuning circuits of selectivity which might "in certain circumstances" (i.e. local listening) give sufficient selectivity though it was considered that they were cheap and trouble free. (Most Battery sets were highly efficient superhet designs from that time and had a performance virtually equal to that of a mains set).

Wired Wireless

The ultimate in simplicity was a "loudspeaker receiver" which was nothing more than an ordinary loudspeaker connected to wires carrying a.f. current. "Wired Wireless" (or relayed wireless) came under special legislation and was provided usually in areas of poor reception. By law companies which provided this service could only supply one programme and could not use r.f. carrier frequencies. The Broadcaster Annual 1932, noted that this type of service had become quite popular in that year, one attraction being that the "set" was cheap. Some companies rented their "loudspeaker receivers". Sturmey (1958) has given a good description of wired wireless in Britain in this period.

66 Wireless World 1931, 29 p.387
67 Wireless World 1934 35 Aug 10 p.96

Accessories and Gadgets

Product design had been found to be one way of boosting sales at times of economic depression in the bicycle industry. This pattern was repeated in the case of the domestic radio receiver industry, especially when market ´saturation´ occurred, as in the later 1930s and during the 1960s.

The late 1930s saw a multiplicity of accessories and gadgets, many were a response to falling sales as in the case of push-button tuning in 1938, when British radio manufacturers, following American ones, introduced this feature which lasted only for a short time. Luxury receivers then bristled with gadgets and novelties such as truly variable selectivity, automatic frequency control, bandspread and others features. The comments made by Rust et al (1941) about receiver accessory inventions have already been noted and it was said that some of these inventions did improve the set´s performance but many did little to improve the basic quality of reception.

An article in Engineering (anon., 1939) commented that these incremental product inventions did little to improve the basic performance of receivers and therefore did not lead to listeners scrapping their existing sets. Because the receiver market had saturated (this was illustrated by reference to the decreasing rate of receiving licences from 1930), radio manufacturers had turned to price cutting.

Reliability: A Later Design Criterion

Another trend of product invention during the mid-1930s was its change of objective from a primary concern with improving the technical performance of domestic receivers to making them more reliable and more easily serviced. Wireless World[68] noted "In the past listeners have developed prejudices either for or against particular makers of sets, their opinions being governed by the number of service visits the set has required --- ingenuity and money have been expended in making instruments more dependable and more easily serviced". This article went on to note that the main troubles had been associated with volume controls and waveband switches which had arisen either from poor design or else corrosive effects from the atmosphere. Consumers were increasingly judging a set by its appearance rather than its technical performance; and the article continued " --- it is a notorious fact that the

[68] Wireless World 1935 Aug 16, p.163

design of the cabinet is the most important selling feature to the general public". Another harsh fact was noted "It is well known that a third of the users of wireless sets operate their controls in a way that would send the designers into paroxysms of scientific rage, and on such listeners as these highly commendable improvements are wasted." By 1935 the design of popular receivers had reached a satisfactory level with regard to the technical criteria of selectivity, sensitivity and tone quality and that 'tidying up' the product design was well under way although not yet quite complete.

During the second world war the vital need for complete reliability and maintenance of military equipment had led to a new design practice now known as Reliability Engineering. Dummer (1983) has described the application of this to military electronic devices. These practices have since been developed and used commercially, a description is given of its application to colour television engineering design.

Scope Of Engineering Design

Engineering design differs from invention in that the weight of external influences is greater on design than it is on invention. Three illustrations are given showing the nature of incremental engineering design. Two of these are taken from colour television technology and the last illustration comes from modern Indian radio design.

Heightman (1979), in a broad assessment of the British radio and television industry, believed that demand had declined largely because British manufacturers had not invested sufficiently in (product) R&D so that they did not have internationally appealing goods to offer. He suggested that at least four major new product programmes were needed which, allowing for a 50% failure rate, would provide two products for the next ten years or so. Competitors had used design to provide cheap reliable products and Britain had relatively failed to do this during the 1970s. Heightman then showed that the pattern of new sales of colour television sets was very similar in Britain, U.S.A. and Japan (given that each had different starting dates). Product and process design had combined to produce a trend of relatively declining product prices. The number of components per colour receiver had declined, Heightman gave a graph showing that between 1967 and 1979 the number of components per set had roughly fallen to one third. This had largely been due to the adoption of i.cs. but he described some other components which had been simplified as well. Product reliability had also greatly improved and a graph was presented showing that a sixfold decline in Faults per set per year had occurred between 1967 and 1977. Product (and process) design had therefore contributed to reduced costs and increase quality and reliability. Sales, of course, had been affected by stop-go policies.

Wilkinson (1980) has described the[69] reliability aspect of colour television receiver design which involved serviceability, consumer ease of operation, external appearance, cost and advances in technology. In general the emphasis was on the day to day operation of the receiver to make it safe, easy to service, reliable and so on. This activity was far removed from pioneer invention and usually involved prolonged testing in accord with government or industry specifications and much more attention was paid to this aspect of consumer goods today.

Pai (1974) has described the different stages and techniques employed in Indian radio receiver design in modern times. Pai outlined the design process from ideas to prototype testing and the need to establish objectives at the outset. Pai considered that a common objective was for good technical performance coupled to low cost. The value of Pai's account lies in the way he shows how modern techniques of incremental design improvements contributed to the overall objective. The design process for radio receivers fused technical (electrical and mechanical) design principles together with other techniques such as standardisation, value engineering, reduction of varieties and industrial design, each of which contributed to the overall objective for a low cost mass-produced receiver.

It is interesting to note that the diverse pattern of receiver design observed in the 1930s was repeated from the late 1960s in the case of transistor sets which ranged from popular, low priced, low performance personal portables to luxury gadget-laden hi-fi 'music centres' - all being

[69] Wireless World 1980, June/July pp. 85-89

examples of market-led design.

The pattern of product design over the industry life-cycle was one in which invention in the early years was dominated by technical considerations and which reduced as technical possibilities were exhausted. In later years product invention was influenced much more by economic and consumer factors.

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5.6.3 Frequency Modulation Receivers

The Frequency Modulation (F.M.) system was developed principally because of its inventor's belief that it would be less susceptible to atmospheric noises and give better reception.

F.M. development involved some extremely complex technological development especially for demodulation circuits; in this account only a summary of the main trends and features will be given.

Origins Of F.M.

There is some doubt about the first person to conceive the F.M. principle. Tucker (1970) has re-examined the pre-1922 history of F.M. and decided that Ehret, an American, did so and not Fessenden as is commonly supposed. However the real pioneer was another American, Armstrong, and a summary of his efforts will now be given.

Pioneer F.M. Invention

Armstrong (1936) gave an historical introduction noting that there had been vague suggestions of F.M. systems prior to 1902, and that difficulties with Poulsen's arc transmitter had led to the idea to key the arc as with the Spark transmitter; this formed a new method of modulation. The idea was to alter the frequency of the transmitter and use a selective receiver to separate the signalling frequency from the idling one, and in turn it was suggested that this system might be applied to radio telephony with the transmitter being modulated by the voice frequency. Some experiments along these lines were undertaken up to 1913; Armstrong gave references, though these were unsuccessful. After the thermionic valve was introduced a further set of F.M. experiments were undertaken and these too proved to be unsuccessful. Soon after the introduction of radio broadcasting in America, the large numbers of transmitters led to much inter-station interference and it was proposed that F.M would increase the number of wavelengths available because it could be made to operate on narrow bandwidths. This proposal envisaged that the F.M. would vary the carrier by only small amounts and at the same time permit a narrow filter which in turn would reduce noise and atmospherics.

Carson (1922) published a paper showing that F.M. would need at least a bandwidth double the highest modulating frequency, and that no saving and no noise reduction would result. This finding from the mathematical analysis of the problem was re-examined by a number of others between 1929 and 1932 (Armstrong gave references) and they too confirmed Carson's original finding. These negative assessments about the suitability of F.M. made it very difficult for a later inventor to try to introduce or even demonstrate the F.M. system as most designers had a mental barrier about the idea.

However Armstrong had swum against the tide of opinion and developed his wideband F.M. system. This was made possible by using ultra short waves (over 40 MHz) as these were not reflected by the ionosphere. These ultra short waves had properties which were known from A.M. use, one being that 'atmospheric noise' was considerably reduced at such high carrier frequencies. Armstrong's main initial concern was to reduce disturbing noise and his initial calculations showed that this should be achieved using F.M. Armstrong then tested his theory and compared A.M. with a 15kHz bandwidth with F.M. having 150kHz bandwidth. Armstrong used a superhet receiver as the basis for these experiments, The results of Armstrong's initial experiments surpassed all expectation and Armstrong found that atmospheric and man-made noise (with the exception of car ignition interference) was much reduced. During these experiments Armstrong also found that F.M. had a much greater selectivity than a comparable A. M. system, a further example of an unanticipated bonus feature of invention. When two A.M. transmitters were broadcasting and their carriers gave audible beats, the reception of one of these stations was confined to a distance where the field strength of the interfering (undesired) station was equal approximately to one percent of the field strength of the desired station. When F.M was used satisfactory reception was obtained when the undesired station field strength was fifty per cent. This bonus feature had a valuable commercial potential as it permitted many more F.M. transmitters to broadcast without mutual interference than would have been the case if A.M. transmitters had been used.

Armstrong stated that his invention had required years of research and experiment. Apart from the original idea itself, much effort had to be expended upon finding and curing a number of problems which prevented the F.M. operating as it should. All these problems were design difficulties and once solved were solved for ever.
Armstrong was essentially a scientist (professor) and acknowledged the assistance which members of the Radio Corporation of America (R.C.A) gave with various aspects of the system.

Although the F.M. system was ready for use in America in 1936 its commercial introduction was delayed firstly because of a reluctance by the radio industry to adopt the new system so that Armstrong himself had to build and operate the first one (as Moulton had to do with his revolutionary new bicycle design in Britain), and secondly the 1939-45 war broke out. During the war military F.M. radio systems were developed and proved to be excellent and partially paved the way for a rapid commercial use of F.M. in the post war period.

In Britain, technical interest in F.M. broadcasting was expressed soon after 1945. Bell (1945) discussed its principles and possible advantages. Pawley (1972) has described how the B.B.C undertook field experiments in that year. Prior to 1939 broadcast F.M. systems used carrier wave frequencies of about 45MHz because that was the most suitable band above 30MHz (the latter frequency being technically determined by the modulation bandwidth). By 1945 it had been proposed to allocate higher frequencies (88-95MHz) and the B.B.C tests were extended to compare F.M. and A.M reception at these two frequency bands. The reason for undertaking these tests was the increased interference from European transmitters after dark. A further advantage of using very high carrier frequencies was that a bigger bandwidth was possible and hence the full audio frequency could be transmitted making the transmission a high fidelity one.

The results[70] were very promising although they did not prove that F.M. was the only method, it was decided to proceed to full power tests because the advantages noted by Armstrong applied to British F.M. too. The tests revealed some added complexities with r.f. propagation patterns, particularly multi-paths due to reflections from hills, tall buildings etc., though it was considered that directional aerials would reduce this effect. The results of the full power tests were sufficient to prove the system and the B.B.C. was authorised to prepare a public F.M. broadcast system for use by 1955.

Trends of F.M. receiver design improvements have been described by Pawley (1972) and Wireless World.[71] These will not be considered in detail here as they deal with complex technical problems associated with the F.M sections. (Other improvements were incorporated, especially in connection with high fidelity features which was main purpose of F.M. then). The F.M. receiver had particular problems in the limiter and demodulator circuits which resulted in many alternative solutions and British manufacturers were encouraged to provide sets with strong A.M. suppression. Langford-Smith (1954) has given a technical description of the variety of F.M. circuits proposed and adopted. When high frequency transistors were developed these circuits were further modified so that they could be used, early F.M. receivers used valves.

F.M. promoted further scientific research and mathematicians investigated F.M. theory with a special interest in the signal and noise characteristics of various circuits. A number of these papers have been published with Klapper (1970) as editor, which typically begin by considering the theoretical aspects of the chosen subject followed by experiments which are then compared with the initial theory. F.M. design now frequently incorporates digital circuitry.

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70 H.L. Kirke "Frequency Modulation: B.B.C. Field Trials" BBC Quarterly, 1946, July, 1(2), p.62

71 Wireless World 1961, April, Anniversary Issue

Much more could be said about incremental F.M. inventions, especially those concerning Stereophonic receivers whose origins stretch back to the 19th century. Instead, a note will be made of the very sluggish consumer acceptance in Britain to illustrate how a technically perfect product can encounter consumer resistance.

Public F.M. broadcasting began in Britain in 1955 and was intended to provide very high quality reception due to the low interference and full tonal range which was broadcast. However public acceptance was slow; it was generally thought that the expense of F.M. receivers was the main reason and by the late 1960s F.M. receivers had been transistorised and cheapened; indeed many of these receivers were imported as note in the I.B.A. 1976 Annual Lecture. This diagnosis could not be proved until market facts were available and no reliable statistics appeared until the results of a B.B.C. special survey were published in 1975.[72] These results showed that 40% of all British radio sets, and 65% of all British listeners could receive F.M. but only 25% chose to do so and even smaller numbers listened to F.M. stereo (which required special F.M. receivers).

These results indicated that the earlier belief (that F.M. receivers were too expensive) was incorrect and that F.M. was unpopular for some other reason. No one can say exactly why F.M. is relatively unpopular, some consider that there are difficulties about its reception, others consider that battery F.M. receivers use more current than A.M. ones but few suggest that listeners are not particularly keen on hi-fi and are quite content with the relatively degraded A.M. signal. The implication is clear, invention and 'perfect' technical performance is not sufficient to ensure market success and F.M. development can be said to owe more to invention-push than to market-pull.

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72 'Reports On Some Ad Hoc Research Studies: 1 Radio Sets And Their Users'. Annual Review Of B.B.C. Audience Research Findings No. 2, 1975.

5.7 Component Invention: The Thermionic Valve and Transistor

Thermionic Valve

The thermionic valve was a most important radio component and in this section an outline will be given of the nature of its invention, the trends of its development and the factors which influenced the course of its development. Some writers such as Sturmey (1958) have considered that valve inventions entirely controlled all radio improvements and he devoted a chapter to valve invention with an emphasis upon British contributions in this field.

Fleming, the first inventor of the thermionic diode, described how he invented it in an article first published in the 1920s.[73] Fleming began with knowledge of the Edison Effect and of J.J. Thomson's experiments which demonstrated the existence of the electron and of electron flow. Fleming's inventive step was to forsee the practical application of the principle in a (diode) valve and its potential use as a detector (rectifier) for r.f. currents. Fleming constructed a suitable diode which worked but not as well as other existing types of detectors so it was not used immediately. Fleming's patent application for this was made in 1904 and the idea attracted others. Eccles (1930) noted that some Germans considered Fleming's arrangement though an American, De Forest sought to improve it by adding a grid between the cathode and anode. De Forest called his device an 'audion' (triode) without realising that it could be used to amplify r.f. signals; this realisation came later. De Forest's valve was 'soft' and not effective and not of any practical use in that form. Other Americans later considered that if a higher (harder) vacuum was formed the triode would be much improved and Langmuir used electric filament lamp technology to achieve this with the result that the hard vacuum triode gave a much improved performance. Buff (1962) has described in some detail the improvements between 1907 and 1913 which cover De Forest's first triode to the discovery that a hard triode could be used as the key element in an oscillator circuit which provided any desired frequency of pure (sine wave) output up to the valve's frequency limit.

The availability of a satisfactory triode valve led inventors to try it in various radio circuits. The well known problems with earlier types of non-

[73] This article was republished in Wireless World 1979, Nov, pp.94-95

valve oscillators led to tests with a valve oscillator as these valves could now satisfactorily amplify r.f. signals. The immediate result of the hard valve was to make a new type of oscillator possible which could generate pure sine wave outputs of any desired specific frequency free (or fairly free) from harmonics. A secondary discovery was that such an tuned circuit arrangement could employ positive feedback ('reaction') which greatly enhanced both its selectivity and sensitivity. A variety of positive feedback circuits were simultaneously developed independently by different inventors who each devised different methods of achieving the feedback. These circuits were soon used on TRF receivers.

Buff (1962) has described how the Federal Telegraph Company's three stage audion amplifier of 1912 was the earliest known use of the cascade principle which, even with the soft valve, gave a considerable degree of amplification, but the development of hard valves meant that virtually limitless amplification could be achieved using valves in cascade.
During the 1914-18 war, Sturmey observed, rapid valve developments were made because of wartime needs and specialised types of valve, such as transmitter and receiver valves emerged, whose design was based upon valve theory and operation which was better understood by 1918.

From 1920 thermionic valve inventions became rapid and branched in several directions. One line of development was to gain greater powers and attempts to do so encountered secondary problems which prompted further inventions to solve them. Another trend of valve development was to produce valves which could handle higher r.f. frequencies and this too encountered secondary problems with consequent further inventions. A third trend was to develop valves with special characteristics such as low noise, miniature size and specialised technical features as in the later variable-mu valve.

The earliest dull emitter valve came out in 1921 though Sturmey did not note that its filament was very fragile and this was the reason for its general acceptance being delayed until 1925. The miniature valve was first produced in 1924 because of the demands of the telephone industry and about 1930 it was generally introduced into radio receiver design making miniature sets possible and also for Short Wave sets. Later still triodes were further improved by the addition of more grids; the Screen Grid valve of 1927 provided[74] a much better r.f. amplification without the bad inter-electrode capacity effects which had previously been troublesome in triodes while the Pentode valve had two grids and gave a much better a.f. amplification.

Broadcast Receiver Valves

Goldup (1944) has reviewed the development of early receiver valve design and manufacturing methods in Britain. He observed that until the screen-grid was invented, various kinds of triodes were made by altering the geometry of the anode, cathode and grid and their materials so producing 'r.f.' and 'a.f.' types and 'detectors' - although all were essentially triodes. A 'bi-grid' (two-grid) valve appeared on the market about 1922; no one was sure of its technical property but it was sold as a 'battery saver' (i.e. a low consumption valve).

The fundamental advance in receiver valve design came with the introduction of the screen-grid in 1927. This made it possible to amplify r.f. signals much better than any neutralised triode could do but it had a kink in its characteristic curve which made it unsuitable for use with the larger signal levels used in a.f. amplifiers. However the investigation for the reasons for the improvement due to the extra grid quickly led to further improvements and even more grids; this feature lasted until the mid-1930s when technical limits were reached and receiver valves were satisfactory. The screen-grid had triggered a logical sequence of inventions.

Aldous (1958) has briefly reviewed receiver valve progress for the period 1935 to 1955. He noted that the electrical characteristics had changed very little over this period; the notable trend had been the progressive reduction in size. This had come about partly because of the all-glass design of the late 1930s, in which the leads went straight through the glass base and reduced interaction among the leads and better high r.f. amplification. This

[74] The Times 1927, Sept 20 p.7. in an article on valves, noted that the chief improvement the screen grid type made was a large increase in r.f. amplification. The old valve only amplified r.f. signals about 8 to 10 times, the new designs (there were two) amplified about 110 times largely because the screen grid design ended inter-electrode capacity effects.

needed less heating (to prevent the glass case overheating) and led to a re-design of the heating filament and resulted in a more robust valve. From 1937 valve designers were pressed to create new battery valves which had much lower current consumption; in 1937 a typical battery valve filament took about 100mA and over the years this decreased to 15mA making it possible to use dry batteries and hence the 'All-Dry' set.

Multiple Valves were introduced, these were compound valves (for example a diode-triode) and were intended to use only a single common filament thereby saving a considerable current; although this idea was not very popular it paved the way for later more specialised valves such as the Variable-Mu and the Frequency Changer which served new receiver functions. By the mid-1930s domestic receiver valve development was virtually complete and superhet designs incorporated them.

Sturmey considered that Incremental Invention had played an important role in valve development; "In valves, as in most of the parts used in radio, these gradual detail improvements have been at least as important as the introduction of new types." (p.42)

Transistor and Subsequent Developments

The transistor was an "amplifying crystal" which had many advantages over the thermionic valve; it was a small robust device which was "cold" in operation, required only very small voltages and currents (and hence ideally suited for battery power), and was soon developed so that cheap portable and other other fairly good quality receivers could be made.

Origin Of Transistors

The origin and development of transistors and 'solid state' technology was a complex affair which date from the 'cat's whisker' discoveries in the early 1900s. Gibbons and Johnson (1970) have examined this history to ascertain if it owed as much to pure science as was frequently suggested. These authors concluded that this was not the case and that many early technological advances were due to empirical efforts and generally that progress was due to technology building upon technology. They concluded that science had a symbiotic relationship. The first investigations began with the discovery of the rectifying principles of the 'cat's whisker' (which, as noted earlier, was not then understood); then, Gibbons and Johnson observed, commercial interest died during the 1930s and academics became involved largely because of contemporary advances in this field of physics. During the second world war an urgent need arose for rectifiers for very high frequencies which valve circuits could not handle, and led to government research and germanium and silicon crystals. After 1945 these new detectors together with complementary advances in solid state physics quickly resulted in the demonstration of an elementary transistor. This type could deal only with low frequency a.f. signals; much more research was needed to produce r.f. transistors and these advances were not particularly guided by theory as the theory itself was not advanced.

Application Of Transistors

The powers and frequencies which early transistors could handle were very limited but these gradually increased, so that the first commercial use of transistors as audio amplifiers only (with valves for the r.f.stages) gave way to the "all-transistor" receiver by the late 1950s. Transistors made it possible to produce small cheap portable receivers and, luckily, that the newly developed printed circuit board method of radio manufacturing was ideally suited for it. The transistorised "personal portable" proved to be a great commercial success and in all countries thousands were bought and per capita ownership rates usually doubled. The transistor had created a huge new demand for portable radio receivers which was intensified by changes to broadcasting with a new greater emphasis on 'pop' programmes and local broadcasting. Later, by the mid-1960s, better transistors caused valve radios to be made obsolete and by this time the transistor could be used in most types of domestic electronic equipment such as tape-recorders, record players, radiograms and even television receivers. It made it possible to reduce the physical sizes of all such equipment and provide cheap robust models.

The invention of the transistor was a revolutionary advance which created a new permanent demand for old and new forms of radio and electronic goods. These radio receivers used the basic superhet circuits which had been developed for valve sets and today the majority of transistor sets are still made using Discrete components. Transistor and solid state technology provides evidence that product invention was used to create demand and prolong the product life-cycle.

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5.8 Patents and Inventive Activity

Patents and Invention

The degree to which patents either promote or inhibit invention is a question which has not been conclusively answered. In the case of radio patents Sturmey (1958), (following Maclaurin (1949)) stated that "the study of the radio industry leads to no general conclusion concerning the effects of patents upon research." (p.234). This view was not shared by Marriott (1917), who, as noted earlier, considered that radio monopolies based on patents stimulated inventors to search for alternative methods of achieving the same effect. Dalton (1975, 3 p.8) noted "Progress was also stimulated by the patent situation: one group of manufacturers held a large number of patents which they would not allow anyone else to use, and so other manufacturers were forced to group together to find alternative methods of attaining the same results. In Britain, all manufacturers had a licence to use all patents, and so less research was conducted".

Patents As An Index Of Inventive Activity

In the following graphs of the annual numbers of British patents granted (which include inventions from abroad) the particular classes or sub-classes have been chosen to illustrate as reliably as possible inventive activity for the receivers described above. Apart from the usual difficulties with any patent classification scheme, radio patents have an added difficulty as many of these inventions were used, or even created for both radio transmitters or non-radio (i.e. electronic) use. A further complication is that specific patent sub-classes usually contain patents for invention for specialised applications; for example the Homodyne sub-class H3Q7G6 contains not only homodyne receiver inventions but also circuits for introducing suppressed carriers, for removing the whole or part of sidebands and for providing separate treatment of sideband or carrier. These patent data are therefore not pure measures of inventive activity for a particular type of receiver but they give a fair indication of the trend of invention for most of the receivers discussed earlier.

T.R.F.

There is no special patent class for the TRF as it was the basic model. The best indication which can be presented here is to show the annual patents granted for all receivers. Unfortunately the number of receiver patents were not separately counted until after 1931 when the TRF began to decline. The best which can be done to show the general trend of radio invention is to give the figures for all radio patents (which includes transmitter patents) from 1909 to 1930. These are shown on graph 5.01 which reveals that inventive activity in this field was at a low level and grew only slowly until 1913, after 1918 the patenting rate surged with fluctuations up to 1930.

The number of patents granted for all radio receivers for the period 1931 to 1963 is shown on graph 5.02. this indicates a rapid increase in inventive activity up to 1940, after which it tailed off to reach a low level by the late 1950s. This is the characteristic pattern noted in the Bicycle industry, and by others for other industries.

Crystal Sets

The British patent classification has three sub-classes for crystal sets. The first was H3Q1E for crystal set receivers for the period 1913 to 1965. These data are shown on graph 5.03 which indicates that over the period 1913 to 1965 the peak years were those of its commercial life, between 1922 and 1927 after which invention rapidly declined to 1933 and thereafter virtually ceased except for single patents in 1952, 1955 and 1962.

The pattern of inventive activity for crystal detectors was different largely because interest in crystal detectors continued throughout the 1930s and 1940s. Graph 5.04 shows the British patents granted for sub-class H3Q7G1 for the period 1913 to 1965 and contained inventions for detectors associated with valve amplifiers (except for dual and reflex circuits). This shows that patenting was most intense during the 1920s and had virtually ceased by 1934.

The other patent sub-class was for electrolytic and other non-thermal detectors patent sub-class H3Q7B6, for the period 1911 to 1965, and the annual data for this group is shown on graph 5.05. Inventive activity in this field was sustained throughout the whole period although it peaked in the late 1920s. Doubtless some of these later patents were for silicon and germanium type crystal detectors.

Neutrodyne

British patents granted for neutralising and associated inventions were divided among three sub-classes.

Sub-class H3Q7A8A contained patents granted for inventions for neutralising arrangements including screen-grid valves. Graph 5.14 shows these and the low and spasmodic levels of activity until 1924; the peak occurred in 1925 after which the activity level reverted to a low and spasmodic one.

Sub-class H3Q1K contained patents for Screening and Arranging Elements To Minimise Coupling; Coating or Sheathings on or in Electric Discharge Tubes, Screening Cans etc. These are shown on Graph 5.15 and reveal that although quite a high level of activity existed from 1918 the peak years were not the 'neutrodyne' ones of the mid-1920s but 1930-1932 and that inventive activity in this sub-class continued at lower levels right up to the 1960s. This prolonged effort was needed as even better screening was required for the improved valves and higher frequencies used from the 1930s.

Sub-class H3Q7A7 contained patents for inventions for Preventing Radiation Of Locally Generated Oscillations Otherwise Than By Screen-Grid Valves. These are shown on Graph 5.16 and reveal that the peak years were 1924 and 1925 although low level activity continued until 1961. These inventions were used on all receivers which had local oscillators so that superhets etc. also shared in the benefits.

Super-Regenerator

British patents granted for Super-Regenerators radio receivers for the period 1920 to 1965 are contained in patent sub-class H3Q7G4 and are shown on graph 5.06. Inventive activity in this group was highest during the 1930s but with another peak between 1945 and 1952 after which it rapidly declined. The most probable explanation for this pattern is that the super-regenerator was best for short wave frequencies, and greatest interest in short waves occurred during the 1930s and 1940s.

Homodyne Receivers

British patents granted for Homodyne receivers for the period 1916 to 1965 are contained in sub-class H3Q7G6 and are shown on graph 5.07. This indicates that there had been a steady amount of activity from 1916 to 1933 with a decided peak for 1930s; after 1945 activity was low. Perhaps the reason for this pattern was the variety of associated inventions covering circuits for introducing suppressed carriers, for removing the whole or part of sidebands and for providing separate treatment of sideband or carrier. These inventions are used in specialised (non-domestic) receivers and other circuits.

Superhet Receivers

British patents granted for Supersonic Heterodyne inventions, 1914-1965, are contained in patent sub-class H3Q7G7 and shown on graph 5.08 which indicates that this was the most intense field of inventive activity reaching a peak in the late 1930s with a secondary peak in 1950 after which activity tailed off.

It was noted in the analysis that that the superhet was really a modified form of the Heterodyne method of reception and British patents for this sub-class H3Q7G5, 1913-1965, are shown on graph 5.09 which indicates a peak in the early 1920s and a tailing off to 1939. After 1945 there was a very low level of inventive activity in this sub-class.

F.M. Receivers

Graph 5.10 indicates the patents granted for the period 1920 to 1965 for F.M. receiving circuits sub-class H3R9R1. Apart from a single patents granted in 1920 and 1922, the real beginning did not start until 1933 with increased activity to 1949 after which activity tailed off.

Graph 5.11 indicates the F.M. patents granted for sub-class H3R9R3 Receiving circuits employing negative feedback of demodulated signals. Activity in this sub-class was later in starting and peaked in the early 1950s, after which it tailed off.

Graph 5.12 indicated the F.M. patents granted for sub-class H3R9R4 which contain inventions which re-combine sidebands and carriers after relative phase shift. This was not an area of great activity though the first patents were granted relatively early; activity ceased after 1949.

Graph 5.13 is for sub-class H3R9R5 covering otherwise unclassified F.M. receiver circuits, for the period 1931 to 1965. There was a low level of activity in this in this sub-class until 1939, The peak activity occurred between 1946 and 1952 and after this date there was a low but fluctuating level of invention until 1965.

The general feature of all these F.M. patents granted is that they were later than all other receiver types, and also of much lower intensity; the former aspect can be explained by the much later start of general interest in F.M.

Conclusion

The overall patenting pattern at both the aggregate and disaggregate levels shows that the characteristic trend of inventive activity in radio was similar to that of the bicycle and other industries. The evidence from particular types of radio receiver, such as the crystal set, suggests that invention more or less ceases once it becomes apparent that the potential for further advance has been exhausted. Other types of receiver, such as the super-regenerator or homodyne continue to attract inventors' attention even when sales are low or non-existent. Schmookler's thesis, that demand is the primary determinant of inventive activity, is thus open to question. Some qualification is needed. Many of these radio patents would be granted for inventions unconnected with domestic receivers; it is hardly to be expected that military inventions would be patented although later commercial versions of military designs would be and the second world war affected the normal stream of invention. Nevertheless the broad pattern is one of a sporadic start followed by increasing activity which peaks and then declines. This accords with the general trend of invention noted in the analysis and established by others.

Radio patents, like bicycle patents, were product inventions.

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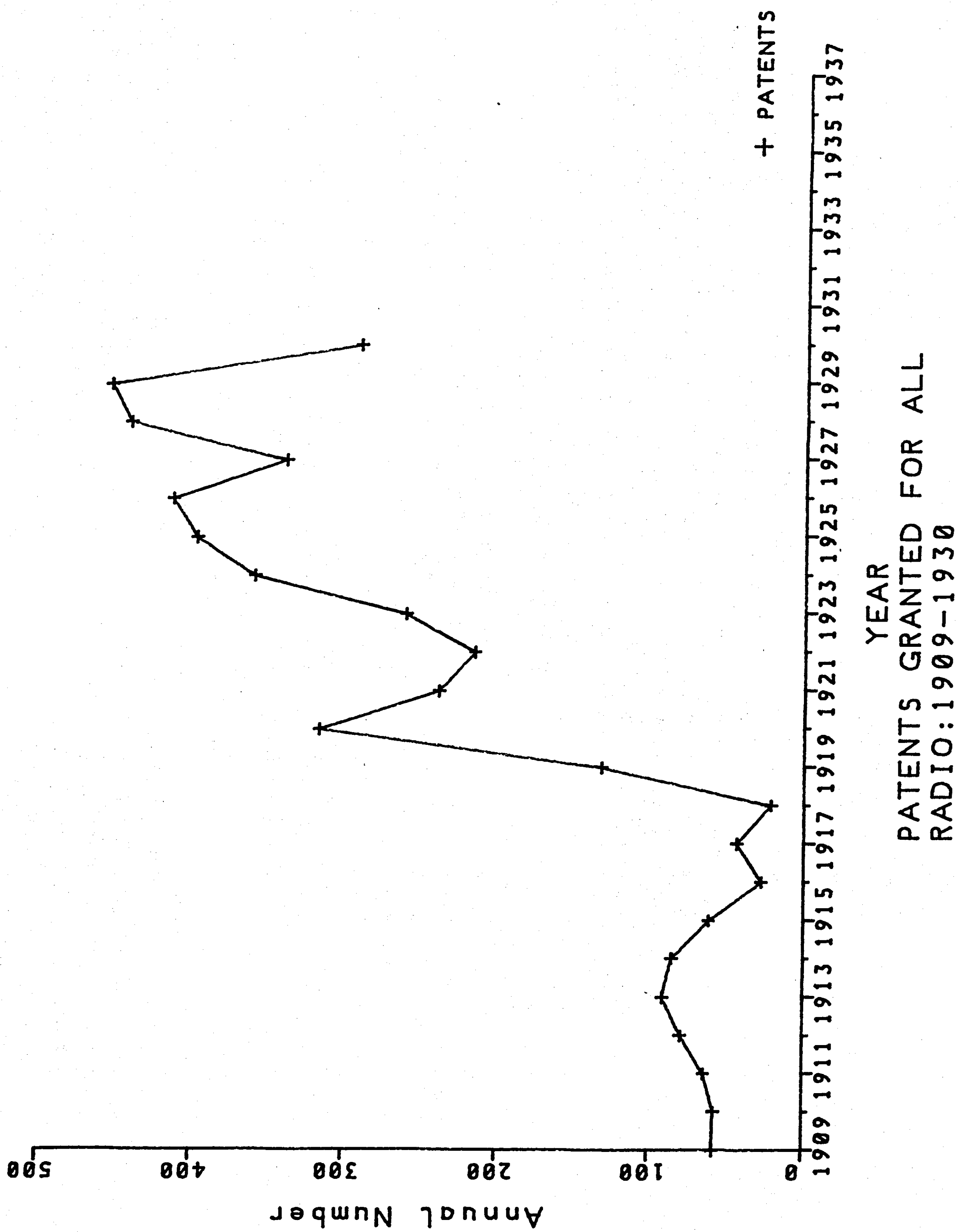
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1909 1909 1911 1913 1915 1917 1917 1919 1921 1923 1923 1925 1927 1927 1929 1929 1931 1933 1935 1937
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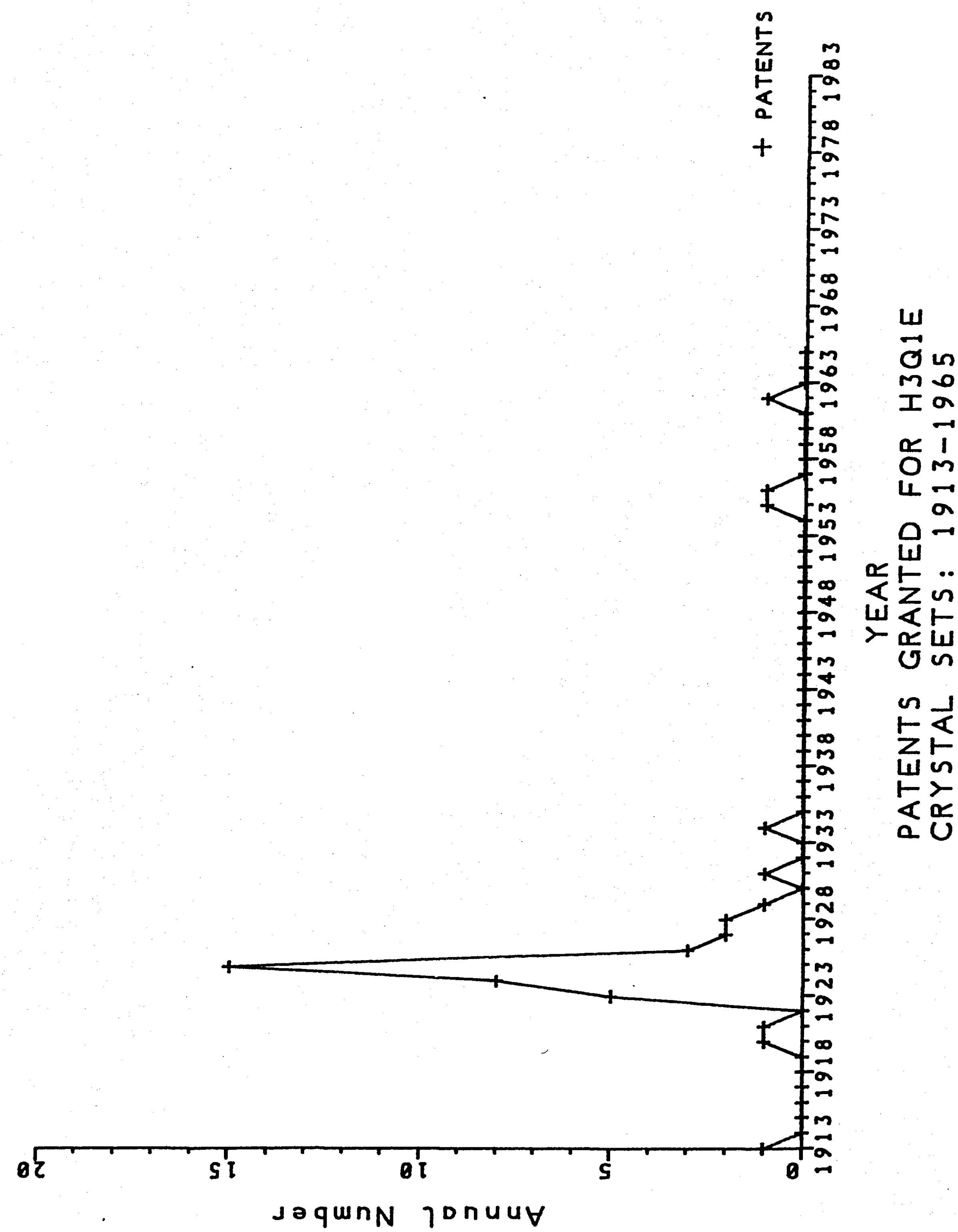
RADIO:1909-1930

PATENTS GRANTED FOR ALL
RECEIVERS: 1931–1963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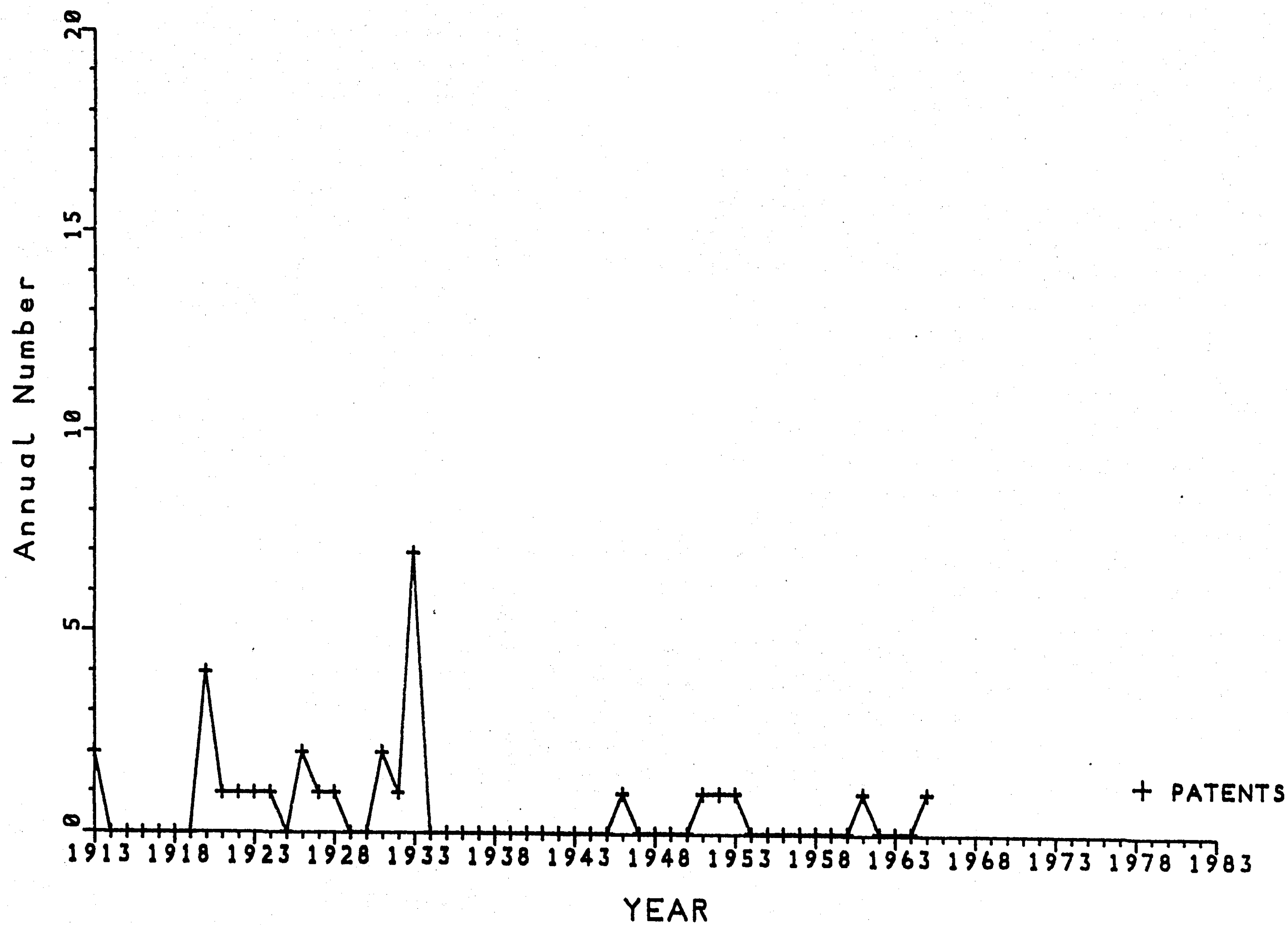

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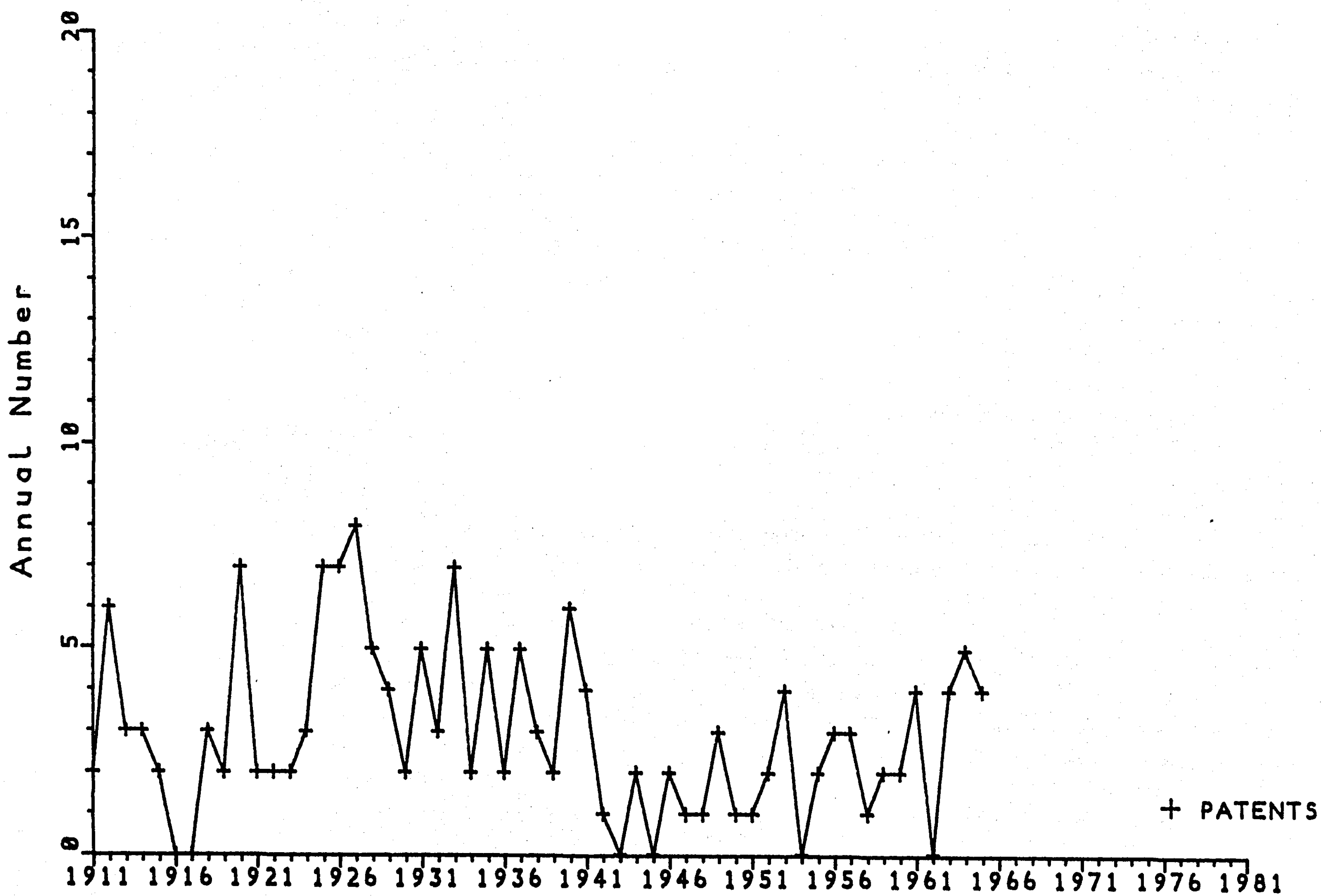

YEAR
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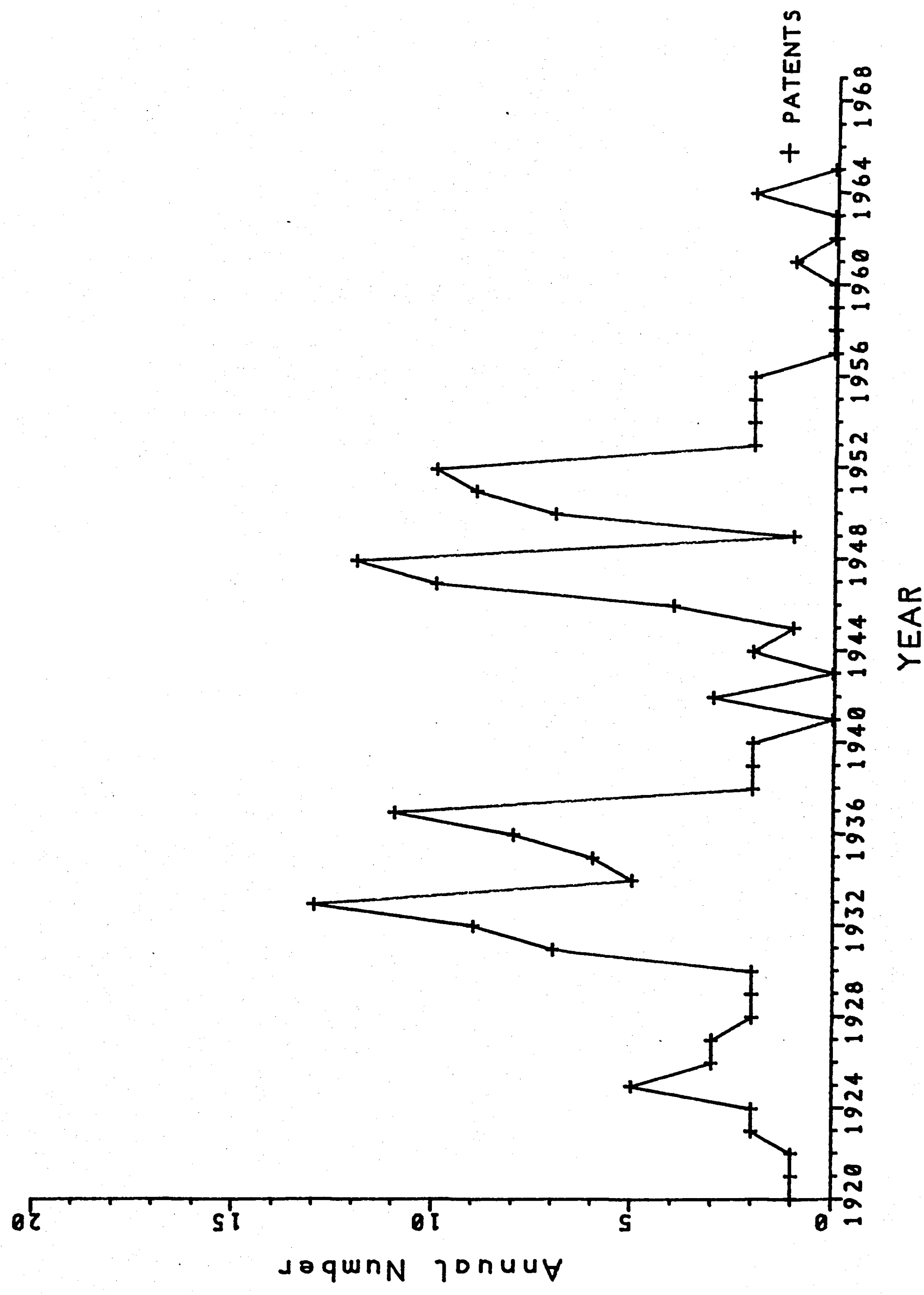

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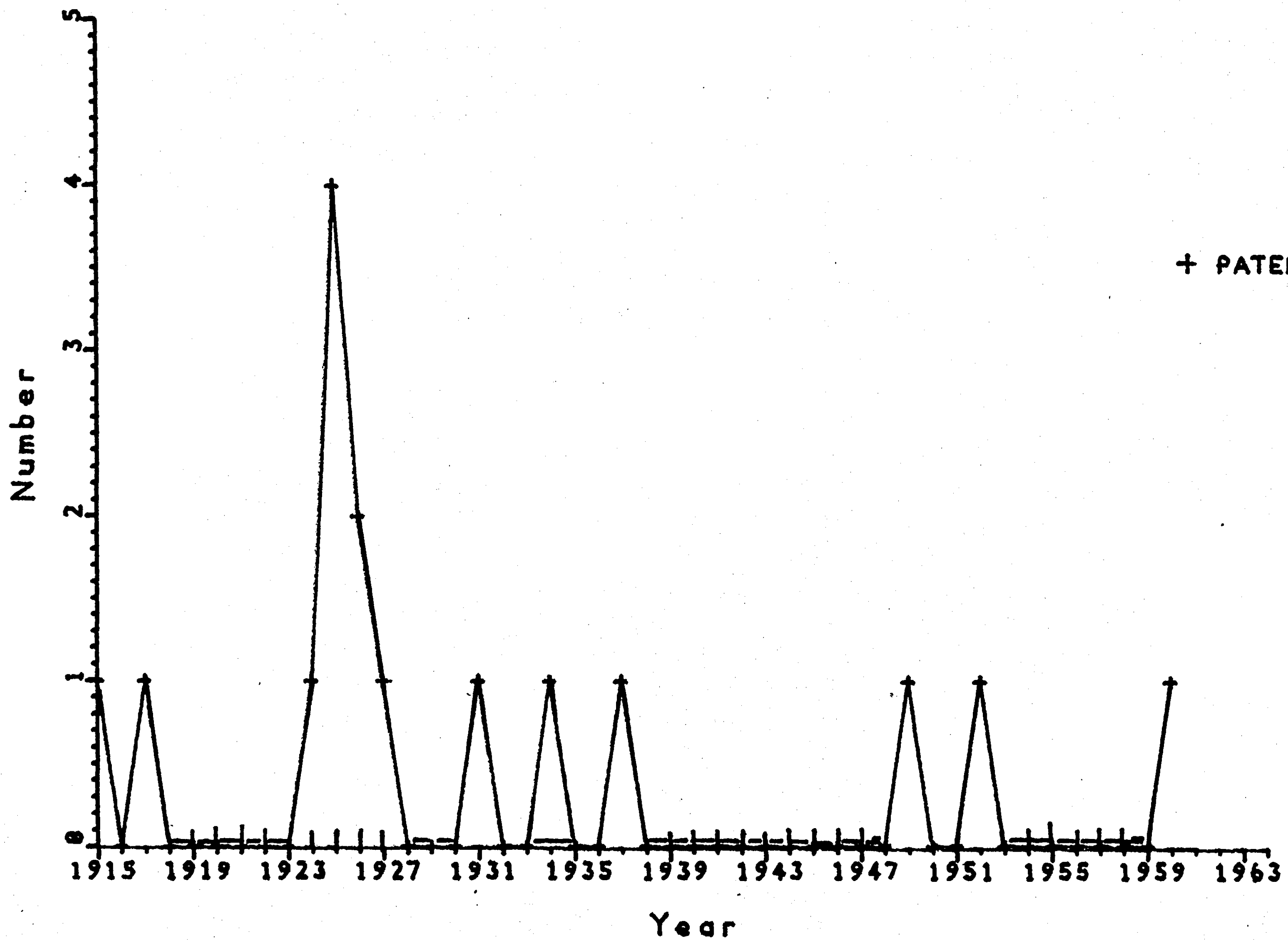
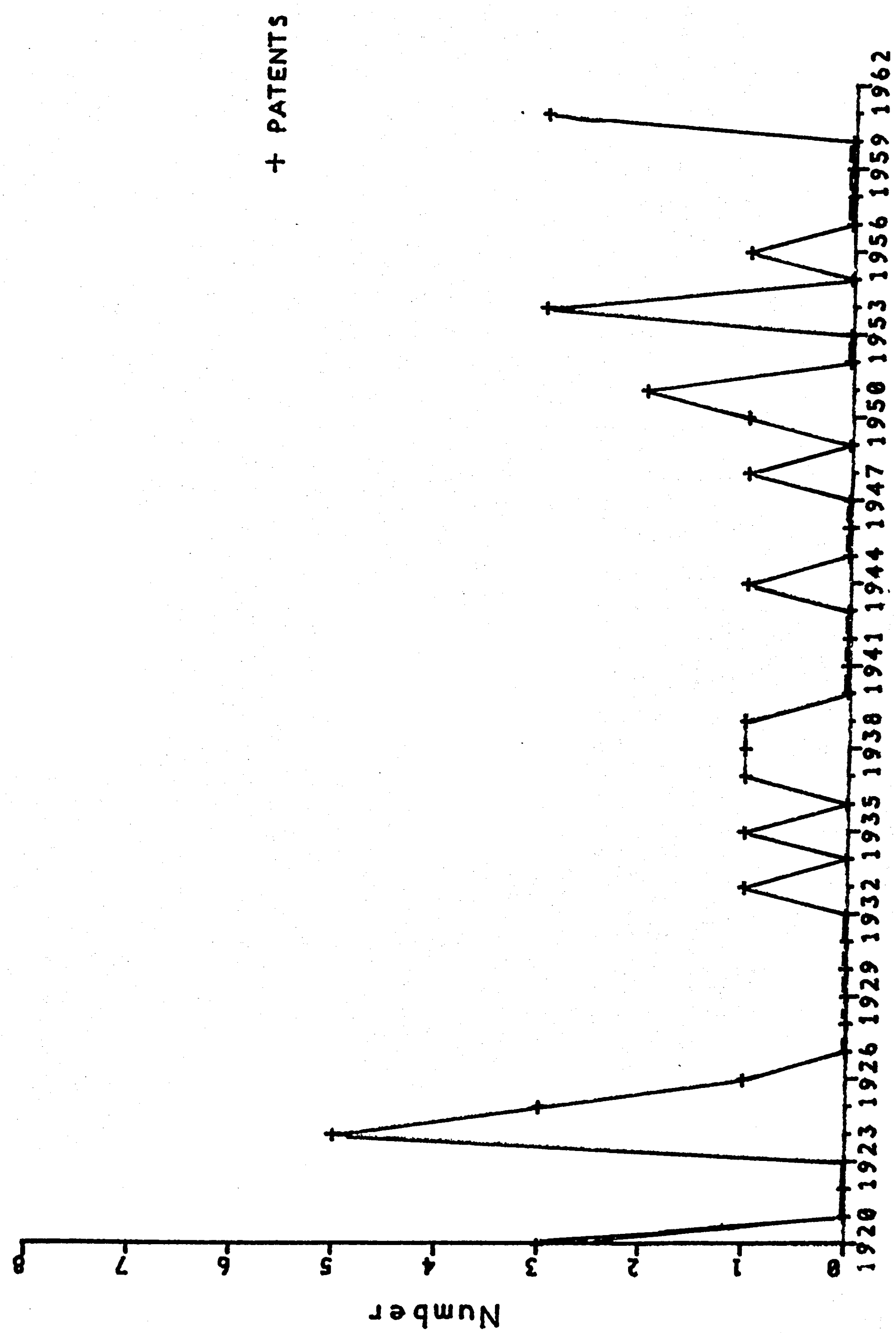


PATENTS GRANTED, SUBCLASS H3Q7A8A
Neutralising Arrangements, 1915-1960



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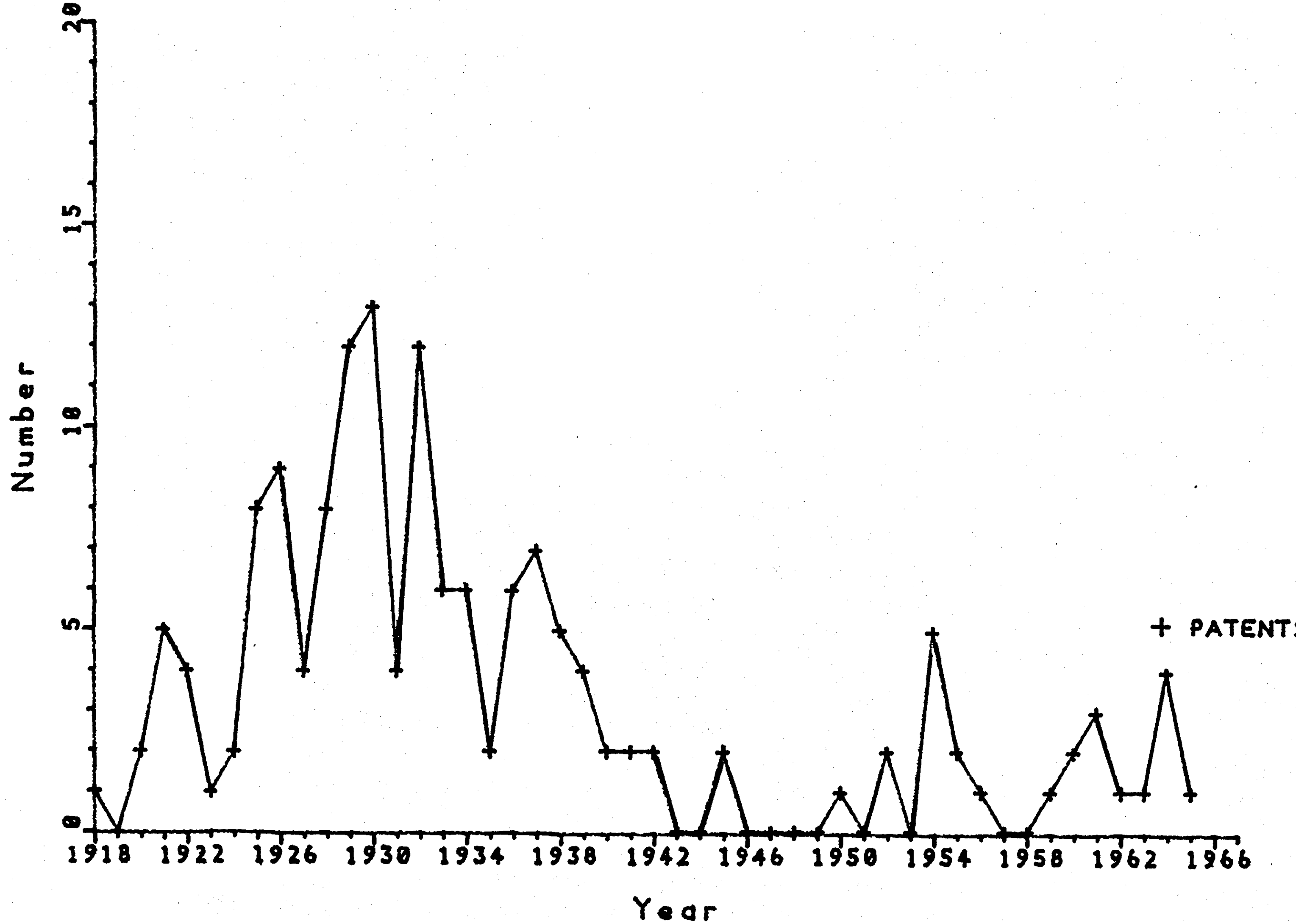
Neutrodyne Screening, 1920-1961



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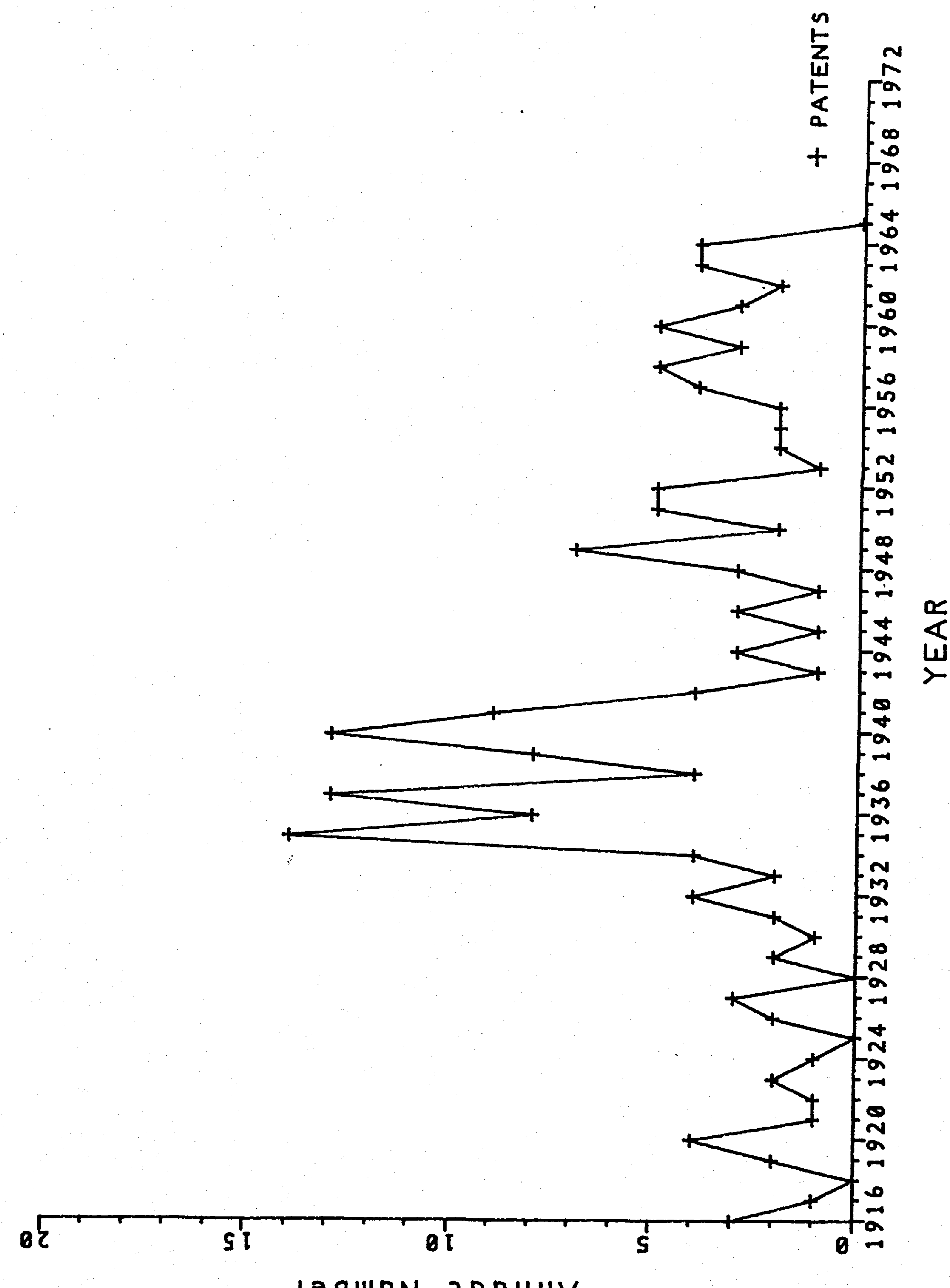

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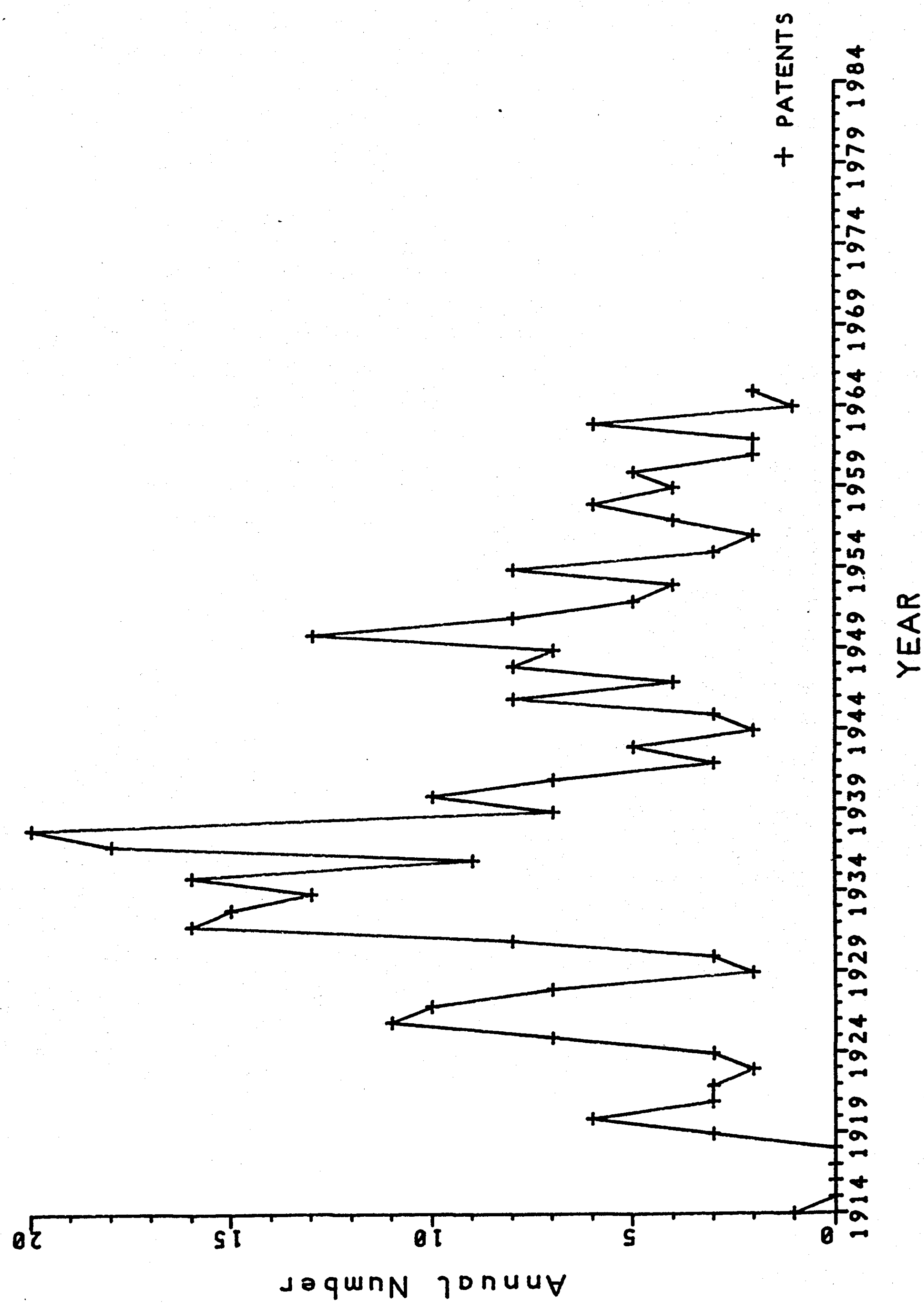
HOMODYNE CIRCUITS:1916–1965



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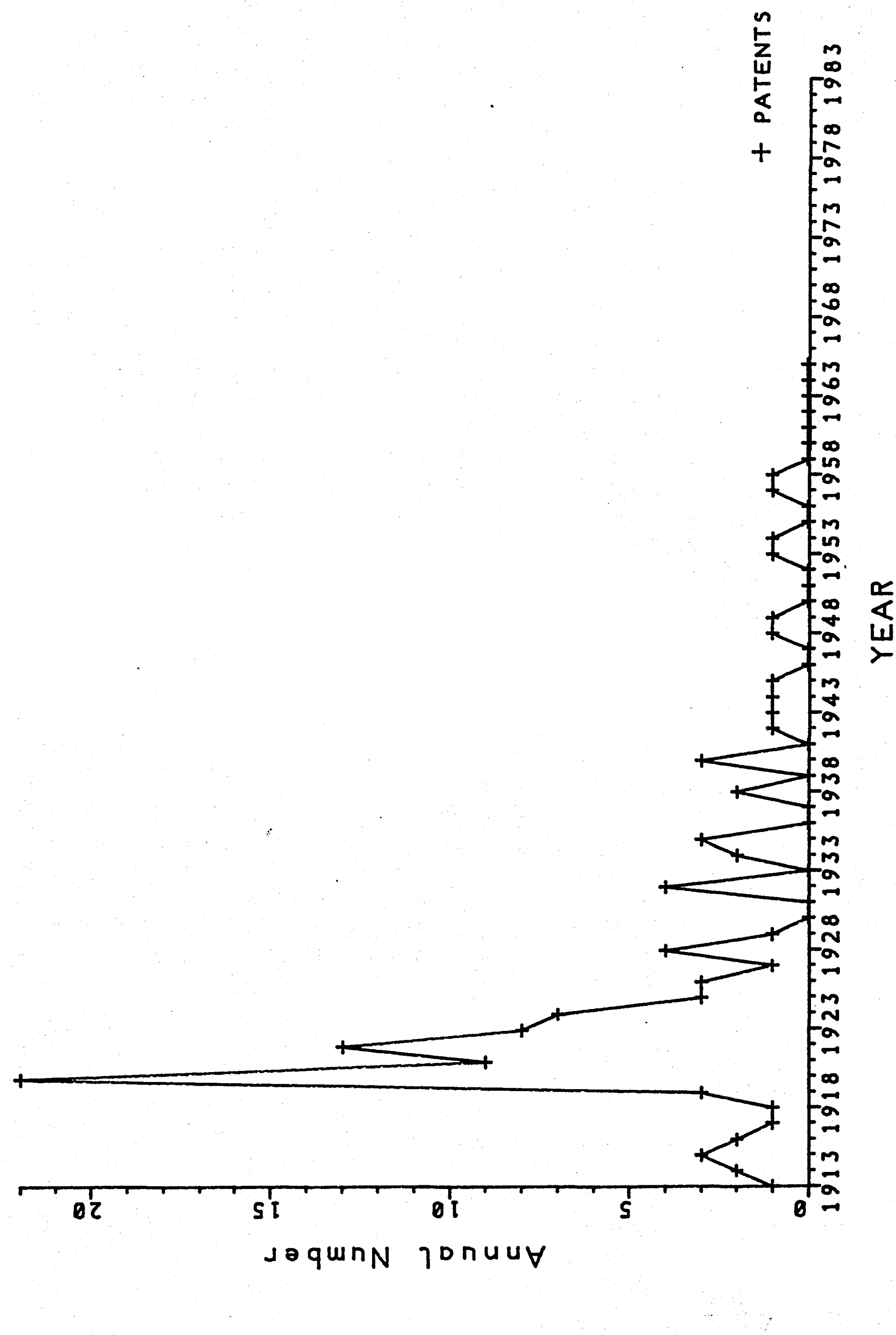

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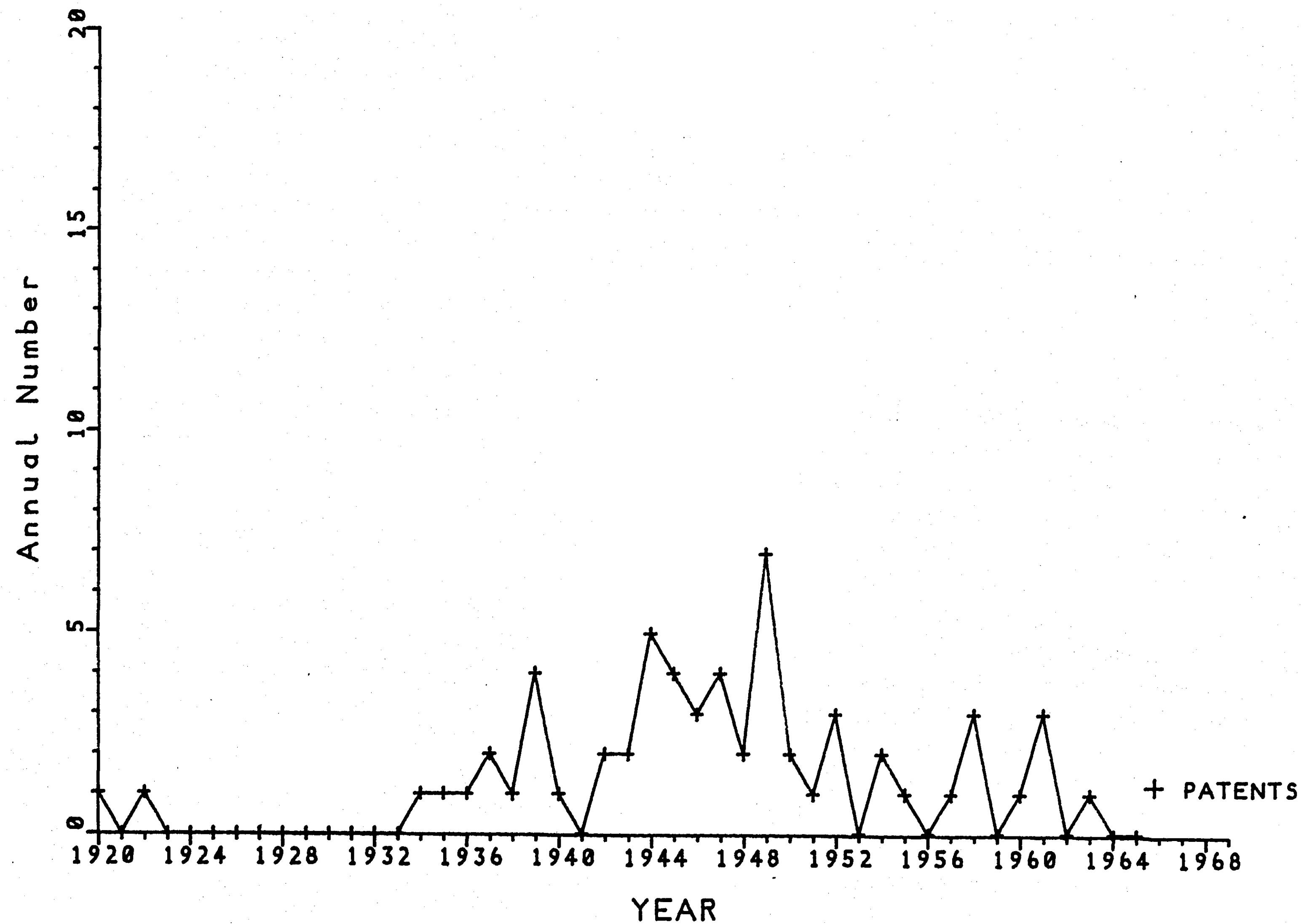
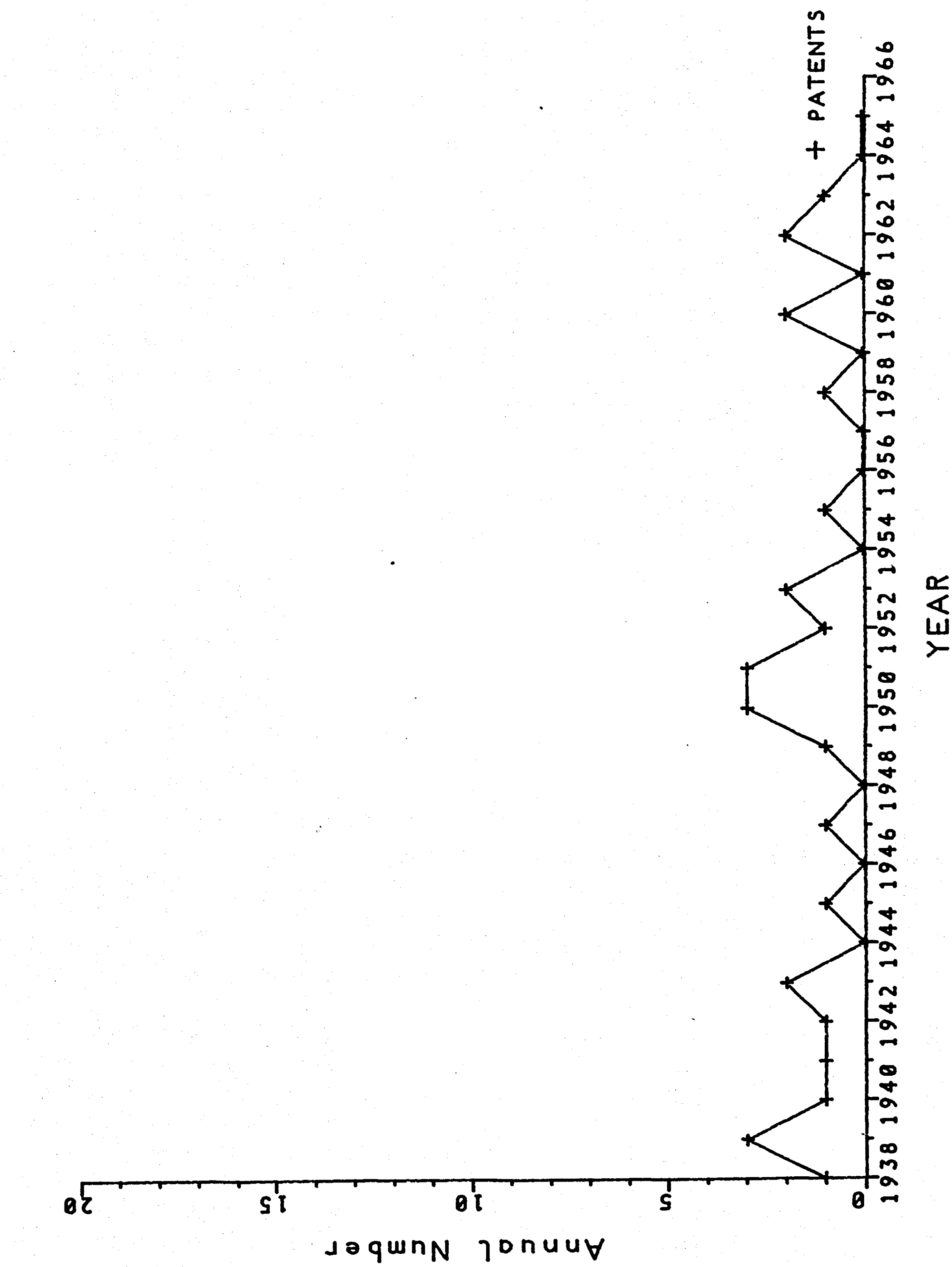
HET CIRCUITS:1913-1965



PATENTS GRANTED FOR H3R9R1
F.M. CIRCUITS:1920-1965



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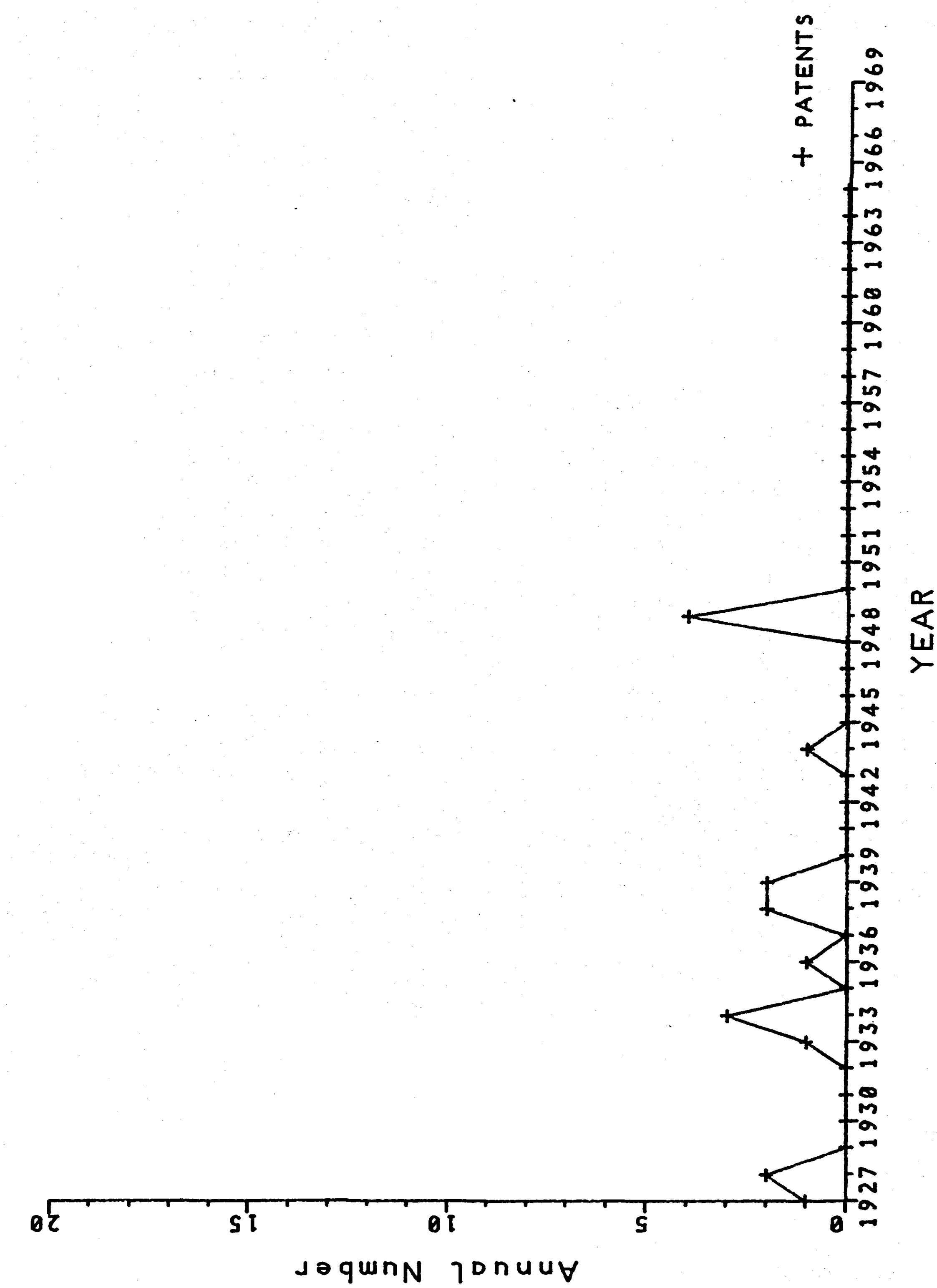
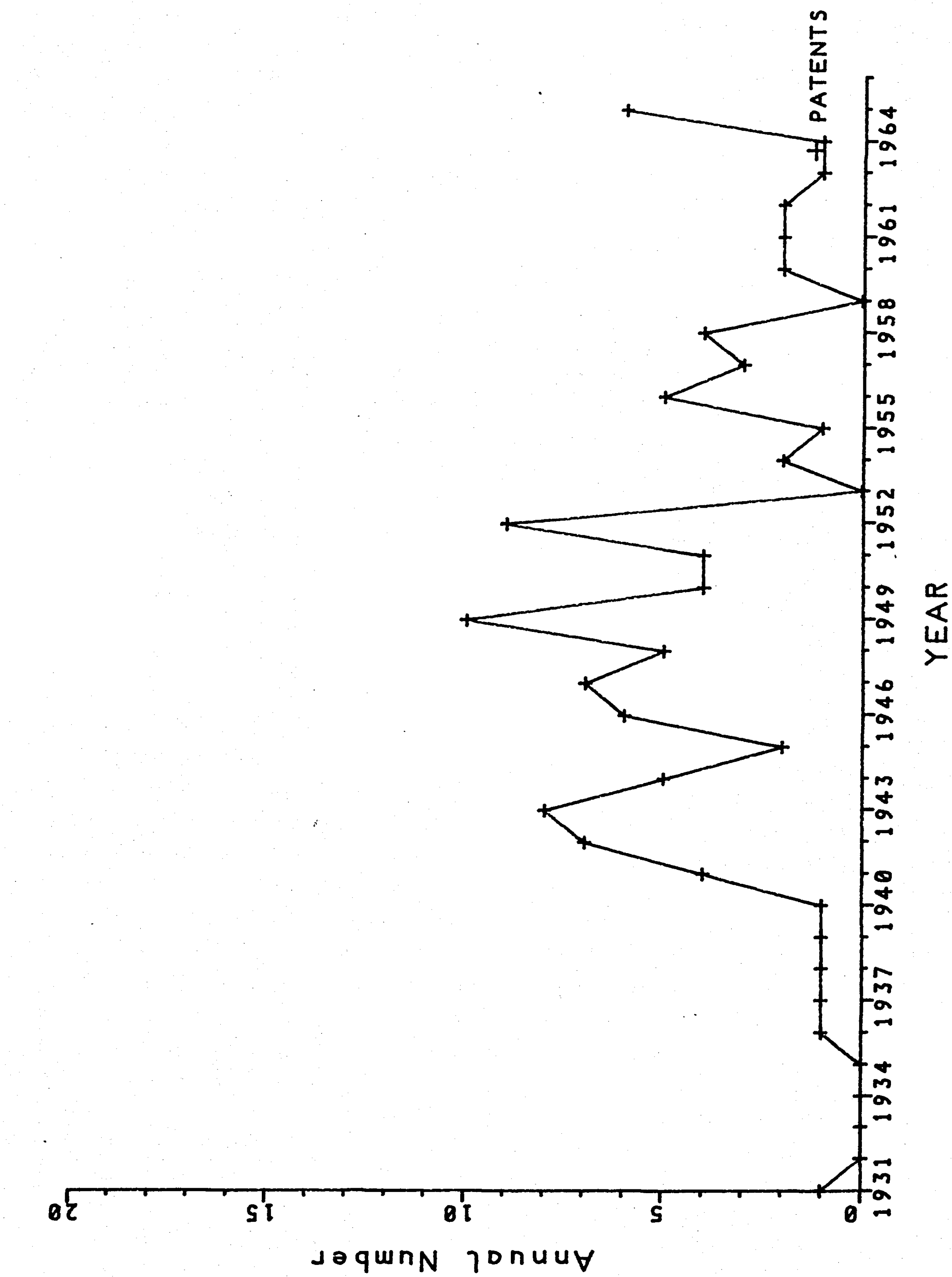
F.M. CIRCUITS:1938-1965



PATENTS GRANTED FOR H3R9R4
F.M. CIRCUITS:1927-1965



PATENTS GRANTED FOR H3R9R5
F.M. CIRCUITS:1931-1965

5.9 Science and its Contribution to Radio Invention

General Theories

After 1945 it became fashionable to stress the role of science, especially pure science, in technological development. The roots of this were briefly described in the literature review. One British example of the stress on the role of science in the radio industry was given by Eastwood (1957).

"This radio industry, which is of such importance in the modern world, is the direct outcome of pure scientific research and continues to draw its rigour from pure and applied research. This is apparent from even a cursory survey of the development of the subject, for it was Faraday himself who reacted against the action-at-a-distance theories used to explain the electric and magnetic phenomena known in his day, and who built up a formidable body of experimental evidence to support his view that the medium surrounding the electric and magnetic elements was the true seat of electromagnetic energy. It was these researches of Faraday that led to field concepts which, in the hands of Maxwell, resulted in the famous equations of 1864 and the Electro-Magnetic Theory of Light. This daring, yet attractively simple theory of travelling electric and magnetic fields was triumphantly verified by Hertz in 1888, who showed that an electrically oscillating circuit could launch an electromagnetic disturbance that behaved in all essential respects as would a light wave. This experiment opened up a new branch of physics, but it was Marconi's work in adapting the experiments of the physicists---" "If it is true that the basis of the radio industry is to be found in the field theories of physicists and the demonstration of radiation and propagation of electromagnetic waves that resulted from them, it is equally true that the spectacular development of the industry derives from the invention of the thermionic valve by Sir Ambrose Fleming (diode 1904) and Lee de Forest (triode, 1906) who based their work on the pure researches of scientists such as Sir J J Thompson and R A Millikan on the electron. The indebtness of radio engineering to pure scientific research could be illustrated by examples from every phase of its development and overall concepts of radio, such as the dependence of television on the experiments in the photo-electric effect which originally led to that early triumph of the quantum theory - the Einstein Equation. But the purpose of this article is to show that this dependence of radio progress on scientific research is just as valid today as in the past---"

In that quotation Eastwood presented the pure science-push theory of radio development without mentioning that either empirical invention or non-technical factors may well have influenced invention as well. He implied that radio design essentially followed scientific discovery.

Nature of Progress of Radio Science

Whittaker (1951, originally 1911) has given a monumental history of Electro-Magnetic theories and described the background to Faraday's work, how Maxwell took up Faraday's ideas about electric field effects and combined some of Lord Kelvin's ideas with it to produce a theoretical model of magnetic field effects which showed that these fields were propagated at the velocity of light and therefore that light was an electromagnetic phenomenon and that other non-light frequencies (radio frequencies) should also exist which should share the physical properties and be able to be refracted, reflected and so on. As far as the development of radio was concerned neither Faraday nor Maxwell had any interest in the commercial application of their work; their prime concern was to try and give some explanation of electrical phenomena. Others were attracted by Maxwell's theory and in Britain both Lodge and FitzGerald succeeded in demonstrating this by means of stationary waves in a closed wire circuit.

Hertz

The key theoretical advance came from Hertz's invention. Hertz foresaw an experimental application for the 'radio wave' (electric field). which could provide him with a means of testing Maxwell's theory. Hertz conducted a series of experiments which showed that his "electric fields" had exactly the same properties as light and Hertz demonstrated reflection, refraction etc., in short that Maxwell's theory was correct.

Not only did Hertz's results advance scientific knowledge, they also made the research into wireless signalling socially respectable though when it was suggested to Hertz that his system might be used for wireless communication, Hertz rejected the idea partly because he was not interested and partly because he considered that the frequencies he employed (about 50 MHz) were too high to be heard in the telephone earpiece.

The main influence which sprang from Hertz's results was that it ushered further speculation and scientific investigation. These subsequent researches were also directed to advancing knowledge rather than with commercial application. Whittaker has described how nineteenth century electrical theories fell into two paradigms; one was the 'field' group propounded by Faraday and Maxwell, the other was based on current flow and later electron flow. The discovery of X-rays by Rontgen in 1896 together with the concept of the electron and electron flow led to changes in physical science concepts culminating in Planck's quantum theory and Rutherford's recognition that a great amount of energy was stored in molecules and might be released by 'splitting the atom'. Such progress also caused some of the earlier concepts to be questioned and by the mid-1920s Maxwell's "aether" was largely discounted although the two paradigms tended to fuse into a composite general theory. However there are still some who doubt the traditional electromagnetic theory.[75]

This grossly abbreviated account of the long and tangled history which Whittaker has detailed, has attempted to show that scientists in the early period were primarily interested in gaining knowledge and a deeper understanding of new physical phenomena rather than with its application. This process was an end in itself and gathered proponents and opponents, a point which science-push advocates rarely mention. Scientific advances did not automatically lead to practical application, as Eastwood's aside about Marconi showed. Whittaker's account dealt with pure science. Other writers have dealt with applied science and radio and summaries of papers by Lodge (1923), Eccles (1930), Maclaurin (1949) and Eastwood (1957) are given to illustrate the views over a long period.

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75 Some recent articles which criticise orthodox electromagnetic theory or radio propagation theories have appeared in Wireless World. I.Catt "Maxwell's Equations Revisited" Wireless World 1980 86 pp.77-78, gave a critique of orthodox electromagnetic theory while W.A. Scott Murray "A Heretics Guide to Modern Physics" Wireless World 1983 (June) 89 pp. 80-81 & p.87 presented a series of articles dealing with the radiation of light and radio energy which questioned the standard physical models; this series concluded in the June issue of Wireless World 1983 89 p.74-76.

Lodge's Paper

Lodge (1923) wished to convey some idea of the uncertainty and controversy which surrounded early radio science and invention. He began by noting early observations by Henry, Edison and others about sparking in the vicinity of electrical discharges and of their intuitive recognition of the possible importance of electrical oscillations.

Scientific Inhibition

Lodge then described Hughes's experiments of 1879/80. Hughes "thought with his fingers", and showed the results of his experiments to eminent scientists of the day who refused to believe that such experimental results were obtained by anything other than induction effects. Hughes was thus dissuaded from publication and Lodge said that this incident showed the danger of "too great a knowledge".

Prediction

Lodge also described how Crookes had also been dissuaded from pursuing further research of phenomena which puzzled contemporary scientists; though Crookes had an "instinctive sagacity" as his brilliant article in the Fortnightly Review (of Feb 1892) in which he (Crookes) foreshadowed actual telegraphic accomplishment, and indicated some possible improvements and uses for wireless telegraphy.

Main Theme

The main subject of Lodge's address was an account of the work of Maxwell, Hertz, Fresnel, FitzGerald and others (including his own) in the development of electromagnetic theory and associated phenomena. He explained how Maxwell's ideas had led others to design experiments to see if Maxwell's theory could be true. These experiments had begun with tests in closed circuits and FitzGerald and Lodge succeeded in producing stationary waves which proved, to their own satisfaction, that Maxwell was correct. Hertz made a much bigger advance by showing that Maxwell's theory also held when electric waves travelled across space. Yet none of the experimenters was interested in practical application of the 'electric waves', these experiments were aimed at advancing knowledge.

Entrepreneurship

Lodge then concluded by saying that he had been too busy to pursue telegraphic development "nor had I the foresight to perceive, what has turned out to be, its extraordinary importance to the Navy --- and War service too. But fortunately in Italy there was a man of sufficient insight to perceive much of this and with leisure to devote himself to its practical development". Thus Marconi and his entrepreneurial motive was needed to change a scientific discovery into a practical invention.

The important point Lodge made in this paper was that early invention was very uncertain, moving sporadically, being very dependent upon personal attributes such as "brilliant surmises", freedom from limiting pre-conceptions and requiring the time to be "ripe". Scientific theorising and experiments were primarily concerned to create new knowledge and the later application of this new knowledge involved invention. In the case of the work of Edison, Hughes or Marconi their connection with science was pretty remote as all of them were practical inventors rather than scientists. Therefore not all radio invention and experiment depended upon prior scientific discovery.

Eccles's Paper

Eccles (1930), in a presidential address to members of the Institute of Physics[76] stressed the influence which "triumphs in the laboratories" had made to the development of wireless. Hertz's work had been prompted by the rivalry between extant theories of electricity and magnetism and this had largely influenced the transmitter side, while Lodge's work had contributed to the receiver side, Lodge's 1897 patent being a "mine of scientific information" which gave the fundamental ideas for engineers who used them for the commercial development of later receivers.

Eccles then outlined how scientific advances had resulted in wireless developments. His first illustration showed how Arc oscillators had been modified to produce outputs which were nearly continuous waves and considered that scientific research had been a key element in this change.

[76] Reported in Nature 1930, (June 14) Vol 125 pp 894-897

Eccles's second illustration described how Fessenden's heterodyne method of receiving telegraphic signals which "came straight from the storehouse of acoustic theory" and could only have arisen in the mind of a student and teacher of physics.[77]

The invention and development of the thermionic valve was Eccles's next topic and he said that the discontinuity of the progress in wireless had arisen largely because of the discontinuity in thermionic valve development. Edison had made the first thermionic valve and this had triggered others, in in many countries, to investigate the problem between 1880 and 1902. These were abstract studies of thermionic current and when tied to the results of other studies dealing with electric discharges through gases to rectify a.c. it meant that a "great deal of material was ready for useful application". Eccles then described the four main applications (by which he meant working prototypes), noting why these early types were not very satisfactory and how some scientists had previously explained the root of these difficulties. By 1913 very satisfactory amplifying valves had been made.

After 1913, Eccles said, wireless developments were relatively undramatic and he then described two new forms of oscillators which had been made in response to War Office requests during the First World War.
During the 1920s, Eccles continued, scientific enquiry had been directed to the study of the electrical properties of the atmosphere which had, and would further, assist the practical operation of wireless. Eccles then concluded by stressing that he had omitted all reference to <u>engineering</u> contributions to development and also that wireless amateurs ("who were neither physicists nor engineers") had made a valuable geophysical discovery by finding that short waves could be transmitted and received over long distances using low powers, and this had been commercially introduced by 1923, "it was a remarkable revolution in method which was not due to, and did not require, any change of technique - a revolution effected by pure discovery."

The important point which Eccles made was that scientific theory and

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[77] In fact this method had been used in France in the 1880s to render ultrasonic telephone signals audible, though Fessenden may not have known that.

experiments aimed to create new knowledge and that this information was the basis for later commercial application in the form of radio inventions. Science was relatively independent of invention, but invention depended upon science.

Maclaurin's Theory

Maclaurin (1949) analysed the historical development of the American radio industry with reference to Schumpeterian concepts of innovation and with regard for Bushs's earlier idea that America had lagged behind Europe in developing pure science. Maclaurin considered that radio had been developed largely because of the theoretical advances made in Europe and that the American contribution owed too much to empiricism, derived from the national characteristic of "Yankee ingenuity". The day of the individual inventor had passed and in modern times large corporations with their strong financial and technical resources, coupled with government interest combined with market aspects to produce advanced innovations. In general these covered products and processes, although Maclaurin followed Schumpeter in his belief that innovations also included non-technological advances such as new uses for an old product. Maclaurin traced the evolution of radio and considered that the greatest development occurred in the early years up to 1928, thereafter the major innovation was F.M. Maclaurin, like many others, coupled the science-push to pioneer inventions.

Scientific progress was discontinuous and originated in pure science. Much of this pure science sprang from university research although the radio industry had shown that large firms had also undertaken pure research. It was wrong to see a monotonic connection between pure science and invention, quite often pure science built up a knowledge base which could lie fallow for years.

The central connection between science (and invention) and economic growth was investment and the factors which affected investment had a more direct bearing on innovation and growth rather than pure science, although the latter also needed funding.

Rostow's work on the process of growth was published in 1952 and his concept of ´propensities´ led Maclaurin (1953) to synthesise his findings of a number of his earlier studies of electronic inventions, into Rostow´s framework. Maclaurin considered that each country´s economic progress depended upon its propensity for pure science, for invention, for innovation, for the financing of innovation and the propensity to accept innovations (the last item being linked to consumer characteristics). In this paper he considered possible measures for each of each of these propensities, though he stressed that the link between pure science and invention was not a direct one.

Maclaurin´s theory places heavy stress upon pure science and he noted that science´s contribution was indirect depending mainly upon investment, and that the high costs of technical progress meant that only large scale commercial and government funded institutions could undertake such projects. Maclaurin also noted that scientific progress was not uniform and did not automatically lead to economic growth. Critics of this ´pure science´ theory of radio invention point to the many American instances of fundamental inventions which owed much to inspiration and little to pure science.

Eastwood´s Account

The final illustration of a science-push model given here is that of Eastwood (1957) who was concerned with post-1945 radio developments.He said that the general trend had been in the direction of higher frequencies and higher powers. Much of this had sprung from wartime needs in the period 1939-1945 when radar had needed new devices to deal with such higher frequencies and powers. The limitations of thermionic valves resulted in the search for new methods and resulted in the invention of the magnetron and klystron which operated on the velocity modulation principle. These devices in turn led to new modes of propagation including tropospheric scatter. The use of higher frequencies also made it possible to increase the bandwidth of transmission, as Hartley´s law showed, though this had brought further problems especially channel interaction (crosstalk) and research provided a solution based on the spin interaction effects of ferrites. In turn the fuller understanding of spin interaction paved the way for further new devices which promised the atomic clock and the maser (both of which have since been developed).

Eastwood then described how the transistor was developed; this also sprang from wartime requirements. Thermionic valves could not deal with the very high frequencies the receiver had to handle and attention was turned to the old "cat's whisker" detector. Intense study of the physics of semi-conducting elements such as silicon and germanium which had been used in cat's whiskers, led to the foundation of solid-state physics. This knowledge paved the way for the invention of the transistor in 1948 although its commercial introduction was delayed by further problems associated with the material, the rectifying junction, and "surface" effects. "It has proved to be necessary to understand the physics of these various effects in order to correct the faults in device development and to allow precise control to beset up in the intricate production processes--- and (make them) carry much larger currents." It had also been necessary to develop special techniques for the production of large crystals of germanium to carry these large currents. Eastwood concluded "Can there be any doubt that the progress of the Radio Industry, and the contribution that radio can make to the modern world are alike completely dependent upon scientific research, vigorously prosecuted and rapidly applied"?.

The answer to Eastwood's rhetorical question is "yes". Eastwood had described a familiar pattern of scientific discovery followed by scientific investigation of problems in use although his reference to production processes was novel as all previous accounts had implied that science mainly affected product design. Although Eastwood dealt with inventions which originated from war needs some of them were later used in commercial radio systems, for example the microwave links are used in the transmission stages of public broadcasting. At the time of Eastwood's article the transistor had just been launched on the commercial market but was unable to deal with high frequencies then; a few years elapsed until the transistor was sufficiently improved to allow all-transistor domestic radio receivers to be used, and there have been further developments in solid state physics and semi-conductors which led to integrated circuits.

The main proposition of all these writers was that prior advances in science, especially pure science, were primarily responsible for subsequent radio inventions. The trend was for much harder versions as time progressed, Lodge noted that other factors influenced events but by the late 1950s the pure science theory was in its most potent form. This theory can be examined with reference to some historical incidents to establish its veracity.

Eastwood´s key theme was of the importance of pure science in radio progress, especially more recent developments. Lags of the application of new theoretical advances were possible because of later secondary problems which often needed further scientific research in order to compensate or correct them. Eastwood´s reference to the link between science and process invention was novel and indicated that previous science-push theorists were concerned primarily with product invention.

The chief function of science for invention appears to have been the creation of new knowledge, a process which itself was reiterative as many scientific theories are tentative and not wholly proved. Nowhere is this more pronounced than in the case of Theories of Electromagnetism where "wave" theories and "particle" theories exist side by side in De Broglie´s compromise. Lodge´s comments on theoretical uncertainty have been noted as well as some recent unorthodox Electromagnetic theories of 1980/83 cited above.

Empirical (Non-Science) Radio Invention

It was noted in the literature review that even during the 19th century doubts had been expressed about the primacy of science in invention and some considered that invention itself was responsible for theoretical or scientific advance.

One example of this view was made at the 1930 meeting of the British Association by Appleton (1931) who began his address by saying "One of the most striking features of the history of wireless communication is the way in which practice has so often been ahead of theory" (p.426).

Several instances have been be given to support this view. Wheatstone´s disbelief in the possibility of wireless telegraphy;

Lodge´s account of the scientific assessment of Hughes´s 1879 experiment, and Marconi´s experience about round the world propagation have already been noted.[78]

Appleton (1950) in his description of Heaviside's researches, noted that Heaviside's article on wireless in the Encyclopeadia Britannica of 1902 suggested that the upper atmosphere acted as a conductor which conveyed radio signals round the world. Appleton said that this was based on intuition rather than a result of long calculation; it was a bold hypothesis and later experiments proved it to be correct.

A further illustration of the lack of scientific understanding in the early stages of some wireless development has been shown by Phillips (1980) in his account of the development of wireless detectors in the period 1870 to 1914. He showed that a large variety of detectors and materials were tried even though experimenters could not explain the principles upon which such devices worked, they empirically explored as many substances and techniques as they could.

Carson (1922) in a paper giving a mathematical analysis of frequency modulation and a comparison of the bandwidths which f.m. and a.m would occupy for a given signal had, as noted noted earlier in the F.M. section, 'proved' that the f.m. system was inferior to the a.m. one in respect of both its bandwidth and signal distortion.

A review of r.f. amplifier design theory, by the Radio Research Board (Special Report No. 9, 1930) contained the following: "The design of short wave amplifiers is almost entirely empirical and, as it is known that the behaviour of a triode at very high frequencies presents features which have not yet been explained, theoretical analysis of radio frequency amplification

78 Marconi's claim that he had transmitted the letter 'S' across the Atlantic was at first disbelieved by many and Nature 1902, Feb 27th, pp 394-395 commented "any new development becomes so soon the centre of numberless contradictory and inaccurate reports" and general scepticism. It was considered by some that wireless telegraphy had no practical value and as the next issue Nature 1902, March 6th, pp416-417 carried a precis of Marconi's article in Century Magazine giving an account of the development of wireless telegraphy saying that he considered that increased power at the transmitter would enable signals to be sent any distance, even to circumscribe the world. "I now know that the curvature of the earth does not in the least affect the waves. Many people who have reasons for hoping so have said that this would prove a fatal defect to the system, but it is not so".

cannot be considered as nearly complete. The growing utility of the short wave receiver demand a more rigid theoretical study of the subject". (p. 27).

These examples highlight three important facts about radio invention. One was that considerable empirical invention took place, a second fact was that quite often eminent scientists or radio inventors often wrongly assessed new ideas or inventions and this had frequently been mentioned in theories of invention as noted in the literature review; a third feature was that scientific investigations usually followed successful empirical inventions in order to either explain the principle or determine the causes of problems.

Science-Technology Relationship

It was noted in the literature review that in general the science-technology relationship was not clear; while the role of science in radio development had recently changed from a heavy emphasis on science-push to a more interactive model as suggested by Aitken (1985) and noted earlier in this chapter. From the early 1970s there has been increasing doubt about simple science-push models. and for this reason a brief analysis is made of loudspeaker development for radio receivers.

5.9.1 Science and Radio Invention: Loudspeaker Development

The aim of this section is to show how the development of the loudspeaker was related to the science-technology continuum.

Most of the previous theories of science and radio development concentrated naturally upon electromagnetic and associated r.f. theory. The development of the loudspeaker depended upon the Physics of Sound rather than Electromagnetic theory, but apart from that distinction there were many similarities in the way that principles or problems were subject to scientific analysis after empirical invention or for an ideal design using scientifically generated knowledge.

The loudspeaker is said to be the part of a radio receiver which had been the subject of most invention. In 1928, an article[79] suggested that the loudspeaker had perhaps presented greater design difficulties than any other

[79] B.B.C. Year Book 1928 pp.245 - 246 "Telephones and Loud-Speakers".

part of the radio set. Colloms (1980) independently made the same observation more than fifty years later.

Empirical Origins of Loudspeaker

The earliest ideas and inventions for loudspeakers were intended for telephone devices and fell into two categories: one group were designs for some kind of valveless amplifier, the other group were inventions for current-to-sound transducers.

A notable feature of radio loudspeaker development was that many of the original ideas or prototypes came from either the telephone or gramophone industries. The reason that loudspeakers were only well developed for domestic receivers was that effective a.f. amplification was only developed for radio and considerable electrical power was needed to drive a loudspeaker, and, paradoxically, revealed the loudspeaker's weaknesses.

O'Dea (1934) has given a concise history of early radio loudspeaker invention and development. He noted that 'telephones' (earpieces) remained the most common kind until 1921 after which the demands of broadcasting led to "consideration of loudspeakers handling large outputs." (p. 87).

If invention is said to begin with ideas then the earliest idea for a loudspeaker was apparently suggested by Elihu Thomson in 1863 who outlined a design for a 'loudspeaking condenser'.

Early headphones were telephone "earpieces" which were made highly sensitive devices by designing them to have a marked resonance point at about 1 kHz with consequent distortion. The article on 'telephones' (earpieces) in the 1928 B.B.C. Handbook[80] noted that by that year an improved type of headphone - the Capacity headphone - had come on the market but as it required a large signal to drive it, it did not prove popular.

Dalton (1975) has given a broad summary of loudspeaker development. He noted that the earliest aim was to increase the volume of the sound, and in the absence of valve amplifiers, led inventors to devise a variety of 'mechanical' amplifiers as well as applying Musical Instrument practice in the form of trumpet-shaped horns to concentrate and direct the sound. The 'megaphone' was

80 (Anon.), 'Telephones And Loudspeakers' B.B.C. Hand Book 1928, pp.245-246.

one of Edison´s inventions and so was his ´mechanical´ (frictional) amplifier; these formed the basis of many later design variations.

In 1879 Elisha Grey continued loudspeaker development by using an iron cone as a diaphragm with an enlarged electrical relay which acted as an amplifier.

Gramophone Loudspeaker Developments

Between 1900 and 1920, Dalton observed, the loudspeaker development followed two trends, the first was to create a louder output and the second was to produce a better tone quality. Two main types of gramophone loudspeaker were used, one was the Horn type, the other was the Cone type.

Early Gramophone Horn Types

Chew (1967) has described the three main methods of amplifying gramophone sound levels; one was to add extra horns (and extra sound boxes), another was to make the stylus control the flow of compressed air (or gas) passing into the horn and the third was the "frictional" amplifier noted above.
Experiments with these forms of amplification were concurrent with developments to the horn itself. The earliest gramophone horns were straight tapered types with a flange at the output end and usually rather narrow. With the invention of the Tone Arm in 1903 the trend of design changed to a "flower" (exponential) type of larger dimension. The latter design was entirely empirical with no scientific investigation of the principle of its operation.

Early Gramophone Cone Types

Chew (1967) has described the evolution of Cone type "speakers" for gramophones which date from Leon Scott´s ´phonoautograph´ of 1857 - a device to record sound waveforms - which consisted of a straight horn with a large membrane with a stylus. Scott´s phonoautograph was shown by scientists, to induce distortion due to resonances of the diaphragm and stylus. Berliner may have been in ignorance of these deficiencies but he functionally reversed Scott´s design so that the vibrating stylus reproduced sound waves from the horn.
Further developments were made culminating in Lumieniere´s cone loudspeaker

which had a large rigid paper diaphragm which was thicker at the centre than at the edges.

The attractive idea which lay behind the cone design of loudspeaker was the belief that the large cone or diaphragm area would give a greater volume of displacement and hence a louder sound. Most of these inventions relied on reed drive units which were combined with "mechanical amplification" based on the lever principle and many variations were produced. The mounting of the cones was also varied some having a fixed outer rim and Pleated cones were tried as well. The sound output levels of these types of loudspeaker were low and led to inventions of other types. One later trend was improved types of Edison's "mechanical amplifier" arrangement by Fessenden, and Johnson and Rahbeck. S.G. Brown developed a Reed drive unit. The pneumatically operated loudspeaker was also developed in this period, Dalton noted a model by Gaydon although Parsons, of steam turbine fame, (and, like Edison, hard of hearing) produced one too; these pneumatic types certainly increased the volume of sound output.

Tone Quality

The other main trend of gramophone loudspeakers was that of improved tone quality. Dalton said that this was achieved by redesigning either the gramophone Sound Box or the Tone Arm or the Horn. These efforts were entirely empirical as evidence at the patent case of the Tone Arm showed; Chew (p.53) quoted the judge's comment on this legal case: "I am not going into the theory of the amplification of sound, about which nobody seems to know anything whatever."

Chew's concluding remarks give the best illustration of the empirical nature of gramophone invention up to 1920, and he had told of a facetious proposal to use a 'hardened bee sting' as a stylus but it typified "many preposterous projects that wasted the time of Patent Office staffs during a period in which the development of the talking machine was unaccompanied by any scientific investigation of the basic principles" (p.72). Such instances bring the 'crank and bogus' bicycle inventions to mind.

5.9.2 Early Radio Loudspeakers

The need for a radio loudspeaker came from consumers' desire to share their listening with family and because listening with headphones was fatiguing due to the weak signals. Crude "telephone" loudspeakers had also been made earlier too; in 1926 The Times[81] published an article on loudspeaker development which noted that this was the first loudspeaker design for domestic radio receivers.

Horn Design Deficiences

As soon as early horn loudspeakers were used it became obvious that they had some severe technical problems; their frequency and dynamic ranges were very limited and they also had marked resonance frequencies. Some of these problems were due to inadequacies in earlier stages of the receiver or even the transmitter, but the main difficulty appeared to be with the loudspeaker which, Dalton said, made it a natural starting point for improvements. These early models scarcely reproduced notes below about 200Hz and over accentuated high notes giving the sound a metallic quality.[82]

Dalton (1975) gave an historical summary of the earliest radio loudspeaker scientific investigations of the horn. Sandeman found that its efficiency was very low, about 1%, and this was confirmed by Balbi who additionally noted during experiments that the acoustical impedance of the horn changed with audio frequency.

The other major component of these early radio loudspeakers was the diaphragm and its performance was also scientifically investigated. These studies employed standard acoustical procedures such as sprinkling sand to determine the vibration pattern. During these investigations it was found that the column of air in the horn dampened diaphragm action and Mallet established that this was due to air back pressure, while Nyman investigated its dynamic

81 The Times 1926, April 27, p.21

82 Another weak link in the fidelity chain was the reduced audio frequency range transmitted; this was due to low fidelity microphones; Pawley (1972) has described how the transmitted a.f. spectrum was increased by improved microphones though the Geneva Plan for wavelength re-allocation limited European broadcasts to 9kHz, so that high fidelity was not possible for A.M. transmissions. In the early years the transmitted spectrum was only 40 to 4,000 Hz (The Times 1926, Jan 20, p.6)

performance and found that rapid pressure changes led to Standing waves and consequently deduced the optimal horn length and throat diameter for a given frequency.

Hanna and Slepian modelled the dynamic performance of the horn loudspeaker as a unit oscillator and were concerned with its radiation parameters. They found that for optimal performance the air pressure at the open end of the horn should be zero (i.e. at atmospheric pressure) and that the horn should diverge to eliminate acoustical reflections. An exponential horn shape in theory fulfilled both requirements, and the designers went on to establish the ideal relationship between the throat diameter and horn length. They tested an experimental model to reproduce a 64Hz note and established that it needed to be 6 feet long. This was considered to be too long for domestic use and led to later domestic loudspeaker designs with Folded and Re-entrant horns. Dalton has described many of the types manufactured in this period. Although further inventions were made to improve the horn loudspeaker the principal role of science had been to define the causes of particular troubles and provide the knowledge needed for an 'ideal' design.

<u>Cone Type Loudspeaker Deficiences</u>

The use of Cone loudspeakers soon showed that they too had severe distortion problems which came from the diaphragm. Cone vibration patterns were scientifically studied by McLachlan (1926) among others, who used stroboscopic light to determine the nature of cone displacement patterns which led to the appreciation that the natural frequency of vibration of the cone should be outwith the reproduced tonal range. McLachlan's improved cone type was said to give an excellent balance between high and low notes with low distortion. Cone type loudspeakers were further improved by improved type of cone structures and cone mounting methods.[83]

Dalton observed that although Cone loudspeakers had now considerably improved tonal quality their volume of output was still too low and this deficiency was scientifically investigated. Hopkinson found, in 1924, that if Cone loudspeakers were fitted with a baffle it would reduce this problem and

[83] <u>The Times</u> 1926, Jan 29 p.6

from then the Cone loudspeaker had moderately good volume and tone quality.

Moving Coil Loudspeaker

Another old idea, that of a moving coil loudspeaker, had been suggested by Siemens in 1877, and Lodge had produced a prototype in 1898. Once again some early models were made but did not prove to be very satisfactory. Rice and Kellog subjected this design to scientific analysis and by 1925 had scientifically established the principles for ideal loudspeaker reproduction, based on the concept loudspeaker as a ′moving piston′. This performance depended on three interrelated factors. These were firstly that the sound-power output was related to the mechanical resistance encountered by the cone, and this varied as the square of the velocity of the diaphragm. The second main factor was that the mechanical resistance also varied with the square of the frequency of the audio signal. The third factor was that the system was mass-controlled so that when a natural resonant frequency of the speaker was outwith the range to be reproduced, then the first and second factors became complementary and the resultant outcome theoretically, was for a uniform reproduction over the whole tonal range and over the whole intensity range (subject to an upper limit) given an infinite baffle.

The theoretical design then gave the basis for an ideal design for distortionless reproduction of any frequency and intensity. The significance of Rice and Kellog′s finding, was that it laid down the correct principles which have formed the design basis of moving coil speakers.

One deficiency of the earliest Moving Coil loudspeaker design was its lack of volume and that it needed a very large input signal and a very powerful magnet which required external current making it unsuitable for battery powered receivers because of very high running costs. By 1930 permanent magnets (which needed no current) had been developed eliminating a major commercial drawback. There were constructional problems too, with the early Moving Coil designs especially getting an accurate location for the moving coil and of the type of cone mounting. These problems were solved by improvements which can be classed as incremental inventions or engineering solutions. From the mid-1930s the moving coil type of loudspeaker became the standard receiver type. Its later improvement aimed to extend the frequency range and power output and this effort was largely undertaken by specialist firms.

Other Pioneer Loudspeaker Inventions

Other types of Loudspeaker were also being considered in the interwar period. In 1925 the Electrostatic type was being tried but it encountered some severe technical difficulties which were gradually solved and was popular in Germany by 1932[84] although Dummer (1983) considered its design was not satisfactory until about 1935. During the 1950s the Electrostatic loudspeaker design became popular again among hi-fi enthusiasts.

The piezo-electric loudspeaker emerged from piezo sounders which were developed during the first world war. This type is best for high audio frequencies and is primarily used used as a "tweeter" in compound loudspeaker systems (usually with a moving coil "woofer" for bass notes); this compound loudspeaker system emerged in the 1934, according to The Broadcaster Annual for that year.

High quality ´public address´ horn loudspeakers were developed, principally for the cinema (talkies) which were both very powerful and had very good bass response. These were far too large for domestic use although some hi-fi enthusiasts do not agree.

Loudspeakers were not developed in isolation and as noted already depended upon improvements in other parts of the receiver (and even transmitter), so that complementary improvements were made to earlier stages in the receiver; for example matching the impedance of the loudspeaker´s coil to that of the a.f. amplifier ensured maximum energy transfer; in the late 1930s some expensive receivers incorporated negative feedback networks with ´notch´ filter frequencies which corresponded to the resonance frequencies of the loudspeaker(s).

[84] According to The Broadcaster Annual 1932 "Trends of Invention"

Market Acceptance Of Loudspeaker Designs

Although the moving coil loudspeaker had showed its technical superiority by 1930 it did not automatically become the consumers' choice because the moving iron type was also much improved at this time and indeed the inductor dynamic model had a performance which nearly equalled the moving coil one but was cheaper and required less current. By 1934 further improvement to magnets helped the moving coil loudspeaker to become the market leader and after 1939 it eclipsed all other types for use in ordinary domestic receivers.

From 1926 to 1934 this Moving Iron (or Reed) type of Cone loudspeaker underwent further improvement and sold in large numbers in spite of competition from the later Moving Coil Cone type. The main improvements were in the kind of driving units. The first type of driving units were Simple Reeds which tended to have a marked resonant frequency and "chatter" which distorted the sound due to its 'spring' (non-positive) return, and required a large a.f. input to obtain sufficient volume. The Reed drive was soon superseded by the Balanced Armature which gave a positive return and later this too was superseded by the Inductor Dynamic drive. These improved drive units were designed from 'first principles'. Further improvements continued to be made as The Times noted[85] the Amplion "Lion" had been designed with a better diaphragm with reduced inertia, a better frequency response and greater volume without distortion "in all nearly equal to a Moving Coil type but needed no (electric driving) current". Scientific investigation had thus led to a greatly improved Cone type loudspeaker. Price and quality were the main factors which kept the Moving Iron loudspeaker on the market in spite of its marginal inferiority to the Moving Coil type, and only by 1934 did the Moving Coil type become the main commercial loudspeaker.

High Fidelity Loudspeakers

The history of the bicycle showed that product invention did not cease once a mature design had been developed but that low level product invention continued often involving re-inventions of old ideas or 'perfectionist' designs This pattern was repeated for loudspeakers, later inventions being made mainly by hi-fi enthusiasts. A number of objectives were sought: good (or

[85] The Times 1928, Sept 22, p.15

perfect) dynamic range, linear frequency response, superb bass response, freedom from loudspeaker distortion. In addition the loudspeaker and its enclosure had to be ventilated (to eliminate 'back pressure') and be free from resonances, for a while large and bulky speakers were regarded as impressive but with the coming of stereo this trend reversed and compact hi-fi speakers were desired. Most loudspeaker systems are based on the 'moving piston' principle although naturally some inventors wished omnidirectional (barrel stove) types. The essence of 'perfect' design was to incorporate all the desired objectives in one model.

Colloms (1980) has given a comprehensive account of modern design theory and practice for high performance loudspeakers. His book gives detailed discussion - and formulae - for the design of the loudspeaker sub-units such as the diaphragm, the enclosure, 'piston efficiency' and distortion of movement, mountings, drive units, cross-over units etc. He noted that each of these sub-units had been the subject of prolonged discussion, testing and analysis and that generally the theory or formulae gave the best combination of design and performance objectives. By the 1970s, Colloms said, loudspeaker design had been rationalised and this had improved its performance; graphs and statistics were given to show the nature of these improvements over the period 1965 - 1976.
Perhaps the most interesting comments made by Colloms occurred on his first page where he noted that to the dismay of engineers (who liked to deal with facts) "fashion plays a considerable part in the consumer stakes" (p.1) and Colloms noted that these fashions for 'new sound' found favour with consumers even if they detracted from other important aspects of loudspeaker performance.

Augspurger (1985) has provided a concise summary of high fidelity inventions since that time. Augspurger noted that high fidelity loudspeaker invention has attracted attention to a level shared by no other radio unit. High fidelity itself created a new market segment, for a limited number of people who sought perfect reproduction. A profusion of hi-fi loudspeaker designs had been proposed since the mid-1930s and Augspurger considered that it was impossible to try an classify the amazing variety of exotic designs. "Over the past 50 years the variety of devices sold as high fidelity loudspeakers is truly amazing. If one includes designs patented but not marketed the category becomes chaotic." (p. 1303)

Augspurger then ingeniously categorised these loudspeaker inventions according to the approach adopted by the inventor. "As in all creative endeavour, loudspeaker designs tell us a lot about their designers". He considered that the majority of inventions came mostly from obscure inventors and grouped them into three classes; the Elegant Theoretician, the Inspired Tinkerer, and the Wishful Wizard. Each of these categories depicted the kind of approach the inventor used to arrive at his loudspeaker design.

Elegant Theoretician

The elegant theoretican produced a design based entirely on prior consideration of the theoretical principles of the proposed design. The Rice-Kellog loudspeaker was a perfect example of this approach though Augspurger said that such an approach was not used by the majority of successful designers.

The Inspired Tinkerer

The inspired tinkerer approach had been the most influential one producing lasting influence, marking new directions in domestic loudspeaker design which owed as much to tinkering as to theory. Augspurger also considered that the trend-setting designs produced by tinkerers gave useful insight into "the twists and turns of consumer acceptance". (p.1304)

Augspurger then described five trend-setting designs, beginning, confusingly, with the Rice-Kellog moving coil loudspeaker which promised perfect reproduction. The second milestone was the Altec-Lansing coaxial loudspeaker first introduced in the 1940s and intended for studio use but later adapted as a hi-fi type for the domestic user. This design inspired many imitations on the basic woofer-plus-tweeter principle and marginally improved versions of the original are still on sale today, although few of the imitations remain on the market.

The third milestone was the Klipsch Corner Horn loudspeaker whose design was "a beautiful example of good theory combined with sudden insight". This had been created from a previous corner horn idea but Klipsch's inventive step had been to realise that the room boundaries themselves would serve as the horn mouth and all he then needed was to design a suitable folded throat section to suit. The result was a miniature horn, about one tenth of the size of theatre horns, which gave a magnificent bass response. The success of Klipsch's model led to many later imitations and improvements which continue to be proposed. However the advent of stereo and the desire for smaller more versatile loudspeakers had diminished the corner horn's status in consumers' eyes.

This later to many later inventions, one was Jensen's 'vented box enclosure' or bass reflex loudspeaker first produced in the 1940s. Augspurger noted that its simple geometry made it very popular with home constructors but results often proved disappointing so that many explanations were given and many "Patented variants of the vented loudspeaker enclosure have pushed the limits of man's imagination to new frontiers, ---". Only after later theoretical research into loudspeaker - box - vent interactions was it possible to design such models with predictable low-frequency characteristics.

The fourth milestone of loudspeaker invention was concerned to reduce resonances of the enclosure and this led the "tinkerer" to invent an enormous range of vents including various slot configurations, sand-filled enclosures, multiple chambers and so on. Some of these were theoretically sound and used with 'inspiration' (but the majority were really bogus inventions and belonged to the Wishful Wizard category). In the 1950s high fidelity showrooms were filled with various models fitted either with resonant devices (horns, pipes, prisms and labyrinths) or an equally varied range of non-resonant devices. The advent of stereo prompted loudspeaker designers to put twin loudspeaker systems into a single enclosure which prompted more design suggestions due to the belief that the position of the loudspeaker in any room was critical.

A fifth milestone was Vilchur's 'acoustic suspension' design which was truly revolutionary and a trend-stter for small loudspeaker designs. The outstanding feature of this type was its performance - "lower distortion and more linear frequency response because of its small size". Vilchur had arrived at this design by ´going back to fundamentals´ and calculating the consequences to design factors if a small enclosure was used and he conceived of the acoustic suspension (or air-spring) which critics pointed out was not a particularly linear device and also that a small cone generated more modulation distortion than a big one. Nevertheless as consumers desired small speakers they continued to sell.

The Wishful Wizard

The wishful wizard was essentially a crank loudspeaker inventor with a "design that could work only if the laws of physics were rearranged to suit the whim of the designer." Augspurger gave an example of a model, which enjoyed considerable popularity in the 1950s. This was ´The Perfect Baffle´ which had a small speaker mounted in an enclosure of just sufficient dimensions without any padding or bracing and its key element, a small trap door mounted on the back panel which was claimed to swing and therefore relieve back-pressure. This design was inspired in its simplicity (even though erroneous) and, inevitably, produced a host of variants and equivalents having valves, vents or permeable membranes to ´bleed-off the back pressure´. Augspurger described one design aimed to neutralise the distortion caused by the loudspeaker itself and ensuring the only ´perfect sound´ would be radiated to the listener, the unwanted product being either absorbed or rectified by means of what appeared to be a thrust reverser and pad absorber. Like most crank and bogus inventions, the chosen problems usually could neither be theoretically proved nor disproved. Most sounded ´plausible on paper´ though many contradicted physical laws. However it was obvious that these ´wizards´ had a considerable knowledge of the theory of sound and of the functions of obscure principles such as acoustic lenses.

This summary has by no means fully described all the hi-fi loudspeaker inventions mentioned by Augspurger but one additional trend, not dealt with by Augspurger, will be outlined which illustrates ´meta-level´ invention. The introduction of stereo systems in both gramophone and radio receivers soon led others to combine systems which, it was hoped, would reproduce ´three dimensional´ sound. These systems used a number of channels and loudspeaker arrangements, as their names suggested (Ambisound, Perisound, Surround sound and Quadraphonics (twin stereo systems)). This is another example of the use of known elements and established technology to produce a new effect.

Augspurger concluded that it would be unlikely that such a profusion of different approaches to loudspeaker design would be manifest as in the 1950s especially but accurate sound reproduction and the perfect loudspeaker remains a challenge which would ensure that all types would continue to pursue the dream and invent.
Stothard (1978) dealing with the potential threat of Japanese imports for the then growing British loudspeaker market, said that British manufacturers were largely a group of small specialist companies who refused to co-operate with each other to meet foreign competition. The main reason for this was that each firm prized its own design and that the British loudspeaker industry was dominated by "fanatical technicians" with little business sense.
Modern headphones have followed speaker trends piezo, electrostatic types and high fidelity types (of normal construction) are made.

This illustration of the actual relationship of science to radio invention shows that it tends to be contempraneous with design improvements and frequently started from an empirical base. The key feature is that scientific analysis identifies the technical principles of operation or problems, and thus establishes the design objective or reason for the problem. The improvement in performance often leaps to almost the theoretical limit once science-based design principles are used, although some constructional problems or secondary difficulties may have to be overcome to achieve this.
Perhaps the most accurate concept which summarises the relation of science to invention is a Parallel Pull in which the initial empirical invention first demonstrates the validity of the general principle but that peak performance can only be attained by designing the product (or component) in accord with the physical laws governing its function whereupon a practical limit to its performance is reached (economic and consumer constraints ignored).

This Parallel Pull concept should include another feature of the trend of scientific enquiry which Eccles briefly mentioned, namely that tendency for the scope of research to widen, as he noted with reference to radio science broadening to include geophysical matters. Indeed radio technology led to Acoustical studies (of broadcasting studios for optimal reverbation periods) and later to studies of stereophonic and "ambi-sound", to say nothing of new measuring instruments and techniques.[86] It is obvious even from recent loudspeaker invention, that not all advances are based on prior scientific discoveries.

Science and Engineering Design

It had been noted that engineering design took much more consideration of economic and consumer influences so that engineering designers were further removed from ´pure technological progress´ than inventors. Thus engineering design interposes a further link in the chain connecting pure science and product design, thereby distancing science from design.

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86 Cardwell (1972) has noted this great broadening of the scope of scientific research consequent upon a new discovery; in his case the discovery of the atmosphere led to scientific advances in Metereology, Chemistry of gases, Physics of gases, Respiration studies, Aeronautics and the first practical heat engines as he illustrated on a diagram (p.52).

5.10 Receiver Manufacturing

Utterback and Abernathy (1975) stressed the importance of high production quantities and market (competitive) stresses as key factors in the change to mechanised (or automated) production techniques. It appears that changes in domestic radio manufacturing methods owed as much to "invention-push" and technological transfers from other electrical industries as to high volume.

In the earliest days of public broadcasting large firms were prepared to invest in equipment and use efficient production methods. The British radio receiver industry did not "take-off" until about 1930 partly because the product design changed very rapidly until then and partly because the industry was dominated by large numbers of small firms who assembled ready-made components. Sturmey (1958) has described the reasons for the dominance of small firms in those early years while Wireless World 1935[87] noted that early radio set producers used only a few hands to assemble bought in components, had a designer test the completed sets and placed this in a polished mahogany cabinet selling it at a handsome profit.

Under the market conditions of that time the small adaptable firm was the most profitable organisation often using copied receiver designs, ex-government parts and producing sets of inferior design. These receivers were constructed on the 'point-to-point' wiring system.

Early factories could be well planned and well equipped as an early description[88] showed. Production arrangements owed a great deal to existing practices and techniques used in other electrical industries such as the Telephone and (wired) Telegraph ones so that operations such as coil winding were based on technological transfers from general electrical engineering practice. Sturmey (1958) observed (p.173) that "the production methods used were largely a matter of the size of the firm" and that larger firms used line production methods with unskilled labour. This led to cheaper and more reliable receivers.

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87 Wireless World 1935, Aug 16,37 pp.195-199 "The Receiver Through The Factory".

88 Wireless Weekly 1924

Chassis Construction

The first real development in radio production technology came in the late 1920s and was primarily due to product invention. Neutralising had led to the use of screening cans for sensitive tuning circuit assemblies and these were produced using dies. This principle was extended to the chassis method of radio construction in which all screened parts were mounted on the top of a metal chassis in their screen cans, while unscreened components were mounted on the underside of the chassis. Sturmey (1958) stated (p.171) that the chassis method had been introduced to Britain by Brandes in 1927, the method having been 'long known' in America. This method required the manufacturer to invest in press tools, drilling jigs and similar production equipment for quantity production and was adopted by radio subsidiaries of large electrical firms. This chassis construction principle was soon extended to the manufacture of other parts of the receiver for example the moulded bakelite cabinets which appeared in the early 1930s. Manufacturers were reluctant to undertake the large investment needed when product design was changing rapidly and its adoption forced manufacturers to produce sets which were in large demand so that the large investment costs would be spread over a large volume of production. In turn this forced manufacturers to consider low cost product designs - an illustration of Utterback and Abernathy's systemic relationship between product and process invention.

1935 Production Technology

By 1935 radio production technology had reached a mature level as this description shows.[89] The subject was Ferranti's new domestic radio receiver factory at Moston (Lancs.) which had newly been erected and embodied all the latest production methods.The key feature of the new factory was that it was designed for its specialised purpose from the outset; whereas 1920s radio production had been characterised by individuality and variety of treatment, modern production arrangements aimed to supply large quantities "whose design was unlikely to be changed for one year". The factors which encouraged this transition also included stability (of market) overcoming the problem of obsolescence and the second hand values of sets. (p.196)

[89] Wireless World 1935, Aug 16, 37 pp.195-199

The remainder of the article then described the layout of the factory and the main technologies. Ferranti's was unusual in buying in so few components and made valves, capacitors and resistors themselves. The layout of the factory was rational having stores for raw material at one end, and this flowed through the factory according to the manufacturing sequence. Thus raw materials were taken to either the machine shop or fabrication shops (for insulators etc). The machine shop used automatic lathes and automatic toggle presses. Many components were plated and conveyed to the Plating shop by a chain conveyor.

Not all processes could be mechanised. Loudspeaker assembly depended upon hand-wound speech coils and hand doping operations for the cone. Generally though the progress was one of higher integration so that components and sub-assemblies were fed forward to finally assembly of the chassis. The chassis was then tested and finally fitted into its cabinet (also entirely manufactured at Moston) and further tests executed before the receiver was despatched.

This article concluded by noting that production was not the only activity which took place in the factory, there was also a central research laboratory together with subsidiary development departments for particular processes and other factory services (such as the supply of compressed air).

By the mid-1930s the method of manufacturing domestic valve receivers had matured and was used well into the 1950s without much alteration.

Printed Circuit Board

The next major change in radio receiver production technology was the transition to Printed Circuit Board (P.C.B.) methods of assembly. The origins of this method stretched back to the 1920s when alternatives had been sought to the traditional point-to-point wiring system. Electronics[90] noted that in 1926 one inventor (Charles Ducas) had patented a method of forming electroplated conductor patterns (copper, gold etc.) on non-conducting boards

[90] Electronics (International) 1980, April 17, 53(9), p.51

- a forerunner of the printed circuit board. Ducas's method was not a commercial success but about this time another method which consisted of riveting pre-formed conductors to a bakelite panel was used and was commercially successful.

Dummer (1983) has described how wartime needs led to the development of various methods of radio and electronic assemblies which did not use the normal point to point wring techniques. These covered chassis-less construction, potted assemblies, wire-wrapping and automatic insertion, the primary aim being to attain a high rate of production of ultra-reliable miniature electronic military devices between 1939 and 1945. One of these techniques, the printed circuit board, was to be used in the manufacture of domestic radio (and electronic) products. The wartime developments soon led to attempts to apply them to commercial radio production.

After 1945 a variety of new production methods, based on wartime success, were suggested and tried. The primary aim of each of them was to eliminate the point-to-point wiring and replace it by a cheaper more mechanised means of production. One early British non-P.C.B. method was Sargrove's. Sargrove (1947a, 1947b) has described his 'Electric Circuit-Making Equipment'. His idea was for a shaped bakelite board to be sprayed with metal then face-milled so that an electrical track was left. In addition Sargrove incorporated a method of making passive components such as resistors, capacitors and inductors by forming suitable configurations of metal and bakelite insulation. His entire sequence of production operations were intended to be mechanised and linked to mass production techniques using conveyor belts and special machines. Sargrove's method was <u>not</u> the P.C.B. one, but it is now used in the production of integrated circuits.

Sargrove claimed thirteen advantages for his manufacturing method; it was cheaper because the number of components did not affect the cost (being embodied in the board shape) and only the size of the bakelite panel affected the cost. Production and inspection costs were lowered because wiring mistakes were impossible; the circuit was automatically tested during manufacture; the rate of production was up to one unit every twenty seconds;

fewer components needed to be stocked and purchased; automatic production meant 24 hour output if needed; material and energy production costs were reduced; circuits could easily be ´tropicalised´ if desired; production times were much shorter than by traditional methods provided high quantity production were produced; field servicing costs were reduced because there was no need to repair old faulty units when cheap new ones could be inserted; labour requirements were reduced leading to lower labour costs and greater labour productivity; the new circuits were much lighter yet more robust therefore transport was easy. Finally Sargrove noted that for high altitude operation it was not necessary to pressurise airborne apparatus.
When asked about typical unit costs of a domestic receiver, Sargrove hedged a little but considered that if the quantities were high it might be possible to make a battery set for two pounds.

Sargrove´s system was not adopted by the industry. A simpler method using a flat board with a sheet of metal on side, which etched the required tracking (but not components) on it with later insertion of resistors, capacitors and other components was adopted. This system using discrete components was less radical than Sargrove´s and made its commercial debut in 1954, at a time when homesales were static. This method rapidly became a ´sales feature´ and when the transistor displaced the valve, the printed circuit board method of construction became universal and was a major factor in low cost production. Its essential principle was to etch the complete circuit on the copper-plated side of an insulated board then insert discrete components and soldering them. These assembly and soldering operations were often done automatically by machines. This technique was ideally suited to transistor circuits, especially miniaturised ones and effected considerable cost savings. Printed circuit technology came largely because of invention-push though its adoption was accelerated by the competitive conditions of the radio industry in the 1950s.

5.10.1 Component Manufacture

Mechanisation of Component Manufacture

The study of the bicycle industry showed that the earliest changes to machine methods of manufacture occurred in the component section of that industry and the same pattern occurred in the radio industry. The leading example was in the manufacture of thermionic valves, as noted earlier, although other radio components such as capacitors, resistors, coils etc., were also made by specialist firms who mechanised production and standardised their product.

Valves

Sturmey observed that the earliest production techniques for radio valves were borrowed from electric filament lamp technology and confined to members of the patent pool which was called the British Valve Manufacturers Association. As valve production techniques could not be established by dismantling a valve these methods could be kept secret. One result was that non-pool firms made their own advances and produced cheaper valves, Mullard and Phillips did this during the 1920s.

High valve prices caused a number of responses; one was to attract cheap valve imports and in Britain this was countered by the extension of the Key Industries Tariff and in turn caused the pool members to include a clause stipulating that B.V.M.A valves only were to be sold. Consumers however were keen on cheaper valves and this demand was stimulated by providing Kit Sets (for home construction) and new radio circuits based on the cheap valves. Another short-lived effect was to repair broken valves but this was not satisfactory and the service stopped.

The main reason for the reduction of valve prices was that higher demand had made mass production methods economical and these benefits were passed on to the consumer although masked to some extent by patent monopolies which lasted until 1956, the valve royalties payable after 1930 being very small. Accounts of the early price reductions were given in The Times;[91] the 1928 article noted that in 1923 a valve had cost about two pounds and in 1928 cost ten shillings and six pence; growing demand and mechanised production had been the main cause of the price reductions.

However the influence of non-pool firms and imports brought valve prices down though again the pool manufacturers introduced an ingenious scheme in which

91 The Times 1925 Jan 9 p.25; 1925 May 7, p.11; 1928 March 22, p10

valves fitted to new sets were sold at low prices while replacements were sold at high prices. From the 1930s the royalty rates on valves were not large although the B.V.M.A. lasted until 1956 when it was abolished.
Reduced component prices was a leading cause of reduced prices of complete receivers and like bicycle components, mechanisation began at component level.

Trend of Receiver Prices

The difficulties in determining an "average" price for a bicycle was noted in the previous chapter and these difficulties were increased many times in the case of domestic radio receivers due to the much greater range of receiver types. This was confounded by a lack of reliable data for the first ten years of the British radio industry as no official figures were published either by the trade or government sources; for example it was only with the publication of the 1934 Census and the 1934 Trade and Navigation Accounts that reliable annual figures for the average price of British domestic receivers became available. This problem about price data will be discussed below.

Only rough indications of the prices of various models can be quoted from contemporary sources and they reveal the wide price range for a particular type. Hill (1978) gave the prices of many crystal sets produced in Britain up to 1927 which showed this wide price range, for example Marconi's Model 'A' crystal set of 1922 sold at nine pounds ten shillings while a cheap Brownie crystal set of 1923 sold at 12/6d. The prices were further confounded by the existence of a large but unquantifiable market for kits for home constructors. As this quotation from Wireless World[92] report of the 1931 Radio Show reveals. "At Olympia there were certainly more "kit" sets for home assembly than ever before, including complete sets of parts, boxed together and sold complete, and also a number of receiver circuits sponsored by the manufacturer producing the majority of components used in them." Many of these kits were supplied by large and well-known radio manufacturers such as Ferranti, while others were produced by specialist kit firms. Sturmey (1958) observed that by 1934 sales of kits had declined because receivers had become

[92] Wireless World 1931 29 p.388

more complex by then and factory built ones were cheaper and usually had a better performance than average home constructors could achieve.

A further complication was that the number of valves did not adequately indicate the trend of performance improvement as a five valve receiver of 1924 could well be inferior to a three valve one made in 1929 and this was particularly the case in the first ten years of the new industry when product progress was rapid. The following examples then give a rough indication of price trends for the early years.

A book[93] published in 1923 gave the following table of British radio receivers prices and ranges.

Receiver Type	Price (pounds)	Range (miles)
Crystal Set	5.5	15 (on headphones)
1-valve	12.5	30 (on headphones)
2-valve	18.0	10 (loudspeaker)
3-valve	25.0	20 (loudspeaker)
4-valve	32.0	50 (loudspeaker)
5-valve	40.0	80 (loudspeaker)

B.B.C. Yearbook 1929

Crystal Set	2 to 4	4 (headphones)
1-valve	5 to 7	25 (headphones)
2-valve	10 to 15	20 (loudspeaker)
3-valve	17 to 23	25 (loudspeaker)
4-valve	20+	35 (loudspeaker)

Other illustrations are taken from Wireless World's Radio show reports; in 1924 a 3-valve sold at six pounds fifteen shillings and a 4-valve at nine pounds fifteen. In 1928 a mains-powered 2-valve receiver sold at twenty pounds, a mains powered 3-valve at twenty four pounds and a 4-valve at thirty eight pounds ten shillings. In 1930 the prices of mains powered receivers were quoted:- 2-valve sixteen pounds ten shillings, 3-valve twenty six pounds fifteen shillings, and a 4-valve thirty three pounds. In 1931 a 2-valve mains

93 "Wireless Receivers Of Today" published by E.J. Burrows, London 1923

set sold at twelve pounds; a 3-valve between eighteen and thirty three pounds; a 4-valve between twenty three and thirty five pounds. By 1933 a very marked reduction had taken place in the prices of the cheapest radio receivers; Willing's Press Guide for 1933 quoted a report that the cheapest 2-valve receiver in 1932 sold at just under five pounds while by 1933 the cheapest was a 3-valve at just over three pounds. Wireless World[94] said that a 3-valve (TRF) was the most popular type of receiver in 1928 and could be bought for about twelve pounds. Despite a dip in its popularity about 1930, Wireless World noted in 1932 that the 3-valve set was "the backbone of the industry" and in that year a model having bandpass circuits sold between sixteen and nineteen guineas whereas a non-bandpass (double tuned circuit) model sold between fourteen and sixteen guineas. These price differences indicate the influence of product design upon product prices.

Price Trends of British Radio Receivers

It is very difficult to specify an "average" price for radio receivers because of the huge variety that were sold. These could range from cheap crystal sets to expensive radiogams and government statistics did not distinguish between them until after 1951. Even so domestic radio receivers came in many varieties making it difficult to specify an "average" price. The most accurate prewar price trends came from the various but spasmodic Census and Import Duties Act returns of 1924, 1930, 1933, 1934, 1935 and 1937 but these were not annual figures. For prewar years the only source of annual prices were those given in the Trade And Navigation Accounts from 1932; but they combined data for both radio receivers and radiograms. Furthermore British radios were exported without valves (because of trade 'agreements') and average prices are therefore lower than they actually were; (the census prices included valves and give a better indication of actual prices). The following tables give the various kinds of average annual export prices: firstly, for the years 1932 to 1951 - radios + radiograms; secondly for the years 1952 to 1965 - mains-powered radios (not including radiograms). All these average prices were reduced to constant prices using Feinstein's Retail price index. Graph 5.17 illustrates the falling trend of receiver prices.

[94] Wireless World 1928 23 p.461

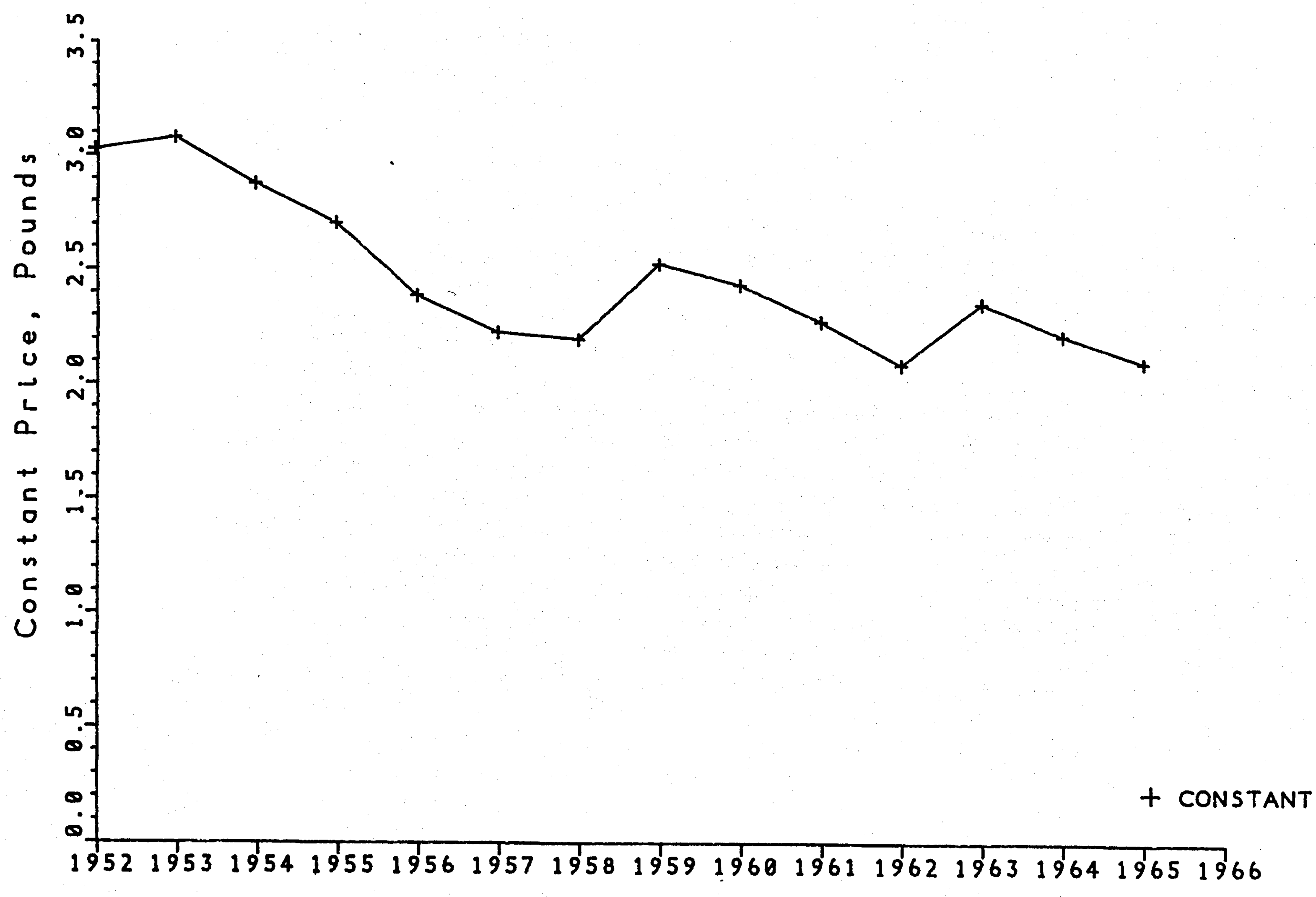
Annual Average Prices of British Radio + Radiogram Exports

Year	Current Price (pounds)	Constant Price (1913=100)
1932	7.61	5.39
1933	6.12	4.46
1934	5.56	4.02
1935	4.87	3.47
1936	5.29	3.67
1937	5.55	3.65
1938	5.20	3.39
1947	11.34	4.55
1948	11.79	4.39
1949	10.04	3.65
1950	9.75	3.44
1951	9.94	3.19

The following table gives the average export prices of mains powered valve radio receivers exported from Britain for the years 1952 to 1965.

Mains-Powered Radio Receiver Exports

Year	Current Prices (pounds)	Constant Prices (1913 =100)
1952	10.27	3.03
1953	10.76	3.08
1954	10.23	2.88
1955	10.09	2.71
1956	9.32	2.39
1957	9.02	2.23
1958	9.17	2.20
1959	10.60	2.53
1960	10.32	2.44
1961	9.99	2.28
1962	9.53	2.09
1963	11.01	2.36
1964	10.69	2.22
1965	10.61	2.10



CONSTANT PRICES OF RADIO
VALVE SETS EXPORTED; 1952-1965
Graph 5.1.

The following table gives the average prices and constant prices of complete radio receivers (excluding radiograms) for the Census and I.D.A. years.

Average Ex-Factory Prices Of Radio Receivers Produced In Britain

Year	Current Price (pounds)	Constant Price (1913 = 100)
1933	5.88	4.29
1934	6.15	4.45
1935	6.07	4.35
1937	6.29	4.13
1948	11.31	4.22
1951	9.75	3.11
1954	8.64	2.43
1958	8.39	2.01
1963	9.97	2.14

The most accurate figures are those given in the censuses of production and I.D.A. reports as they were average prices based on the total annual production for that given year. Export numbers were much smaller. Although some difficulties have been noted about the accuracy of these prices, it is clear that the trend of the constant prices shows a larger reduction in the early years which gradually tails off and levelled by about 1958. Not all this price reduction was due to process improvements as product invention was also involved. It does show the long run price pattern observed in the bicycle industry which suggested that process technology (like product technology) was essentially transient and reached a practical limit relatively soon after the commercial start. The introduction of transistor radios showed a repetition of the same pattern.

Reasons For Price Reduction

Radio receiver prices were not reduced solely because of process inventions. It has already been noted that product invention was another very important cause and it would be desirable to determine the relative contribution of each to the total price reduction over time. This is not possible but it is possible to describe the factors responsible for price trends of British receivers.

In 1929 Wireless World[95] noted that in 1929 there had been no sweeping changes in the product design of receivers and manufacturers had embarked on an extensive manufacturing programme in which sets were to be re-designed and simplified to cheapen them and for a change in production methods which necessitated a large enough quantity to be sold in order that the new manufacturing methods would be economical. These savings were to be passed to the customer in the form of either cheaper sets or as better sets at the old prices. The changes had largely been to the chassis method of construction but some had supplied metal cabinets covered with leatherette. The reasons for this change had partly been the royalty reduction, partly the adoption of mass production techniques, partly by (product) design for simple sets and partly due to competition. The new cheap simple receivers were intended to "satisfy a large but hitherto unexploited section of potential listeners" who would be satisfied with a 3-valve set made using metal pressings and perhaps a moulded bakelite case.

The Broadcaster Annual 1932 (p.31) said that in the past few years a striking reduction in receiver prices had taken place with 3-valve sets selling at half their price of a few years ago. The reasons for this marked reduction had been valve price reductions, patent royalty reductions though the chief reasons had been improvements in (product) design and the use of mass production methods.

Another factor of great importance in the 1930s was competition. This had its roots in the patent pool and foreign firms. Sturmey (1958) has commented extensively about this; in the first years of broadcasting in Britain some of the new firms were subsidiaries of American ones and they complied with the patent monopoly arrangements. The only threat in the 1920s came from Germany and this was countered by patent pool agreements to limit imports. From 1930, when the main patents were beginning to expire, some American firms signalled their intention to establish radio manufacturing firms in Britain which would not be members of the then declining patent pool and a Dutch firm initiated a similar arrangement soon after. It was said that the tariff barrier had contributed to this change. Another element was the rise of new British radio

[95] Wireless World 1929 25 p.369

firms who were eager to research and innovate.

This indicates that price reductions in British radio receiver prices were due to five factors; product re-design, improved production techniques, valve (and other component) price reductions, royalty reductions and competition. Product re-design, changes in manufacturing and valve price reductions have been described above, and a brief note will now be made of the other factors.

Patent Royalties For Receivers

The amounts of patent royalties which consumers had to pay were established after some discussion in 1922 when public broadcasting began in Britain. Sturmey (1958) has given a full account of the various changes in patent royalties in the British radio industry. These were quite complex as a scale of charges for non-valve sets (such as crystal sets), battery eliminators and other equipment, together with later rebates for replacement sets; Sturmey has tabulated the first 1922 schedule (p.145). The basic receiver royalty was then 12/6d per valve-holder; in 1929 this was reduced to 5/- then in 1932 further reduced to 2/6d then in 1938 change to a charge of six per cent of the retail price. These reductions in the late 1920s and early 1930s made a big difference to receiver prices, especially multi-valve models.

Competition

The British market for domestic radio receivers had been a protected one since its inception. It was noted above that in order to get a B.B.Co./P.O. stamp on a receiver it had, among other things, to be of British manufacture. This arrangement was slightly upset in 1924 when import controls were relaxed for a year but conditions reverted to normal again and as the radio cartel had international influence, imports and exports were effectively controlled. During the 1920s some fears were expressed about German exports to Britain as German sets were considerably cheaper but this fear subsided until the

1930s,[96] when the main British patents had expired making it easier for new entrants to the trade. The Ullswater Report (1935)[97] noted (para.141) that in spite of difficulties in comparing international prices of domestic radio receivers it "was fair to say" that the average price for a set of medium quality in Britain was somewhat high. It was noted that in Germany co-operation between the broadcasting authority and the wireless trade had resulted in a standardised design of receiver which sold at a low price which enabled a larger proportion of the German population to become listeners. It was suggested that the B.B.C. and the British wireless trade might engage in a similar exercise.

However as Rogers (1973) noted Philco (an American producer) immediately launched 'People's Sets', (a three valve battery model selling at five guineas, and a mains superhet selling at six guineas) but a policy which was "not proceeded with further owing to increasing prosperity bringing radio receivers readily within most pockets and the pressure of cheap imports" (p.87). Rogers went on to describe another cheap design by Phillips which did not have a chassis, but attached all the components virtually individually to the bakelite cabinet - an interesting use of product design for product price reduction. In fact the combination of lower receiver prices and rising purchasing power in the early years of the 1930s had led to a rapid growth of demand by lower income groups as well as a considerable increase in home purchases of luxury receivers and radiograms which led to a saturated market by 1938 - a matter which will be more closely examined in the section on Demand. By the mid-1930s British radio prices had bottomed and the competitive pressure had been exerted from about 1929. This competitive

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96 The Times 1925 Sept 28, p.21 briefly described the German radio receiver industry noting that mechanised production methods and standardisation had been widely adopted there and that as a consequence of the need for high quantities of production, German radio manufacturers had began to export radios. The German home market then was mainly for small sets ranging from crystal sets to three valve receivers. The Times 1926 Nov 2, p.8 printed a summary of a German report which noted that British radio receiver prices were 25% to 50% higher than German ones. The Times 1927 Sept 20, p.7 commented on the German Radio Show and noted the low prices and beautiful finish of their sets. Crystal sets sold at 5/6d, three valve sets sold at three pounds and four valve sets sold for four pounds seventeen shillings. The Times 1928 Aug 28, p.9 noted that a German radio company sold a cheap set costing Germans about two pounds and that in Britain the need was for a 2-valve set costing about three pounds; this would tempt crystal set users to a valve set.

97 Report Of The Ullswater Committee 1936, Cmnd 5091 para.141

pressure was concerned as much with extending demand as of lowering prices, and earlier accounts of inventions have shown how radio manufacturers catered both for new low priced buyers as well as luxury sets, portables and car radios in the competitive 1930s; a highly diversified product range. The trend of radio receiver prices, like bicycle ones, showed a rapid decline soon after the transition to mechanised production with a tailing off and later levelling.

There is a similarity here with the bicycle industry as manufacturers were not greatly concerned about relatively high prices for their products in the first commercial years of the new industry. The key factors which initiated the search for low cost products and low cost methods of producing them, were competitive market pressures in the form of real or threatened cheap imports and product invention (chassis-less construction). In the very first years of radio broadcasting crystal sets and sets for home constructors explicitly appealed to lower income consumers but it was not until 1930 or so that manufacturers made any real effort to make cheaper sets using mechanised methods of production. This observation is slightly different to Utterback and Abernathy's emphasis on the role of high volume based on high demand.

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5.11 Output

The analysis of the output of the Bicycle industry showed that this was multi-dimensional as it consisted of components as well as completed products, and that some of both categories were exported and that the factors which affected exports were not necessarily the same as those which affected the home market. In addition it was found that there were difficulties in determining the actual quantities of output for pre-1939 years, which were of greatest importance as the most rapid growth of output occurred then, and also that after 1946 government (stop-go) economic policies affected homesales in the short run. All these difficulties apply equally to the British radio industry but with further complications as the following quotation will show.

Sturmey (1958) (p.184) said "In a work of this nature it is customary to include a series of production figures or indices showing the manner in which output has grown over the years being covered. In the case of radio this is not easy. For one thing the term ´radio´ covers a multitude of devices and uses. One of the most significant trends in the industry has been the manner in which the larger set makers, the specialiser under the impetus of wartime controls, and partly as a natural development of their enterprise, have begun producing products other than receiving sets. In saying therefore that the output of the industry has increased from 6.3 million pounds in 1924, of which 1.5 million represented valves, to some 62 million in 1948, of which some 8 million represented valves, it must be realised that whereas the former figure was almost entirely made up of receiving sets, only about 52 per cent of the latter comprised receiving sets. --- Another difficulty in using these figures is that they cover only those firms covered by the Census of Production. The smaller producer important in both 1924 and 1948 being omitted though probably of greater relative importance in the earlier than in the later years."

British Radio Receiver Exports

The most notable feature of the British radio receiver industry was its very low incidence of exports compared with traditional industries including the bicycle. Little over three per cent of its total output was exported before and after the second world war. There were a number of reasons for this; the prime one in the pre-war period was the existence of the trade agreements which sought to, and succeeded, in limiting international trade in radio sets. Such agreements were coupled to the Valve agreements so that British receiver exports were sent without valves (making average export prices lower than they would have been if the sets had had valves fitted). Sturmey noted that the annual values of British exports of radio receivers and radio components had remained remarkably constant since 1925 but that the introduction of the Empire Broadcasting service in 1932 had been partly intended to boost British radio exports although by 1937 it was evident that other countries had gained. Sturmey (p. 183) has noted criticisms of both the product design and prices of British sets made at the end of the 1930s. Sets were exported which did not were not designed for overseas conditions, were too expensive and

British export efforts then lacked good overseas sales organisations. "From New Zealand came complaints that British sets were too expensive, not powerful enough, and incorporated an unwanted long-wave band." Indians also complained of the high prices of British receivers and bought cheaper sets made in other countries.

The following table shows the proportion of total British production which radio receivers alone accounted for; total production included radio receivers, radiograms, radio components and radio (and other) valves.

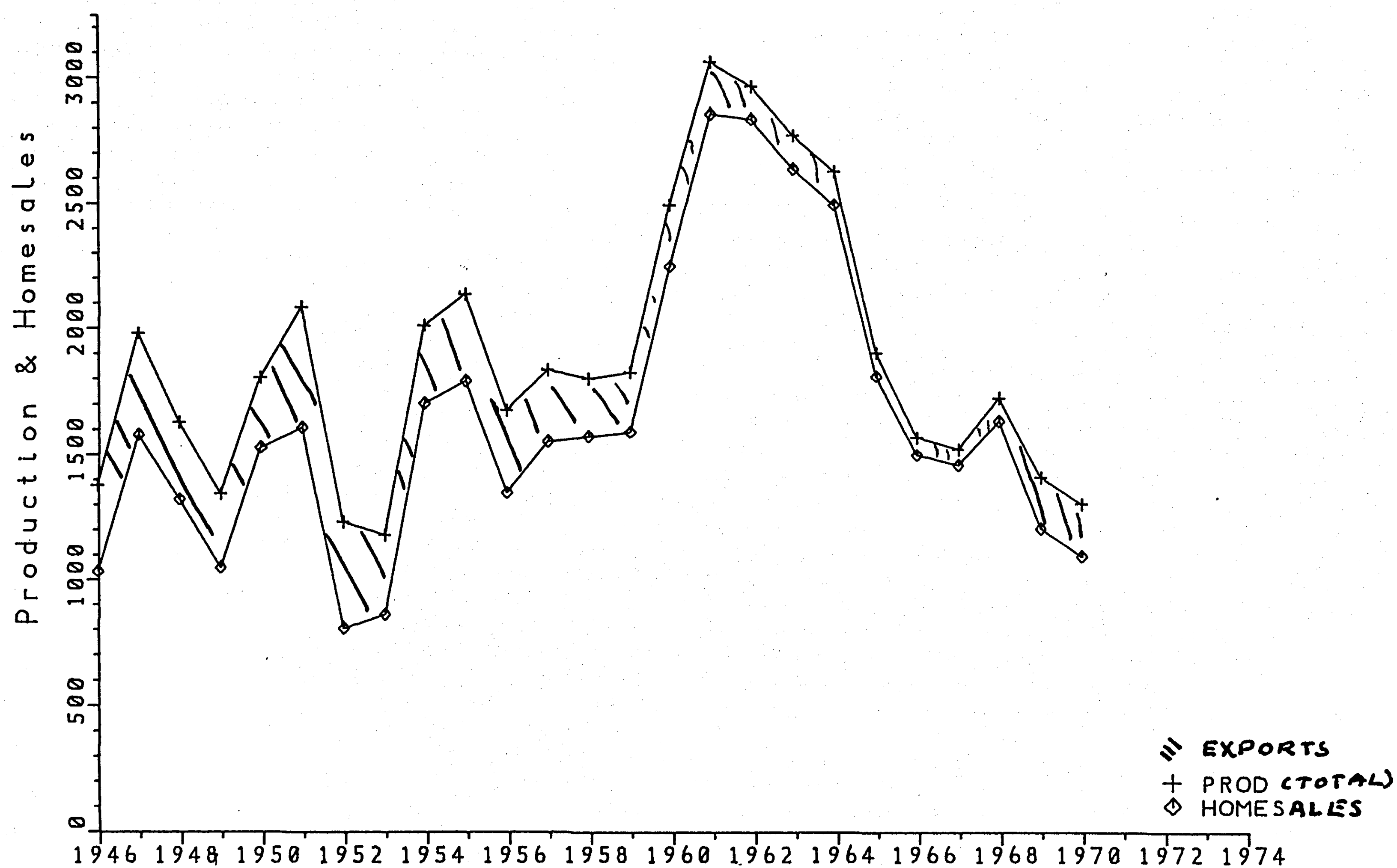
Radio Receivers As a Proportion Of Total Output (by Value)

Year	Radio Sets	Radiograms (Million	Components Pounds)	Valves	Proportion
1930	2.77	0.21	3.266	1.516	35%
1933	7.28	0.758	3.00	2.102	55%
1934	9.87	2.167	2.622	2.204	58%
1935	10.463	1.766	2.905	2.215	60%
1937	11.325	1.954	3.171	2.068	61%

(Source: Censuses of Production and I.D.A. Reports)

About three per cent of the British production of radio receivers (measured by quantity) were exported in these years. The proportion of components exported has been given in these census and I.D.A. returns though this was counter-balanced by sizeable radio component imports.

Graph 5.13, on the following page, shows that total output and exports of complete radio sets only, for the period 1946 to 1970 which illustrates the small and reducing proportion of British exports. The immediate post-1945 years saw Bicycle exports at record levels, so that radio exports never had the importance to British production which bicycle exports did. The prime determinant of changes in total output of the British radio receiver industry was therefore changes in home demand.



PRODUCTION & HOMESALES
RADIOS: 1946–1970

GRAPH 5·18

5.12 Demand for Domestic Radio Receivers

The study of demand for the bicycle showed that Katona's two factor theory was satisfactory and that consumers were motivated by two different factors, one -the willingness to buy - depended upon socio-psychological variables while the other - the ability to buy - depended upon economic variables. This mixture of economic and non-economic demand factors also affected the demand for British radio receivers as Catterall (in Buxton & Aldcroft, 1979) showed when they stated that the demand for radio sets, like any other demand, was not just dependent on price, but also on consumers' tastes and incomes. (p.263) The post-1945 market for radios was also profoundly affected by the 'stop-go' government policies of demand management.

Willingness to Buy

A number of socio-psychological variables affect British purchases of domestic radio receivers, the main ones were Novelty, Uses, and Purpose of Use.

Novelty

The introduction of public broadcasting captured the public imagination and filled them with the 'wonder of wireless'. This non-economic variable was primarily responsible for the huge initial demand for radio sets at the start of broadcasting. Evidence of this craze is provided not only by the clamour for broadcasting itself but from proof of widespread interest; Hill (1978) reproduced a photograph (p.22) of fete-goers crowding to hear the new wireless a few months before official public broadcasting began. This wonder continued for many years as the number of radio journals and newspaper articles indicated as well as high demand itself. Catterall (op.cit., 1979), dealing with the inter-war radio industry in Britain, said that even with the increased capacity of the radio making trade in the 1920s demand outran supply. Pickering (1977) in his study of consumer acceptance of new products found that radio had the most rapid consumer diffusion of any new product in terms of per capita ownership rates. This social craze for radio was not confined to Britain as Herron (1969) pointed out when he compared American radio ownership per family with that of the telephone and electricity supply. Undoubtedly novelty was the key factor behind this initial demand.

Uses

From the technical viewpoint a domestic radio receiver had only one use - that of reproducing audio signals from a suitable transmission. From the consumers' viewpoint however a receiver had a variety of uses, it could convey news, be a music box, provide entertainment (e.g. music hall shows), inform and educate. Most of these facilities had previously been provided by other media or sources for example the newspapers, theatres, concert halls, home entertainment, libraries and educational establishments. One new "use" was Background Listening. The outstanding feature of radio was its instanteous communication and for this reason consumers' showed an early interest in Portable and Car radios and, once the (electric gramophone pick-up had been developed) in radiograms. Although these were not technically satisfactory until the 1930s, they show that manufacturers were willing to diversify their product range to increase demand.

Radio ownership in the early years was greater in rural areas than in cities and one explanation suggested[98] was that cities such as London offered public entertainments which were preferred to radio. Allen (1968) using market research data for the 1950s and 1960s has noted large regional differences in consumers' tastes and habits in Britain. Tyne-Tees and Scotland have large radio audiences for Radio Luxemburg, while Yorkshire has a high percentage of rediffusion radio sets, in Wales the sales of pocket transistor radios was very sluggish and confined mainly to schoolchildren. Scots had lower possession rates of radio and television than other parts of Britain and also low readership rates for the Radio Times and TV Guide. Some of these differences may be explained by economic factors though it appears that social influences are important too.

Programme Preference

Consumers were also affected by what was broadcast and it was noted that this affected receiver design especially in the 1930s when Radio Luxemburg and Short Wave listening became popular. Broadcasting policy generated controversy from the moment transmissions began. Both in Britain and America it was felt that radio had to be 'better' than the cinema (a new public

[98] The Times 1922 Dec 22, p.7

entertainment which many considered had degenerated into sensationalism). In America the high aspirations were voiced by Nelson[99] in his introduction dealing with radio as new medium of education and entertainment which potentially would bring listeners in contact with "the world's most gifted minds, of hearing the greatest artists and the most renowned musical organisations, of sitting at the banquet table with the world's leaders in every field of human activity ---" and so on. John Reith, of the B.B.Co (and B.B.C) had even higher aspirations for British listeners and made no secret that they would not get what they wanted. Briggs (1961) has given an extended history of British broadcasting and of this whole issue. The Reithian standard gave way to a more popular one partly because of technical progress (anti-fading and pocket transistors for 'pop') and partly because of political and social changes in which consumers' preferences were given greater consideration than in Reith's time.

5.12.1 Economic Aspects Of Demand

In this section the main interest is with the major economic causes of the increase in the homesales of radio receivers in Britain. It was noted in the earlier section dealing with changes in output of the British radio receiver industry that homesales were the most important determinant of output and that market saturation had occurred for the traditional valve wireless set by 1938. Any economic account of growth of demand should concentrated upon this first period of the new industry.

Ideally it would be desirable to have full details of the models (two valves, three valves etc.) and average prices for each of these types in order to show their values and from that assess the probable value of product invention. This cannot be done; the best indication of the importance of cheap low powered domestic receivers comes from the numbers of each type exhibited at the Radio Shows. Constable (1980) gave figures for the 1926 Show which clearly indicated that crystal sets and receivers with up to three valves were by far the most numerous. Another indication was the frequent references

[99] E.L.Nelson "Transmitting Equipment for Radio Telephone Broadcasting" Proc. I. R. E. (NY), 1924, Oct, 12 p.553

already noted that three valve receivers were the backbone of the (British) radio receiver industry and of the popularity of crystal sets and home construction sets. Taken together these point to the considerable commercial importance of such basic low cost receivers during the 1920s, an importance which increased during the 1930s. The implies that much new demand was due to 'trickling down'.

A trade source estimate of total radio plus radiogram production in Britain for the years 1930 to 1939 has been given by Wilson (in Burn (Ed.) 1961). Unfortunately this does not separate radio receiver sales from radiogram sales, and as 1930s radiograms were luxury models costing up to two hundred pounds each and unlikely to be purchased by lower income groups. However Wilson has also given estimates of annual consumers' expenditure on radio receivers alone so that the regression procedure used in the bicycle industry can be repeated here.

Regression

The purpose and method of the following regression is exactly the same as that executed in the case of bicycle demand. The twofold purpose - of estimating the equation parameters and the contribution each independent variable made to demand (homesales) and also to establish if growth of demand appeared to be due to trickling down - remained the same as with the bicycle equation.

The simple and direct equation model of the form

Homesales = f(Price, Income, Net saving)

was used with Income and Net saving data in their Real, per capita/per depositor form for the period 1930 to 1938. Product prices were Real average British radio export prices (excluding radiogram prices) for the years 1932 to 1938 taken from the Trade and Navigation Accounts and estimated for the years 1930 and 1931 by extrapolation. Homesales were taken as the annual U.K. consumers' expenditure on radio receivers (excluding car sets and radiograms) given in Wilson's chapter in Burn (ed.) (1961), Table 2, Col. 1, p.138 - the trickle down sector. All these data are tabulated in the statistical appendix.

Regression Results

The results obtained using the SPSS Regression program, described in chapter three, are now presented.

Regression Equation Parameters

$$H = -8.749C - 0.265P + 0.090E + 0.1296NS$$

$$(4.7992) \quad (0.0330) \quad (0.1504)$$

Where H = Homesales

C = Constant

P = Product Prices

E = Average Manual Earnings

NS = Net Saving

The terms in parentheses below each independent variable indicate their standard error values. The coefficient of determination (R-squared) for simultaneous entry of all three independent variables in this equation was 0.95.

Relative Importance Of Each Independent Variable

The use of the 'Enter' method allowed each independent variable to be entered either singly or in combination and thus indicate the changes in homesales (R-squared) due to each and therefore the relative importance of each in determining demand. The results using cumulative entry were as follows:-

Variable Included In Equation	Corresponding R-Squared Value	Proportion Of Demand Explained
Product **Price**	85.9%	85.9%
Price+**Earnings**	94.1%	8.2%
Price+Earnings+**Net Saving**	94.8%	0.7%

These separate computations of R-squared due to each independent variable show that in the case of demand for radios the effects of changes in product prices was very much greater than in the case of the demand for bicycles, and that changes in real earnings and net saving had only a very small effect upon homesales. This result is due to the rapid price falls in British radio receivers in the early years of the 1930s which in turn were due to changes in patent royalties, product design and manufacturing improvements described earlier in this chapter.

Trickling Down

The very high R-squared value (0.95) obtained means, that like the demand for bicycles, changes (growth) of homesales can, in the statistical sense, be almost wholly explained by changes in the three independent variables for this period 1930 to 1938 and that as these variables primarily reflected changes in lower income groups' earnings and savings, that a primary source of home demand was due to trickle down.

Further assessment of trend of growth of homesales can be made as each household had to possess a Wireless Receiving Licence which was bought annually. The official returns for the number of wireless licences taken out each year to the 31st Dec. were obtained (and are given in the appendix). An estimate of homesales of radio receivers and radiograms were calculated from 1932 using total production data less exports plus imports for 1932-1938. Both these series are plotted on graph 5.19 and show that the physical volume of homesales rose faster than the number of wireless licences. The most probable explanation for this is that Replacement demand was also active due to obsolescence caused by product design. In other words radio (and radiogram) owners were replacing their existing receiver for a newer one, and that in doing so they "traded up" by buying a new model which had a better technical performance than their old set. Product design had an important role to play in this change.

Examination of graph 5.19 (next page) shows that replacement demand was greatest in 1936 and declined in 1937 and 1938. This additional information shows some demand was due to technological obsolescence. Another explanation could be that some households or individuals were buying more than one set, motor car radios and portables were becoming popular at this time. It is not possible to tell exactly how many of these were sold and the emphasis given to obsolescence in the sales section of The Broadcaster Trade Annual (1938) strongly suggests that this was the main source of replacement demand.

A further economic factor affecting homesales of consumer durable goods from the interwar period was the rate of increase of the number of households, which as PEP (1945) noted, was faster than the rate of increase of the population in Britain.

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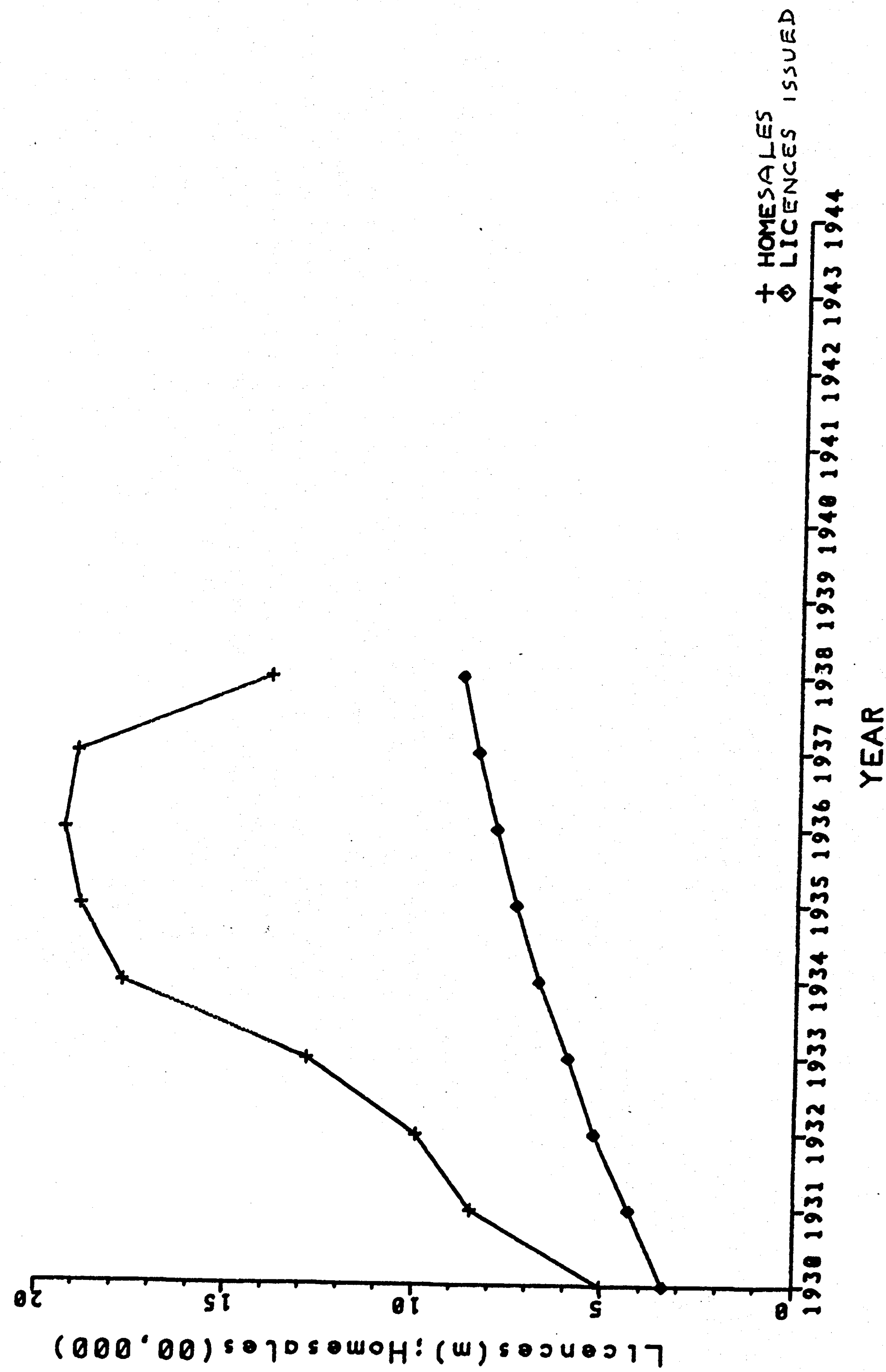

RADIO HOMESALES AND Rx LICENCES: 1930-1938

5.13 Invention and Growth

The broad aim of this analysis of the radio receiver industry was to establish if the general pattern of invention and growth of output was the same as that observed in the bicycle industry. Although there were differences between both these industries there were also a number of similarities and these similarities are taken to represent the general pattern for the radio industry.

Product Invention

It was frequently noted that ideas formed a major starting point for many new inventions. The initial search for some means of wire-less communication itself was wholly due to the idea and early inventors had no clear idea of what was needed. There was often opposition to new ideas and and designs based on unknown electrical principles but once Hertzian waves had been demonstrated experimenters felt freer to invent methods of sending and receiving them. Many later broadcast receiver inventions also depended upon ideas or applications of new principles and it was noted that these inventors worked the idea out "on paper" before proceeding to test it.

Another major starting point for product invention in the radio industry was the search for solutions to problems which had come to light during use of the apparatus. These problems frequently required a prior theoretical analysis of the principles in order to accurately define the problem and its solution.

The historical evidence of product invention shows that systematic investigation was needed to a far greater degree than was apparent in the bicycle industry. This can largely be explained by the novelty of radio technology and of the need to understand electrical phenomena and principles, and these systematic investigations had the prime purpose of creating that knowledge. This may be described as 'scientific' or 'theoretical' effort and, as loudspeaker development showed, was called upon when needed; it did not establish the global objective.

Many pioneer radio inventions ultimately resulted in devices or effects which were not anticipated at the outset, revealing uncertainty and sometimes 'bonus' features. There was no linearity as was often portrayed in innovation models as sometimes inventions were 'caused' by new discoveries, more often by prior analysis of problems, sometimes because of technology transfers, sometimes because of economic needs or non-economic consumer needs and sometimes because of hunch or inspiration. It was also obvious that much product invention was exploratory and tested often against multi-dimensional trade-offs, so that the view of the 'rational inventor' - implicit in many models - is not accurate.

The linear succession of new models, so clearly seen in the case of the bicycle, was not so clearly repeated in the case of the radio receiver.

Another feature of radio invention was the importance of advances at lower component or sub-unit levels as in the case of the bicycle. Although inner logic pressure was very important at this stage, both economic and non-economic consumer influences impinged upon product design.

Incremental Invention

Product invention did not cease one the new idea or principle had been successfully demonstrated as further incremental inventions were needed to deal with later problems or 'tidying up' the design. In many cases there was strong evidence to support the inner logic theory of technological progress with inventors' attention being drawn to associated circuits or features, or else the need for an overall or holistic balance among the elements to give an optimal solution to conflicting requirements. Here too inventors produced a huge variety of equivalent inventions or designs which, like those in the bicycle industry, represented explorations of alternatives which permitted their secondary features to be evaluated and compared. The notable feature of product invention and design at this stage was its marked broadening to other objectives so that a more diversified product range was created, sales appeal was added by the introduction of gadgets and accessories, inventions were made to reduce running costs, reliability became of increasing concern and obove all product performance changed only marginally as technological possibilities were either exhausted or rejected; many of these later marginal improvements were due to technology transfers from other fields.

Product Performance

The broad pattern of product performance was seen to parallel that of the bicycle with the rapid initial rise which later tailed off and ultimately reached a practical level after which further improvement inventions were often rejected. Later, 'over-invention' could occur in the form of gadgets which were usually intended to add product attractiveness and used at times of stagnant sales.

Two revolutionary product inventions were made in the radio industry in its mature stage. One of these was the transistor and its subsequent solid-state developments. This had a marked effect upon the sale of radio receivers and an even greater one upon the Electronics industry. One reason for its large effect upon radio sales was that it combined a variety of consumer desires into a single unit so that its portability, robustness, cheapness and low current requirements made for a highly desirable form of receiver. The second revolutionary radio invention was F.M. which had only a marginal effect upon the radio market, being particularly slow to be adopted in Britain. These two examples point to the importance of consumer preferences as a major determinant of the market success of revolutionary inventions.

Economic and Consumer Influences Upon Design

Radio invention in the commercial years showed very clearly that designers had to take economic and other consumer influences into account. Product invention was shown to have been a major method of reducing the price of a product, this usually involved simplification of the design, the use of cheaper materials and the sacrifice of some of its technical performance. This aspect of product design was shown to be very important in receiver design.

Non-economic consumer influences also exerted a considerable impact upon product design making inventors create receivers which could be easily operated by unskilled listeners. New varieties of receiver, such as portables and car radios were produced to suit users' needs and in addition 'perfectionist' models were developed for hi-fi listeners.

Patenting

The broad pattern of radio patents agreed with that observed in the bicycle industry, and noticed in other industries. The peak was reached at the time when the greatest variety of inventions were being tried and thereafter the rate of patenting tailed off. As in the case of the bicycle, radio patents were overwhelmingly product inventions.

Process Inventions

The development of process technology in the radio industry accorded well with that seen in the bicycle industry. The initial production methods owed much to technological transfers from other related industries and early commercial production depended little upon specialised machinery. Once product design had stabilised and once competitive pressure had forced radio prices downwards, manufacturers began to search for low cost production methods. Many process inventions were the result of invention push and military requirements distorted the commercial picture to some extent. Other non-technological measures including standardisation and the use of cheaper labour in mechanised factories, as was the case in the bicycle industry. These process improvements were fused with product improvements to achieve the low cost models which formed the "backbone of the industry". A noteworthy endorsement of the bicycle industry's pattern was the mechanisation began in the Component sector and later spread to the final product.

Demand

The study of the radio industry's changes of output confirmed the importance of demand factors as a determinant of growth (and later decline). Here too it was seen that initial sales largely depended upon consumers' attitudes to a novel product. The later growth of home demand could be almost entirely explained by economic changes, the key features being changes in radio prices, the increase due to generally growing purchasing power and above all the 'trickling down' of new demand so that an ever increasing proportion of lower income groups, began to buy low cost receivers. One novel feature was the evidence for some new demand due to technological obsolescence. Once the home market had saturated growth ceased but, as in the case of the 1950s bicycle industry, a later increase in demand was created by a change to secondary uses, in the case of radio this was mainly the rise of portable, personal cheap transistor sets, although the high fidelity sector also experienced expansion at this time.

Invention And Growth

In general the broad pattern of invention and its distant relation to growth paralleled that observed in the bicycle industry and enhanced the concepts created there. This pattern showed that invention was most intense in the early commercial years of the new industry when inventors were concentrating on experimental designs, better technical performance and solving technical problems. This appeared to be achieved without much reference to demand and was more closely related to the age of industry. Growth of output (homesales) was much more sensitive to consumer linked macroeconomic changes than to supply side changes and social factors, competition from later new alternative products and market saturation had a more direct effect upon demand and therefore output. In the British radio receiver industry, as in the bicycle industry, invention was not directly and proportionally linked to growth.

The results from both these analyses will be used to create a general model of the process of technological change which depicts invention as a resultant or synthesis of three main factors: the inner logic of technological development, economic influences and non-economic consumer influences.

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6. CHAPTER SIX: THE MODEL

6.1 Introduction

The review of the literature on invention pointed to the importance of three factors - technology, economic and consumer influences upon product design. It was also noted that most innovation models and economic theories had been relatively unsatisfactory in dealing with the product invention and growth. Innovation researches have established that the technological development and growth of any new industry depended upon a complex variety of factors each having differing relative importance at different times and that simple ´linear´ models were generally unsatisfactory. The framework supplied by Utterback and Abernathy has been useful especially as it separated the varying forces which affected product and process invention although it was highly oriented towards modern innovations, internal and external organisational factors affecting the firm. However a modification has been made to Utterback and Abernathy´s framework to suit the analysis of an industry (rather than a firm) over its life-cycle and concentrate upon product invention and demand. Although each industry differs and each historical period is unique, a number of similarities have been found to have been shared by both the bicycle and radio receiver industries as they developed, grew and declined. The following model represents the broad pattern of development of these similar features.

This chapter will begin with a presentation of the model and will be followed by a comparison with Utterback and Abernathy´s original model with further general comments.

6.2 The Model

6.2.1 Product Invention

The time scale of most innovation models is based on some division of the commercial product life-cycle and incorporates the product life cycle concept of increasing output (sales) which grows to a peak then later declines.

In the model presented in this chapter an additional incubation stage has been added to the usual life-cycle to show the nature of product inventive activity in this pre-commercial period. This model will have three stages; an Incubation stage, a pre-commercial stage (in which only ideas and experiments are made but with no sales or production). The second stage is designated as the Early Growth stage (which covers the period from the commercial start of a new product industry to that time when a satisfactory basic product design had been developed). The Mature stage refers to the post-saturation phase in which declining sales usually induce incremental inventions to make marginal improvements and sometimes with revolutionary product inventions, which prolonged the product life-cycle.

6.2.2 Incubation Stage

Throughout this first incubation stage inventors were primarily concerned to transform an idea into a technically feasible working model. No production for consumers was undertaken and therefore economic and consumer influences had no real significance at this stage. Technology-push was a most important factor which operated in a characteristic pattern involving several sub-factors.

Technological Sub-Factors

Ideas and Concepts

New product invention began with the first conceptualisation or ideas about the proposed new product. How these ideas arose was never clear but inventors had a mental image of the product's function although they had no appreciation of necessary design requirements.

These ideas were often linked to concepts based on existing knowledge, scientific or engineering principles or technology transfers from technologically related fields. Concepts were very fluid at this stage and could be refined by discussion, published articles, or combined with existing knowledge, experimental results, new discoveries (including 'bonus' effects), and creative intuition (or insight). One consequence was that a wide variety of different designs were tried using different principles or techniques, some of which were 'ahead of their time' and only satisfactorily developed very much later.

In the case of the bicycle it was noted that such experimental efforts included trials of unicycles, tricycles, water-cycles and other configurations during the 1820s, while in the case of radio the early experimenters tried ground current, electrostatic and induction communication systems. The role of science was found to be minimal at this stage and empirical invention was important.
These incubation stage product inventions largely depended upon the efforts of a limited number of enthusiasts who appeared to have no great interest in economic gain or desires to solve social problems. Their chief desire was to demonstrate the technological feasibility of the idea and their exploratory inventions created new knowledge which often built upon the results of experiments.

Perception Of Success

Ultimately these incubation stage cumulative advances led to an awareness of imminent (or actual) success, as in the case of the bicycle in 1869 or radio (wireless telegraphy) in 1892. The pace of product invention rapidly increased at this time because many inventors were attracted to the field and experimented with variants of the basic design which promised success.

Once the successful demonstration had been made further inventions were affected by the product's market potential which was based on its inherent technical or market advantage over existing substitutes or equivalent products. From this time the inventors' scope narrowed to the method or a near equivalent to that of the demonstration model, and subsequent inventions were directed to improvements at either the Overall Configuration level or lower product levels in order to try and increase the product's technical performance.

6.2.3 Early Growth Stage

The main features of this stage were that product designs were affected by all the three main factors (technical, economic and consumer ones). Inventive activity reached its absolute peak in this early growth stage, mainly because of further explorations of promising new ideas or because of the commercial incentive to find other non-patented methods of achieving the same technological objective, or because of the additional economic and consumer design requirements.

Product invention lost much (but not all) of its empirical character and rational or scientific methods of enquiry were increasingly adopted. Product technology advanced over a broad range by a sequence of new models, each of which were rapidly improved and which rendered older designs obsolete. Towards the end of the early growth stage a basic design had emerged which was wholly satisfactory from the technical, economic and consumer aspects and 'robust' in the sense used by Gardiner and Rothwell (1985).
Then variants of this basic design were often developed for new uses such as message cycles or portable radios, or luxury models of superior technical performance or low cost models of technically inferior performance though of sufficient price-performance-quality to suit market needs.

Technological Sub-Factors In The Early Growth Stage

The first market product design was usually carried forward from the Incubation stage and immediately became the subject of a variety of improvement inventions which sought to better the product's technical performance and eliminate any problems which its use had revealed. Much of this trend of improvement could be explained by the concept of inner logic. Product invention occurred at all levels from overall configuration, functional sub-units, components, raw materials and external improvements. (Examples of external improvements were better roads for bicycles which effectively reduced bicycle vibration and wavelength re-allocation which effectively increased receiver selectivity).

Exploratory invention continued, often because of the technical promise some new idea or principle offered, though in practice some unexpected defect usually became evident.

In general product inventions to solve technical problems often required prior knowledge which came from investigations or scientific research to establish the reason for the problem and which led to new knowledge either because of new discoveries, unforseen effects ('bonus' and negative), or new technical developments. Quite often the results of these investigations or researches led to the ability to formulate a physical law of the functional relationship which provided the basis for a theoretically perfect design, though in practice this required further constructional improvement inventions to make it wholly satisfactory after which the design remained unchanged for many years.

It was in this early growth stage that scientific research made its biggest contribution to product design. Science was used main to elicit the theoretical relationships or the causes of problems, which, as noted, provided the new knowledge for a theoretically 'perfect' design. However scientific research itself was outspreading and brought further new knowledge which extended beyond the product industry. It was suggested that the concept of parallel-pull was a better description of the relationship between science and invention than science-push. The history of loudspeaker invention showed that the pure-science approach was not the most fruitful and 'insight' or inspiration was often added to research based knowledge to yield a major advance in product design or product performance.

Inner Logic Mechanism

These product inventions were directed along technically related links so that pressure was exerted to improve associated parts. These secondary improvements had various causes, some were secondary problems, others were: sustaining reactions, circularity and external influences. Each pressurised a continuance of the trend of improvement, so that a better design of amplifier created pressure for a better loudspeaker and detector unit. Another cause was 'reversal of principle' which led to the development of another technically related product (for example loudspeaker design was "reversed" to create the gramophone pick-up). Not only were each of the parts or sub-units improved but the product became perceived as a "whole" and each of the parts improved so that their performance was balanced, for example the bicycle became seen as 'bicycle-plus-rider' while the receiver was no longer a linear sequence of special sub-units but a meta-level entity, or, as in the case of the radio amplifier that its technical performance was optimised not just for adequate volume but for better performance in terms of a wide frequency range, good transient reproduction and an adequate dynamic range.

Trade-Off

Many product inventions encountered a trade-off criterion which required the designer to simultaneously satisfy two or more conflicting objectives; often these were purely technical objectives although they could involve economic and consumer factors.

The temporal course of product development involved a repeating sequence of introduction and subsequent improvement, of different models so that the temporal course of bicycle development was for the Hobby Horse to be introduced then improved and followed by the introduction of the Velocipede which in turn was improved and so on. This was a linear succession but the history of radio receiver types showed that a non-linear sequence could also occur.

Knowledge was carried forward to later models by internal technology transfer; external technology transfer also operated, for example rubber and aircraft technology contributed to improved bicycle performance. New knowledge continued to be generated by various means; scientific research, new problems, empirical inventions and accidental discoveries or precocious inventions and all became increasingly international in character.

Ultimately the rate of improvement of technical performance decreased as a satisfactory design and level of performance was reached; it was possible for even better perfectionist designs to be created but often these were too expensive or otherwise unsuitable and seldom became commercially successful.

Many inventions were made at this Early Growth stage in order to by-pass successful patents or to create novel or alternative designs and these led to the exploration of all possible methods of achieving a known goal. These by-pass inventions, together with inventions stimulated by promising new ideas for product inventions at all levels, largely accounted for the intense inventive activity at this stage.

The fundamental objective of all these technology-push inventions at this early growth stage was to improve the technical performance of the product in its first years and then for designers to satisfy consumer desires about cost and product appeal.

Economic Sub-Factors In The Early Growth Stage

Product invention was also affected by economic considerations during the Early Growth stage. This acted through various elements and had diverse effects. One effect was to produce a range of products (such as 1, 2, 3 and more valve receivers); another was to produce a range of products of differing cost, technical performance and quality (from low cost inferior models to expensive ones with superlative technical performance). This product range catered for a variety of consumers who had differing price-performance-quality criteria.

Economic product invention was used to simplify and cheapen the design using the various techniques of Value Engineering. Another economic element was the creation of New variants of a standard model (such as a message bicycle or portable radio) in order to increase sales. (There was evidence to suggest that this originated on the supply side rather than from demand pull in both the bicycle and radio receiver industries). Another economic element was to reduce running costs (as the dull emitter valve or mains powered radio set showed).

Cheaper models were the basis of mass markets which satisfied demand by lower income groups and was the major cause of growth of output at this early stage.

The intense inventive activity in this (early growth) stage of rising demand could have been due to profitability but it appeared to be due to the age of industry as evidence showed that many exploratory inventions were solely a response to technical promise. One illustration of this invention-without-demand was the prolonged efforts made to improve the Homodyne receiver. One illustration of the cessation of invention due to exhaustion of further advance was the decline of crystal set patents in 1927 when it was obvious that further improvements were unlikely. The potential for technological improvement was a powerful determinant of inventive activity at this early growth stage.

This suggests that inventive activity in any new product industry is primarily determined by technological opportunity and that inventors continue to invent until these opportunities are exhausted or a satisfactory design has been achieved regardless of economic conditions or the state of demand.

Product prices were not solely determined by product inventions; process inventions and associated non-technological changes made a big contribution as well.

Consumer Sub-Factors In The Early Growth Stage

The technological development of the bicycle and domestic radio receiver showed that consumer influences had a direct bearing on product invention. The radio provided some outstanding examples of the consumer-inventor link; the desire for an ´ideal´ set which was easy to operate even if this involved some loss of performance, another example was single knob tuning which entailed a series of quite complex inventions in order to make tuning a simple task for the consumer. Similar instances occurred in bicycle development, for example many of the pneumatic tyre inventions had ease of removal as their key objective so that consumers could repair a puncture without great difficulty. Other instances were not quite so clear, for example the trend to high fidelity in radio receivers was said to originate because consumers had become more discriminating but there was evidence of a considerable push from designers. In general consumer influences affected product design in order to simplify or ease operation but they also acted with reference to social forces; but consumer influence made its greatest impact in the later mature stage.

Demand Factors In The Early Growth Stage

The initial sales of new products depended greatly on public attitudes to the new product, its function and its novelty. Both the bicycle and to a greater extent the radio, were probably exceptional in the enthusiasm they created on their introduction to the market. Early growth appeared not to be too sensitive to price as manufacturers were not concerned to lower these very rapidly in the first years of the early growth stage. The prevalance of cheap radio receivers and the extent of home construction kits throws some doubt on this matter but it was clear from the history of both the bicycle and radio industries that a deliberate effort by manufacturers to reduce product prices did not take place until competition became intense; cheap imports, expired patent monopolies and declining sales appeared to be the principal causes in both industries. There was an indication that technological obsolescence increased demand at this at this early growth stage when product improvement was rapid. Once product prices were reduced the main source of growth came from 'trickling down' as the increased numbers of lower income groups were able to afford the product. This was not a uniform trend but fluctuated; one reason for this fluctuation appeared to be the influence of world prices on the general purchasing power of lower income groups. It was established that changes in product prices, earnings of manual groups, and net savings could almost wholly explain the growth of homesales. Thus growth of demand at this stage, can be regarded as almost entirely determined by economic forces: trickle down and market segmentation (expensive high performance designs and new models for new uses).

6.2.4 Mature Stage

Technology Sub-Factors In The Mature Stage

The chief characteristic of product invention at this stage was that it greatly declined in intensity and changed in style. The days of experiment and exploration were over and a fairly standard design had been created which was satisfactory in its technical, economic and consumer aspects and its general level of performance became well known. Technological possibilities were more or less exhausted as far as the basic design was concerned and further inventions were incremental, often being due technology transfers from other industries. Manufacturers were prone to use technology to introduce gimmicks especially at times of stagnant or falling sales.

At the same time many high performance and costly luxury models were created and sold at this time. These product designs appealed to affluent consumers who were said to demand peak performance and who were financially able to keep up to date with any further technical advances. This sector of high price-performance-quality involved a great many diverse designs usually supplied by specialist firms and often led to models which were said to reflect the ´golden age´ of the particular industry.

Product invention changed from a primary concern with technical performance to a secondary one of engineering design, in which the main concern was with detailed product improvements to achieve optimal product performance based on the application of now established engineering principles and also with improved reliability, serviceablity and routine aspects of "everyday engineering". These seldom involved originality in the way that pioneer inventions did. Product designs were refined and optimised using established knowledge and known principles at this stage. The basic technological product design remained the same for many years, although later in the mature stage this product technology could be re-designed for newer versions with secondary uses due to changes in consumers´ tastes. This was later upset by the introduction of a revolutionary new design of product which typically came from an "outsider" who had to manufacture and launch it himself as the main producers were reluctant to do so. These revolutionary new products seldom superseded the basic Mature stage product, but rather created new demand by further diversifying the market by segmentation.

Economic Sub-Factors In The Mature Stage

By the mature stage product prices had largely stabilised and product design had largely matured so that economic changes had little effect on long run product design but there was evidence that in short economic depressions manufacturers used product design to add sales appeal to their products. This often meant the addition of accessories and gimmicks. Economic influence upon product invention was "double-acting" in the sense that product invention intensified at both at times of rising and falling (or stagnant) sales. During the mature stage the real price of products remained remarkably constant at a low level so that stabilised product prices had little effect on sales (except the postwar "stop-go" effects which are not included in this model).

Another feature at this mature stage was the development of new variants of the mature model (such as the lightweight roadster bicycle or the portable radio receiver). These used the mature product design to create a new market sector and therefore promoted growth. Revolutionary product inventions could, as in the case of the transistor, have a huge effect upon the later market though generally revolutionary inventions had more limited market consequences.

Consumer Sub-Factors In The Mature Stage

By this mature stage consumer influences acted mainly through the market. The basic product design by this time was entirely satisfactory and in the saturated market the onus fell upon manufacturers to 'follow the market', in order to keep abreast of the changes in consumers' tastes. This led to an increasingly diversified product range with much emphasis upon high performance luxury models as well as cheap but satisfactory ones. Gimmick inventions and 'badge engineering' were frequent features for a while. Revolutionary new product inventions appeared at this time but these never completely captured the market and the earlier 'basic' design of the mature stage usually continued to sell in relatively large quantities.

Demand In The Mature Stage

By the mature stage the market had reached saturation point and the prospect of much lower levels of future home sales as only replacement demand had to be catered for and which was relatively immune to changes in either product prices or consumer-income related variables. Indeed after home market saturation had occurred, a new factor intervened, namely the availability of a substitute (in the case of the bicycle, a moped or cheap car; in the case of radio, television). These new substitute products curtailed demand for the old products but further old product invention revived homesales by altering the bicycle and radio receiver for new secondary uses. In the case of the bicycle this did not increase post 1960 sales to anything like the record levels of the 1930s and 1950s; in the case of transistor receivers it increased per capita ownership levels far above previous levels.

Varying Importance of Each Factor Over The Stages

The Technology factor was virtually the only one operating during the Incubation stage; during the Early Growth stage all three factors - Technology, Economic and Consumer - were operating and all were of about equal importance; in the Mature stage the Technology factor was of little importance, the Economic factor was quite important but the Consumer factor was of great importance. The varying importance of these factors is illustrated diagrammatically on the second graph.

6.2.5 Patents and Process Invention

Some general observations will now be made about process inventions and patents, based on the findings from the bicycle and radio industries.

Patents as an Index of Inventive Activity

The results of this study have supported the typical pattern of patenting for new product industries observed by Merton (1935) and others.

At the Incubation stage of this model, the number of patents granted was very small and sporadic until the perception of utility point was reached when a sudden surge occurred.

By the early growth stage of this model, the number of patents granted increased greatly, reaching a peak after which the annual numbers began to decline, but as patenting patterns for specific radio receivers showed inventive activity at the 'micro-level' was relatively independent of aggregate activity for aggregate radio patents. This micro-level patenting pattern appeared to be related to technological possibilities as once these were exhausted micro-level patenting ceased - the crystal set patents being a good example. During this stage the rate of increase of patents granted appeared to be related to the rate of improvement of technical performance (a multi-dimensional property) and in other stages they did not.

In the period corresponding to the mature stage of this model, the number of patents granted continued to decline and for certain sub-groups ceased altogether although patenting often continued at a very low level for an indefinite period.

The outstanding feature of patents granted for the two consumer products studied was that they were for product inventions; process patents for both industries appeared in other patent classes.

Process Inventions

The results of the study of the bicycle and domestic radio receiver suggests that some modification of Utterback & Abernathy's process model is needed when dealing with older industries.

The chief new features revealed were that many of the early processes were technological transfers from other, often technologically related, industries and that the switch to mechanised (rather than automated) production largely began at component level because of the high quantities involved. Many of these process changes were due to invention-push. These components rapidly become standardised designs and soon standardised production methods are developed to produce them.

Incubation Process Inventions

As no commercial production was undertaken in this period and manufacturing was limited to prototypes, Process invention was not involved.

Early Growth Stage Process Inventions

In both new industries studied the initial production began mainly with new small firms whose main concern appeared to be with functionally satisfactory models and price was not a major concern. These small producers used technological transfers to create production facilities and appeared to have encountered no great difficulty with this. These were usually technology transfers from other industries.

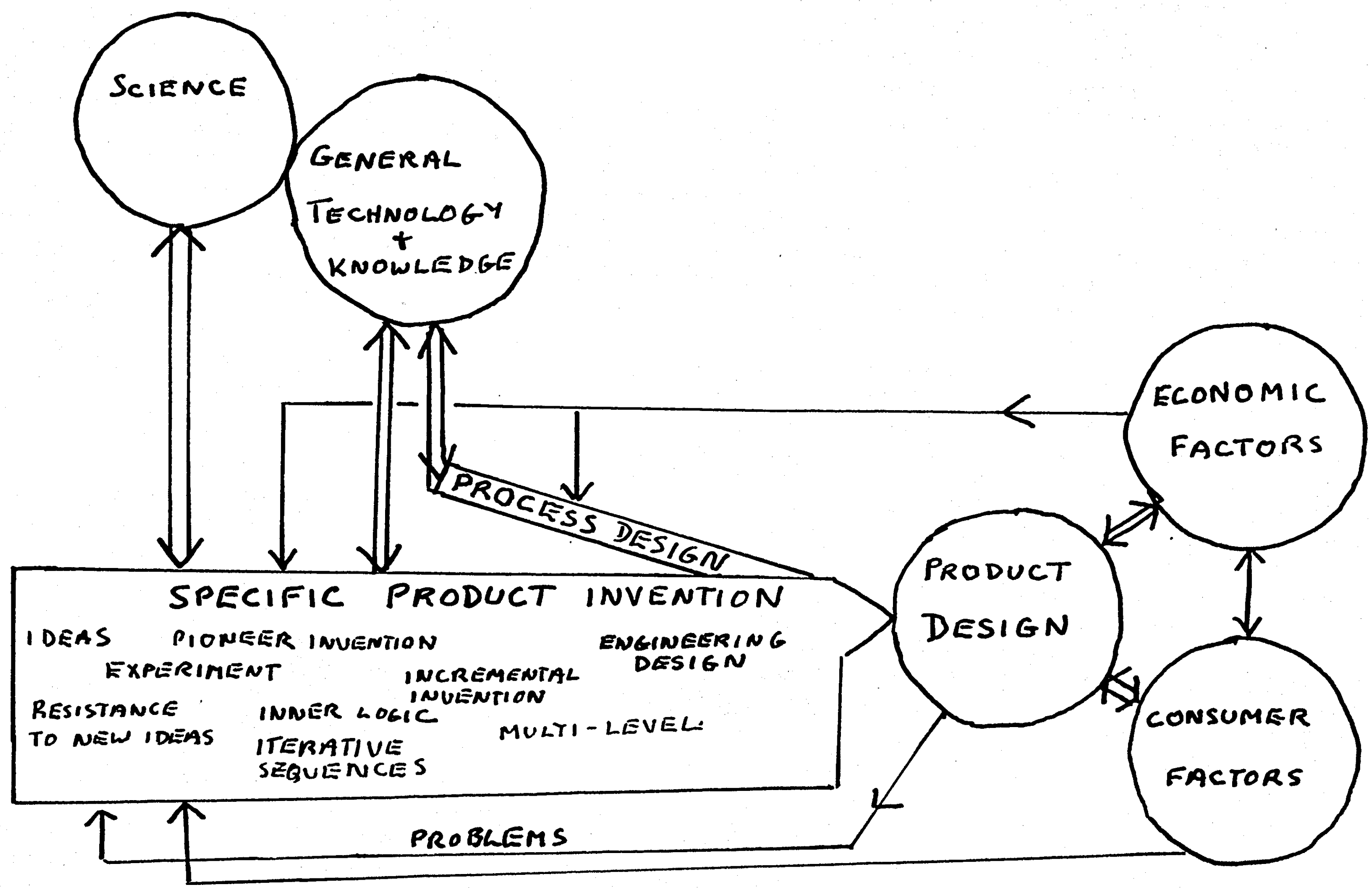
The first indication of real process invention which was specific to the industry involved came with the switch to mechanised production of components which itself often involved further technological transfer, standardised products, and reduced production costs. This change was inhibited by rapidly changing product design so that component producers waited until design stability and standardisation emerged.

Later in the early growth stage the final product manufacturers changed to a more mechanised production system using a great deal of technological transfer although some specific production techniques were developed. This was done in order to reduce prices and often to improve the quality and reliability of the product too. These new processes often owed as much to manufacturers' invention-push as manufacturers' responses to demand-pull, and frequently process invention was intense at times of falling sales.

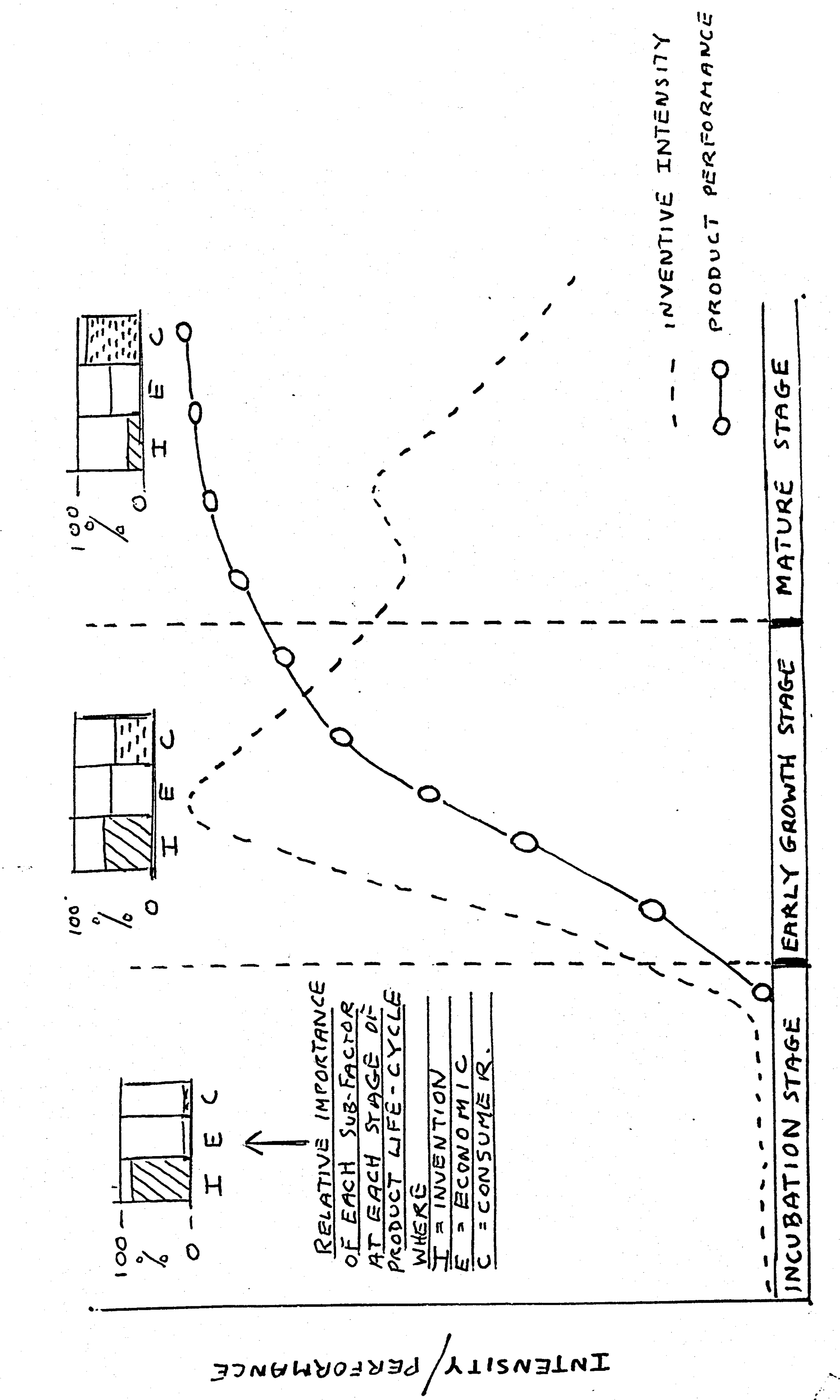
Mature Stage Process Inventions

The chief features of the Mature stage process inventions were that they catered for high volumes of output against a trend of levelling or declining growth of output, that is for a saturated market.
Typically the product prices remained fairly constant in real terms although an expansion of lower priced products sales came from cheaper, simpler models. The overall trend of production improvement also reached a practical limit and non-technological improvements became of increasing importance throughout the Mature stage covering not only production but marketing and sales arrangements too.

This model is now depicted in graphical form to show the inter-relationships among the factors and sub-factors; and, in the second graph, to illustrate the typical dynamic pattern over the life cycle of the industry and is followed by a summary in tabular form.



PRODUCT INVENTION - MAIN FACTORS



PRODUCT INVENTION + PERFORMANCE – DYNAMIC PATTERN

Model Factors and Sub-Factors

Technology Sub-factors	Economic Sub-factors	Consumer/Market Sub-factors
Incubation Stage		
Ideas	(none)	(none)
First Concept		
Creative Imagination		
Various methods		
experiments, trials		
New Knowledge		
Techno. Transfer		
Perception of Utility	Best Profit	Best Use
Narrower designs		
Early Growth Stage		
Inner Logic	Inc. Product Range	Novelty
Problem-induced	Cheaper designs	Consumer Desires
inventions.	Low buying cost	Ease of operation
By-pass inventions	Lower Running Costs	Automatic Controls
Exploratory designs	Simplify Design	Compact Designs
Wide Model Range	Low Cost Mat'ls	Better Performance
Multi-level	New Variants	Sales features
Science		
Eng. Trade-Off	Cost Trade-off	Price-Perform-Qual.
Techno.Transfers	Big Price Range	Many features
Basic design	Competitive Price	Known capability
Mature Stage		
Stabilised Design	Stabilised Prices	Establish perf.
Incremental inventions	Luxury Models	Perfect Perf.
Reliability	Competitive Prices	Marketing Appeal
Badge-Eng.	Competition	Consumers turn to
& gimmicks		new substitute products
Market-driven designs		Consumer desires supreme
Revolutionary	Limited Demand	Discriminating buyers
Model		Market niche

6.3 Comparison With Utterback & Abernathy's Model

The accounts of innovation studies mentioned in the literature review, showed that many researchers found it difficult to classify the causes of innovation or invention because of multiple causation. This was noted with particular reference to the innovation case histories given by Carter and Williams (1957,1959) and Langrish et al (1972); neither believing that simple linear models of innovation existed in reality. Other researchers had sought to create models based on simple principles such as technology-push or demand-pull but these had not been accepted without qualification. Utterback and Abernathy's framework offered a realistic way of depicting the salient features of innovation and change, although it was felt that some modifications were required in order to deal with older industries. The results of the analyses of the bicycle and radio industries suggest that some modifications to Utterback and Abernathy's model would be beneficial and these will now be discussed.

Utterback & Abernathy's Model

Utterback and Abernathy's model was fully described in the literature review; in the following summary only the salient features of the factors and pattern of their product and process changes will be given here. They employed a three stage model in which their first stage corresponded to the beginning of the Early Growth stage, their second stage corresponded to the latter half of the Early Growth stage and their mature stage corresponded roughly to the Mature stage of this model based on the bicycle and radio industries.

Utterback and Abernathy's Product Model

Utterback and Abernathy's overall pattern of product invention intensity for the whole three periods was in the form of a curve of exponential decay. In their first stage 'need stimulation' was the critical stimulus; in their second stage it was 'technology stimulation' and in their third stage it was 'cost stimulation'.

Product inventive activity and product performance decreased over the whole product life cycle. Product invention was intense in their first stage due to the need to maximise product performance and this was caused mainly by users' needs which generated many varieties of product design and many improvements (some of which were made by users themselves).[1] However Utterback and Abernathy recognised that science and advanced technology could also contribute to product invention though they did not think that this source was important at this stage.

Product invention in their second (sales maximising) stage was primarily affected by the firm's competitive strategy and resulted mainly in product differentiation. These product inventions were only adopted if they made a noticeable improvement to the product's performance and science-based (or advanced technology) designs were used only if they were going to be profitable, in effect only if they were going to be high sales models unless applied to difficult technical products. The general trend during this second stage was for high volume sales designs to be further improved and for the other products to be dropped.

Product invention in their third (cost minimising) stage was primarily affected by overall costs and overall returns. In this stage product design had largely been standardised and linked to process technology so that any large change in product design also required a compensating alteration in production equipment; product and process invention had become systemic. In addition the incremental product inventions were likely to involve costly science or advanced technology so that generally there was little incentive to make product design changes unless these were embodied in goods purchased from suppliers. Often revolutionary new products would appear in this third stage but these, Utterback and Abernathy said, were unlikely to produce high enough growth rates to offset the secular decline met in the later phases of this stage.

Utterback and Abernathy's Process Model

In the first stage Of Utterback and Abernathy's process model, production equipment was intentionally non-specialised so that the rapidly changing product designs did not involve costly equipment alterations and skilled flexible labour and general purpose machinery was used to produce the low

1 Reference had been made in the literature review to observations that many consumers of capital goods were technologically sophisticated and were able to make such modifications or developments.

volumes demanded.

In the second of their stages, the high volumes demanded made it economically worthwhile to change to expensive automated process equipment and hence process invention peaked at this stage and resulted in rapidly reducing production costs.

In the third stage of their process model the systemic product-process relationship inhibitted all but the most rewarding process changes because of the very high cost of changing the whole system and as a result production economies were more often achieved by organisational and non-technological changes.

The dynamic patterns given by Utterback and Abernathy for both product and process invention accord well with the patterns observed in the bicycle industry especially, but their explanations (causes or sub-factors) are quite different and these differences will now be discussed.

Product Differences

Utterback and Abernathy did not consider any pre-commercial product invention. The results of the study of the bicycle and radio industries indicate that important developments had taken place in the incubation stage. This aspect of invention has been previously noted by Gilfillan (1952, 1970) and Langrish et al (1972).

Utterback and Abernathy laid great stress upon the role of users as the main agents of product invention and did not regard invention-push (science and advanced technology) as a very powerful force. The results of the bicycle and radio industry analyses would not support that view at all and showed that invention-push and inner logic patterns were very important. Utterback and Abernathy did not suggest that product invention was an important element in product cost reduction.

They did observe the rapid product design changes and improvements in product performance but considered that the most successful product design was one which had the widest market whereas the evidence provided by the bicycle and radio industries indicated that the product with the best technical performance combined at the lowest price was likely to be the biggest seller. Utterback and Abernathy considered that the broad trend was to a reduction of product varieties whereas the evidence showed that manufacturers supplied an increasing range to suit various consumer preferences and various uses and that product diversification tended to increase as the industries matured.

The incremental and revolutionary product inventions of the Mature stage of this model do correspond to Utterback and Abernathy's pattern for their third stage although in the case of the radio industry the revolutionary inventions in their mature stage led to considerable later growth.
Utterback and Abernathy's 'users' needs' does not correspond to the consumer-inventor relationship found in bicycle and radio invention, but at least they have recognised that this form of feedback exists. In practice it has proved to be impossible to be dogmatic about demand-pull invention, as many instances occurred of the reverse. The greatest difference however is the low emphasis on technological push in Utterback and Abernathy's model.

Process Differences

In general the factors and patterns of process changes given in Utterback and Abernathy's model were an accurate reflection of events noted in the bicycle and radio industries. Two main differences were apparent; one was that the change to mechanisation first took place in component producing firms, largely because they were first to engage in high volume production of standardised products. The second main difference was that Utterback and Abernathy's process model implicitly equated product costs with the cost of production, and the evidence from the bicycle and radio industries showed that not only was product invention also a price reducing factor but that other elements entered into the product cost structure including materials and sometimes patent monopolies. Bicycle and radio receiver histories also showed that the returns to (process or product) invention reached some limit and that further invention or improvement was not justified, this feature is contained in Utterback and Abernathy's model, though without the idea that time (age of industry) is an important determinant of it.

Demand

Utterback and Abernathy did not deal with the factors affecting demand but implied by use of the product life cycle concept that maturity would be reached and then this would be followed by a decline. Most product life cycle models imply or state that the peak is reached because of saturation of the market and that later decline is due to the successful sales of a new, competing substitute product. The results of the study of the bicycle and radio industries show that this indeed occurred but that the decline was critically dependent upon the new substitute product (mopeds and cars in the case of the bicycle industry and television in the case of the radio industry) and this was the main cause of depressed sales in the mature stage. However both the bicycle and radio industries relatively increased post-saturation sales by changing their product to suit new secondary uses and consumer desires based and partly on revolutionary product inventions.

In general Utterback and Abernathy's model provides a most useful method of portraying the dynamic aspects of invention but it requires some modifications in terms of the causal sub-factors.

6.3.1 Invention and Growth

The results of the analyses of the bicycle and radio industries showed that there was no direct and linear association between invention and growth as so many had believed. Technical development was seen to be more or less independent of demand.

Demand, in the first years of the new industry, depended upon consumer attitudes to the new product's function and novelty appeal; after this increased demand (i.e. growth) depended very much upon consumers' economic circumstances especially their income and income-related purchasing power, to a considerable extent manufacturers recognised this by reducing their product prices although they continued to supply expensive high performance models showing that not all growth was due to trickle down. Then later, in the mature stage, secular product prices changed little but sales decline was countered as far as possible by diversifying the product range for new market segments. It was demand-related variables which determined the pattern of growth (and decline) and no evidence of a direct relationship between 'invention' (or improved product performance) and sales was evident in either

of the two industries examined.
The effects of specific (bicycle and radio) inventions were not confined to each respective industry so that again another factor intervened between invention and growth. The effect of product and process invention in the bicycle and radio industries also was not confined to these industries but was later transferred to other industries (and other countries).

It would have been desirable to quantify the relative contribution which product invention alone made to growth but this was not possible. Another question which could not be answered was that dealing with the relative quantitative importance of the three main product invention factors, although it appears that technical factor and its inner logic component was a most important one in the earliest commercial years of the new industry. After that both economic and consumer factors exerted increasing importance upon product design.

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7. CHAPTER SEVEN: THEORETICAL IMPLICATIONS OF RESULTS

7.1 Introduction

In this chapter the results of the study of the bicycle and radio receiver industries will be used to clarify some of the theoretical issues involved in invention and growth.

The review of the literature dealing with invention, engineering design, the patterns of technological development and the role of invention and technical progress in growth showed that many theories had been suggested, that diverse concepts existed, none of which had been particularly satisfactory. Whilst the results of the study of the bicycle and radio receiver industries are not sufficient to establish a definitive theory of invention or of invention and growth, there is enough information to permit a comparison of the actual events with the various theories.

The first section of this chapter will discuss product invention and its relation to theories of invention, engineering design and science.
The second section will be concerned with process invention and its relation to economic theories of growth incorporating technical progress.
The third section will deal with invention and demand and in the final section some general comments will be made about the role of invention in growth.

7.2 Discussion of Theories of Product Invention

The main task of any theory of invention is to explain the pattern of technological development with reference to inventors and the factors affecting invention. The variety of theories of invention, engineering design and technological development noted in the literature review can be classified into two groups; one group envisaged the act of invention as being primarily concerned with a single, usually pioneer, invention; while the other group dealt with a broader pattern of technological development as a temporal sequence of events in which the early inventions were regarded mainly as pioneer ones followed by later incremental inventions which were considered to make only marginal improvements.

7.2.1 Incremental and Pioneer Theories Of Invention

The majority of theories of pioneer invention attributed progress to heroic inventors who were presumed to be geniuses with exceptional mental abilities. The history of the bicycle and radio industries showed that indeed some of the inventions made were truly brilliant, novel and a 'breakthrough' in terms of technological advance but that for every pioneer invention there were at least ten incremental ones. The distinguishing feature of the pioneer inventions were that they significantly affected the course of technological development and usually initiated a new avenue or branch. It is more difficult to try and define the mental processes involved in the creation of pioneer inventions though it seems that ideas or new concepts are more important than with incremental inventions.

Ideas

Ideas, often unorthodox ideas, were the primary driving forces which led experimenters to think about and experiment with various devices even if they did not have a clear appreciation of the necessary design requirements. Inventive efforts ranged widely and even outlandish prototypes were tested as the bicycle and radio histories showed. Often the initial idea involved previous knowledge, principles or practice from other fields, for example the early "wire-less" experiments relied on electrical knowledge thus leading to Electrostatic and Induction designs. These explorations eventually led inventors to partial success in the form of a prototype which reduces the idea to practice and the principles were quickly appreciated and led others to attempt to improve these designs.

How or why these ideas arose was never clear. Ideas could be developed, or refined or expanded by discussion or publication. Ideas could also be opposed although the evidence suggested that this generally did not have any marked effect on pioneer inventors.

The role of ideas in invention is a complex matter which will not be fully discussed here. The best accounts of ideas and their contribution to progress have been given in studies of the philosophy of science and psychological theories of concept formation. Hertz (1956, originally 1893) had discussed this matter and considered that researchers created ´mental images´ (concepts) with reference to both prior knowledge and the aspects of the theory or problem which interested the researcher. The essential function of the concept was to allow the researcher to predict the likely outcome of an experiment. "We are enabled (by means of the image) to be in advance of the facts"; but Hertz went on to note that "various images of the same objects are possible" as scientists could have different concepts of the same facts or problem.

The importance of ideas and concepts in invention has been described by Fiske (1921) who said that both formed the basis of ´projective´ invention meaning that inventors clearly perceived their goal. Fiske considered that no invention could be greater than its conception (except by chance) and gave a comparison of Reis´s and Bell´s telephone inventions to demonstrate this. Reis´s telephone could only deal with periodic tones because of Reis´s original conception; Bell´s telephone was able to deal with speech because of Bell´s different original conception and, as could be demonstrated, Reis´s telephone could be changed to a speaking model simply by the alteration of a screw, an obvious alteration if the correct concept was known.

The evidence from the bicycle and radio receiver inventions showed that ideas did establish the inventors´ objectives, as in the case of the suspension wheel or negative feedback amplifier designs. Therefore any comprehensive theory of invention should take ideas into account.

Chance, Serendipity and Insight

Some theories of invention placed great emphasis on chance, creative intuition, precocious inventions and insight, all of which primarily refer to the sudden perception of new mental concepts or the 'bright idea'. The most popular of these theories of invention is the Gestalt one which places insight at its core. There was evidence in both the bicycle and radio receiver industries that such insights had occurred and that they were associated with important technological advances. The most common instances were the discovery of some unforeseen 'bonus' feature which became evident only from experience, although there were other instances where empirical (precocious) inventions were made 'ahead of theory'. How these new concepts arise is something of a mystery; they have not been logically deduced from established knowledge or previously observed facts. Mach (1896) noted that chance made its biggest contribution to invention when concepts or knowledge was fuzzy. These instances of chance or insight inventions were not frequent but underscored the importance of mental acts in the development of invention.

The Motives Of Inventors

The motives of inventors is another issue which is often included in heroic theories of invention. A number of researchers have found that 'love of inventing' is a very powerful motive, and that many inventors wish to develop technology 'for technology's sake'. Thring and Laithwaite (1977) considered that some inventors suffered from an obsession ('mono-mania') about their idea. Some firms also shared this enthusiasm for technological progress (and perhaps prestige); Jones and Marriott (1972) indicate that the designers at Metropolitan Vickers Ltd. were of this inclination. The analysis of loudspeaker development was only one instance where 'fanatical technicians' were more concerned about technological excellence than costs or profits. Thus the promise of economic reward is not always paramount and some recognition should be made of the importance of the attraction which technology has for inventors.

The controversy about the relative importance of either pioneer or incremental invention is something of a red herring as technological development involves both types; usually the pioneer inventions establish the new product or principle, while incremental inventions generally aim to improve upon the original design.

7.2.2 Temporal Sequence Of Technological Development

The second class of theories of invention and technological progress laid much greater stress on the pattern of technological development with its sequence of early pioneer inventions followed by later incremental inventions in any new product industry. This class of theory usually emphasised the importance of environmental factors as well as 'internal' ones and the most influential group of these theories employed the concepts of evolutionary theory.

Evolutionary theories are grounded on biological analogies which have recognised deficiencies when applied to physical models; one major criticism is that evolutionary theory provides no basis for the prediction of the kind of future changes. Nevertheless evolutionary concepts have been helpful by showing the nature of the temporal sequence of technological development and a number of associated features. The significant feature of this kind of theory was that early pioneer inventions were said to be due to 'genetic' (autonomous) causes while later incremental inventions were said to be 'adaptations' to environmental forces, especially economic ones. The results of the study of the bicycle and radio receiver largely confirmed the existence of an evolutionary sequence but showed that adaptations were mainly due to economic and consumer forces.

Decreasing Invention Over The Product-Life Cycle

An early observation that the rate of invention decreased as an industry matured, was made by Babbage (1833) who noted that technological development ultimately reached some satisfactory level after which subsequent invention ceased to be of much importance. This pattern was confirmed by later investigators especially Kuznets (1929, 1967), as noted in the literature review, and led to the concept of diminishing returns to invention and the life-cycle hypothesis of technological development.

The history of bicycle and radio technological development clearly confirmed this life-cycle concept and although product invention continued in both industries the majority of the later incremental inventions were often rejected either because they did not materially improve the product's technical performance or because these models were unsuccessful on the market. (Revolutionary inventions at this time could be technically and commercially successful). However it was found that the post-1900 bicycle and post-1938 superhet receiver had attained design maturity with little potential for fundamental improvement thereafter.

Wave-Like Sequence

The actual pattern of bicycle and radio receiver development has shown that the temporal sequence consisted of a wave-like succession of new models (or new sub-units or components etc.). A new design was introduced and subsequently improved only to be superseded by the introduction of a newer model which was also improved and which rendered the previous model obsolete. The bicycle industry showed that this could be an almost linear pattern of succession although the radio receiver industry revealed that a non-linear pattern could also exist. It was a cumulative sequence, rather as depicted by A. P. Usher's 'cumulative synthesis', in which earlier advances were often carried forward to later models because of modifications or combinations of new ideas or new inventions.

Patents and The Wave-Like Sequence

A further confirmation of the existence of the wave-like sequence of technological development was seen in the pattern of patent statistics for the bicycle industry and radio receiver classes.

A summary of the results of a study by Merton (1935) was given in the literature review and showed that for a particular product or aggregate patent class the temporal pattern was a rapid rise in numbers from about the commercial start of the new industry and for this to reach a peak, often with fluctuations and then decline quite quickly.

The results of the analyses of the bicycle and radio patents broadly confirmed Merton's pattern. However the trend of annual patents granted for sub-classes for some types radio receiver showed the wave-like sequence of temporal succession though with a rapid termination of inventive activity once further potential was considered to be exhausted or if that particular design had been superseded by later inventions. For example Crystal Set patents increased shortly after the commercial start of the industry, rose to a peak and thereafter declined to a very low level with only sporadic patents in subsequent years. The technical history of the Crystal Set showed that these models were the subject of much improvement up to 1927 but after that date inventors ceased their efforts because the technical limits had been reached and the design was seen to have lost its commercial value. Likewise the patents for F.M. receivers followed the same broad trend but started much later during the 1930s.

The reason for the peak patenting activity in the early commercial years was that many were exploratory inventions made at this time, because of the need to improve product performance at all levels (including sub-units, components and raw materials), and often to by-pass successful patented designs. Many of these exploratory designs were rendered obsolete once a basic standard model had been developed and future product inventions were much less intense. The pattern of patenting was loosely associated with the age of the industry.

Three additional points about British patents were noteworthy; one was that visual inspection revealed that these were product inventions and that process inventions for the bicycle and radio were included in other patent classes. The second point was that British patents granted included foreign bicycle and radio inventions from abroad and which pointed to the importance of international aspects of invention and technological development. The third point was that there appeared to be a fairly close association between the rate of patenting and the improvement in the technical performance of the product although technical performance was multi-dimensional and therefore these effects could not be easily measured.

However there were instances where inventions continued to be made even when the model was no longer in production or indeed had never been a commercial success; Sharp's air-sprung bicycle or the Homodyne receiver are two examples.

Patent statistics are therefore useful in the analysis of invention and show the pattern of inventive activity and the range of designs for a given industry.

Inner Logic Theory Of Evolutionary Invention

One of the most powerful modern versions of evolutionary invention theory is the inner logic concept in which the major cause of progress is considered to be due to technology-push or autonomous forces, which somehow cause one idea to lead to another, or for one solution to create pressure to solve a related or complementary problem. Rosenberg (1976) presented a modern version of this theory which, as noted in the literature review, was chiefly oriented to process inventions and had as its main trigger, problems or ´bottlenecks in production´. The history of bicycle and radio invention has shown that inner logic mechanisms are also very important in product design and that often problems stimulated product inventions. The pattern of progress was not only of sequential nature but involved an ´outspreading´ dimension at various levels of product design so that individual components, raw materials and even ´external´ improvements were made sequentially usually involving pioneer advances in the earliest stages, followed by incremental inventions in later stages to ´tidy up´ designs often adding accessories and finally for a concern with secondary performance features such as reliability or ease of servicing. This outspreading feature also included multi-dimensional improvements to product performance so that bicycles became lighter and more easily propelled, and radio receivers became more selective, more sensitive and with better reproduction.

The most difficult problem Inner Logic theories have to contend with is to explain how the process begins. Many consider that external forces initiate the inner logic sequence, for example Rosenberg (1976, chapter 6) showed that strikes, a sudden change in demand, a cut-off (as in wartime supplies), accidents and disasters or new legislation had triggered inventions. Others have also suggested that patent blocking was responsible for initiating the search but new inventions also sprang from new ideas.

Inter-Relatedness

It was also noted in the literature review that others (such as Ashton (1968) and Sayers (1950)) had observed that technological inter-relationships existed among industries and that inventive pressure travelled along these links so that inner logic induced invention in unexpected places. For example the early cotton industry induced chemical invention for bleaching and dyeing and also to some extent in steam engine design and power transmission systems. These links among different industries were noted in the case of the bicycle and radio, one example was the use of bicycle technology in the motor car and aircraft industries, while radio invention interacted with earlier electrical such as (wired) telegraphy, (wired) telephony, the gramophone and filament lamp technology.

Inter-relatedness also applied to the effects as bicycle and radio inventions were transferred to other industries and other products such as aircraft and electronics at a later date; indeed these transferred applications often had a much greater economic importance than the original product or industry so that the limited view of specific inventions affecting only specific industries is not correct.

Such inter-industry links could also be international and generally product invention became global as radio showed.

New Uses

Inter-relatedness was also connected with inventions for new uses for products. Frequently a new invention or principle turned out to have an unforseen new application which emerged ´sideways´ at a later date. The application of holography to information storage was a good example. Such new applications involve further sequence of product inventions as Bradbury, McCarthy & Suckling (1972) have shown.

Trade-Off

It was also noted that inventors frequently encountered technical problems which involved ´trade-off´, a need to provide solutions which had two or more conflicting requirements. These trade-off inventions often involved sophisticated designs, much ingenuity and elegant solutions to a degree seldom encountered in simpler inventions.

Meta-Level Invention

Another insight into the inner logic nature of product invention was given by the evidence of a change in concept. Dalton described how early radio receiver inventors primarily conceived a set as being a sequence of functional sub-units each of which were designed to give peak performance. Then about 1927 a new concept was created in which the whole receiver was seen as a total unit whose sub-units balanced or matched each other and the design criteria altered in accord with the holistic requirements. A similar change in design concept was seen in bicycle development when later designs considered the vehicle as a bicycle-plus-rider, and introduced what today would be called ergonomic design.

Automatic Control

Another feature of inner logic pressure, highlighted especially in radio receiver technology, was the trend to increased application of automatic controls. Some examples included the invention of automatic volume control circuits, automatic grid bias circuits automatic frequency circuits and other forms of feedback control circuits. All these inventions made the operation and adjustment of the receiver much easier for the consumer as well as improving its technical performance or reducing its running costs.

The pattern of bicycle and radio receiver product development therefore strongly supported the inner logic theory of technological progress and of the importance of invention-push forces alone, regardless of changes in the environment.

7.2.3 Historical Generality and Validity

The question of the generality and validity of this inner logic concept of product invention in consumer goods may be briefly illustrated by two references. One is an article by Gruenberg (1910), who considered that many similar inventions and discoveries were made in each epoch because of the common concepts which prevailed. He also stressed that similar problems led to similar solutions. The other reference deals with the early development of the motor car. Nicholson (1970) has etched the pattern of development of motor cars up to 1904 and is summarised here.

Nicholson began by noting that the earliest prototypes were steam cars as existing steam engines were the best form of power units. He then went on to show that product invention was patchy, owed much to the previous technological background of the car inventors and that invention was very much a matter of exploration.

"Technical changes --- came slowly and patchily and in great variety --- The designers were feeling their way in largely unknown territory. Their prior experience lay in different fields - horse carriage practice, steam, bicycle manufacturing, stationary engines for factories. They contended not only with new methods, but with new materials --- While general trends were in certain directions, experiment was the rule: this was a period of exploration in a new medium" (p.5).

Nicholson then noted the enormous variety of early motor car designs at both the overall configuration and sub-unit level. "Anything went --- three or four wheelers; gasoline, steam, electricity or combinations; air or water cooling or both" (p.5). Nicholson went on to describe the variety of suspension systems, driving arrangements (front or rear wheel), transmission systems (gears, shafts, chain, belts etc.), ignition systems (hot-tube, battery coil, magneto), types of internal combustion engines (two stroke or four stroke), engine arrangement (one to four cylinders, horizontal, vertical or vee), engine mounting (longitudinal or transverse) and types of tyres (solid or pneumatic). All these product inventions were essentially design explorations which were tested.

Nicholson then discussed the meta-level development by saying that although much of the inventors' effort was concentrated on improvements to specific parts, quite soon they turned their attention to the most satisfactory overall configuration which turned out to by Panhard's system with the engine placed in front and driving the rear wheels via a friction clutch and gear box. This became 'the basic layout of the conventional car for generations'. These developments were essentially empirical and those which performed best usually became most popular. However some pioneers, such as Lanchester, were ahead of their time and produced 'entirely original designs which owed nothing to engineering practice from other fields' but foreshadowed many later developments as the majority of car manufacturers developed their designs more slowly and consumers preferred less adventurous designs.

Nicholson also noted that two other factors had important influences on motor car design; one was demand, the other was the structure of the industry. Demand did not depend upon technical improvement alone but involved other diverse factors such as 'national character', economic conditions and competition from other forms of transport. Frequently the vested interests of competing transport systems had reduced demand, in Britain they had been responsible for much repressive car legislation. The structure of demand was also important, in Britain the early producers catered almost exclusively for high quality expensive cars while in America early car designs aimed to increase demand 'by providing low-priced simplicity' partly because of the very poor state of rural roads and partly because of the very long distances which American motorists travelled. Americans rapidly adopted mass production techniques in their automobile industry in order to stimulate demand, and demand appeared to be linked to the general rate of technological development. Both France and Germany had led in early product inventions.

The structure of the car industry also affected product design. In Britain early car producers were essentially small firms with low capital resources whose methods were 'leisurely' employing slow careful craftsmen working mainly with hand tools often to high standards of finish and low standards of accuracy and uniformity with consequent high prices which limited supply to expensive models. These car designs were 'often erroneous because of the prevalent ignorance of the art' and were generally copies of designs which originated in leading countries. Such small firms were unable to undertaken design and production of complex units and hence these were purchased from specialist suppliers.

These illustrations by Gruenberg and Nicholson endorse some of the inner logic and evolutionary theories of technological development and also give considerable support to the validity of the model of invention and technological development of the British bicycle and radio receiver industries.

7.2.4 Engineering Design

Although it has proved difficult to distinguish between invention and engineering design it was noted in the literature review that models of engineering design were largely representations of the activities of designers in a new product programme and that they included a broader range of factors and activities than theories of invention.

Models of engineering design largely followed the evolutionary schema with its distinction between pioneer and incremental invention. These models frequently saw the origin as 'a problem' and the succeeding activities as 'the solution' noting that at many stages designers faced choices. However engineering designers also took economic criteria into account in their product designs and more advanced models catered for such possibilities.
M. S. Gregory (1971), in his analysis of the design process has noted that in many cases the initial difficulty at the outset is to define the problem.

The results of the study of the bicycle and radio receiver showed that while much of the engineering design model was a fairly accurate representation, it omitted to include consumer influences upon product design, had little to say about the diversification of product ranges and the change in the mature stages of the industry to an increased concern with product reliability, ease of servicing and other secondary aspects of product design.

7.2.5 Science and Product Invention

It was noted in the literature review that a variety of relationships had been supposed to exist between science and invention. The most common one was of recent origin and supposed that new scientific discoveries provided the basis for subsequent inventions; 'science discovers, technology applies'. On the other hand some earlier views suggested that inventions themselves had been responsible for subsequent scientific research and theoretical advances.

Bicycle and radio receiver development indicated that both empirical and science-based inventions had been important but that the relationship between science and product invention was more complex than that depicted in the simple linear models. Science contributed to product design by the discovery or deduction of physical laws or new principles either by ideas, or research into the operation of devices or because of problem-centred investigations. The concept of Parallel-Pull was created to illustrate the essentially transient nature of the science-invention relationship which was concerned solely with the technological aspects of invention and performance. An inner logic inter-relatedness sequence of induced scientific analysis also existed and after potential benefits had been exhausted, scientists turned their attention to other fields. The major contribution which scientific research made was to provide the information for a theoretically perfect product design which was often further improved by empirical inventions or the application of engineering design principles.

It was only after the commercial introduction of broadcasting that radio receiver invention began to utilise science for further improvement. It was shown how loudspeaker problems had instigated scientific enquiry to elicit the principles upon which the device or circuit operated and how this provided an ideal design which was then tested and further improved by empirical invention. Consideration of the fundamental principles of operation were also used to make an early assessment of proposed designs (ideas) so that the inventors of Automatic Volume Control or Negative Feedback worked out their ideas ´on paper´ to begin with and then proceeded to test the invention. Science added to the stock of knowledge and this knowledge could be later refined.

These science-based product inventions usually proved to be lasting designs in the sense that they continued to be used for many years with little alteration.

7.2.6 Empirical Invention

Empirical invention was and remained important. It was noted that many historians regarded empirical invention as the main cause of technological development until the beginning of the twentieth century (or even later). However the implication of this concept is that empirical inventors did not use some kind of analysis or theoretical speculation or testing procedure to assist with their product designs. This was not the case. Bicycle development

was cited by Rosenberg as an example of nineteenth century empirical invention. Bicycle invention did not involve any pure science but there was evidence that a great deal of ´intellectual experimenting´ occurred through exchanges in magazines and discussion which frequently resulted in experimental tests of new ideas. The development of the Suspension wheel provided an example of this. In addition a great deal of truly trial and error bicycle invention did take place but nonetheless these intellectual experiments and subsequent tests can be regarded as a "scientific" approach so that the empirical invention was not as empirical as theorists depict.
Much radio invention was also due to trial and error as many of the problems were so complex (and knowledge limited) that the scientific approach could not be used and inventions were made without an understanding of the principles involved and ahead of scientific knowledge.
It was also noted that the majority of hi-fi loudspeaker inventions made from the mid-1930s owed more to ´inspiration´ than to straightforward deductions from scientific theory.

Science therefore has multiple causes and effects. Basic (pure) science has the creation of new knowledge as its primary objective and this is not done because of potential economic reward; applied science is concerned to advance technology and contributed to invention by providing the knowledge necessary for a better design but does so only to a limited degree, the initial design often stemming from an empirical invention.

7.2.7 Other Aspects Of Product Invention

Simultaneous and Equivalent Invention

One related topic in the literature on invention is the existence of Simultaneous or Equivalent inventions. These occur when a number of inventors, unaware of the efforts of the others, produce an identical or equivalent invention often at the same time as the others. Sahal (1981) has briefly noted some of the Chicago School literature on ´duplicate´ inventions. This was explained by them as being largely due to social influences but inner logic seems to provide a better explanation as the same principles or problems have led to the same or equivalent solutions. The results of a bicycle competition reported in 1979, showed that many independent proposals of a similar nature and of a similar design were submitted to the judges. The production of identical or equivalent inventions about the same time lends strong support to the idea that they are the results of internal stimulants and give evidence for the operation of inner logic. One example was the simultaneous thermionic valve oscillation/regeneration circuits of 1913.

Prediction Of Invention

The prediction of invention is another minor topic which is discussed in the literature. In the past this was largely a matter for imaginative writers such as Jules Verne or H. G. Wells. Jewkes et al (1969) examined the predictability of invention and concluded that specific inventions could not be predicted while the source and factors affecting general invention were so varied that it would be unlikely that their course could be predicted either. This belief is in sharp contrast to that of the Chicago School who considered that invention and the pattern of technological progress was fairly predictable. Since then Technological Forecasting has been more fully developed and uses a variety of techniques to attempt to predict invention or technical performance. The study of radio invention showed that predictions were made and were often quite accurate, for example Crookes's prediction of the achievement of wireless, its best use and tuning improvement; while the 1924 article on probable future radio problems and their solutions given in Pitman's Radio Yearbook that year were accurate. This suggests that the inner logic dimension of invention is considerable and can form the basis for partial prediction.

Classifications Of Technological Development

It was briefly noted in the literature review that various classifications of technological development had been proposed, none of which were very satisfactory.

One proposed classification was based on the intrinsic nature of the product design and employed a Simplicity-Complexity dimension. Various interpretations of this classification scheme had been suggested; one, embodied in most evolutionary theories of invention, was that the pattern of progress was from simplicity to complexity, the more complex designs being specialised ones. Another interpretation was that product design went through a Simplicity-Complexity cycle. The results of the analyses of the bicycle and radio receiver suggested that the trend was one of increasing complexity for basic models although design simplicity was used for cheaper lower performance models - an aspect which will be discussed in the later section dealing with the economic aspects of product design.

Another classification sought to distinguish between 'high' and 'low' technologies. Here again there are difficulties with the definition of terms; the bicycle in its early years would have been regarded as a high technology product and today the domestic radio receiver would be regarded as a low technology product. The underlying assumption of this kind of classification is that products (or industries) can be neatly classified as either high or low and that they are self-contained. The results of the analyses of both the bicycle and radio industries showed that many inventions for these products were transferred from older industries while many bicycle and radio inventions were transferred to newer products and industries. In practice it is difficult to predict such transfers which may well be from high-technology to low-technology industries or vice versa.

Uncertainty

One recurring theme in the literature of invention is the great uncertainty associated with it. Rosenberg (1959, 1976) has consistently noted this feature and considered that theories of invention should take it into account. Product invention involves much that is novel and creative efforts cannot be equated with routine activities. Creative efforts are inherently uncertain and many instances were found in the history of bicycle and radio invention in which ideas or inventions appeared 'plausible on paper' or 'could neither be proved nor disproved' except by experiment or test. The main consequence of this uncertainty is that a great deal of exploratory inventions are made and the historical descriptions of bicycle and radio receiver products showed that this occurred especially in the first commercial years of the new industry when knowledge was growing. Other consequences of this uncertainty have been described by Ravenshear (1908) who noted that only a small proportion of British patents were renewed for their full permissible life, and that most 'died' quite soon after the initial issue. Taussig (1915) considered that of all the thousands of patents issued for cotton production technology no more than 800 had ever been used. Therefore the 'coupling' between invention (patenting) and technological development is apparently very weak and indicates uncertainty.

However the analyses of the bicycle and radio industries revealed that quite frequently uncertainty also provided unexpected 'bonus' features of invention which had not been anticipated at the outset. Therefore the predominantly negative connotation surrounding uncertainty is not wholly correct.

Incremental Invention

A number of theorists still adhere to the Chicago School idea that incremental inventions are as important in the long run as pioneer ones. The history of bicycle and radio receiver development has shown that while incremental inventions do contribute to further improvements in the technical performance of a mature design, they make a greater contribution by diversifying that mature design in the form of superior and inferior models and new variant models. Such incremental inventions thus build upon pioneer ones which makes statements about the relative importance of either incremental or pioneer inventions questionable as the incremental inventions depend upon the pioneer ones. Technology builds upon technology regardless of the 'importance' of each of its constituent inventions.

Invention-Push

It has been shown that many features which form the core of separate theories of invention were manifest in the history of bicycle and radio invention but that no single narrow theory could satisfactorily account for their pattern of technological development. Most of these narrow theories were concerned only with invention-push factors but the analyses showed that non-technological factors also affected product designs and these will now be discussed.

7.2.8 Economic Influence Upon Product Invention

Economists have generally unable to fit product invention into their theories and have tended to ignore it. Innovation models, however, have highlighted the

importance of product invention as a means of creating new products or improving existing ones for commercial purposes.
The results of the study of the bicycle and radio receiver industries can shed further light on the relation between economic influences and product invention.

The first noteworthy feature was that the range of products created showed that consumers possessed Price-Performance-Quality criteria so that some consumers were prepared to pay much more for a high quality product giving superb technical performance, while others preferred a low cost product with an inferior technical performance. This meant that manufacturers had to produce a range of models to suit all consumers and in order to do so had to employ product invention to create the appropriate designs. The desire to create models with a superlative technical performance often involved lengthy and costly 'perfectionist' inventions and such models were often very complex. Although these superlative models were the subject of laudatory reviews in the technical press they did not appear to sell in anything like the quantities which ordinary models did. Very often the simpler, cheaper models formed the backbone of the mass market being of much greater economic value due to trickling down of demand by new lower income buyers.

It was also noted that product invention was a major tool in product price reduction. Product invention was employed to simplify the design, to use cheaper materials and components and less sophisticated sub-units and generally to employ product design techniques used in Value Analysis or Value Engineering. By these means considerable reductions could be made in product costs; this aspect of invention is largely ignored in economic models.

A third use of Product invention was to create new models for specialised purposes. This generally involved adaptations of the basic model, for example the design of message bicycles or portable radios. Export models often required this additional invention as well. Economic influences upon product invention are also directed to growth (as opposed to cost reduction), and for this reason cause inventors to produced new variants, which expanded new market sectors.

A fourth use of Product invention which stimulated demand was that which reduced the running costs of the product. Radio receivers were made cheaper to run by developing low consumption valves and altering the design to suit mains operation. Similar benefits can come from increased reliability which also involves product invention.

Demand-Led Invention

The results show that economic influences upon product invention and design were largely a response to the mature market especially and raises another controversial issue about the relative importance of ´technology-push´ and ´demand-pull´. It was noted in the literature review that no clear answer could be given to the question of the relative importance of either demand-pull or technology-push.

As far as the relation of invention to changes in the economic environment was concerned, the results of both the bicycle and radio receiver industries showed that product invention was also stimulated at times of stagnant or depressed sales and product alterations were made to add "sales" appeal, many of them involving substantial product invention. Product invention in times of economic depression or stagnant sales is general; Langrish et al (1972) cited the case of Plasticisers Ltd who needed a new product in order to counter the declining sales of their established lines. Langrish et al also illustrated how some new products had been developed because of prior market research and how the firm´s output had grown as a result. However Langrish et al expressed reservations about any simple and linear model of demand-pull invention because other factors were often involved and rejected the idea "that sophisticated market research is a sure-fire path to success across the whole spectrum of industrial innovative activity". (p.57).

Therefore economic forces have a "double-acting" influence in that they stimulate product invention in both boom and slump. This feature was noted in both the bicycle and radio industries.

These demand-pull inventions were often responses to short-term market (or business cycle) changes but demand-pull forces could also be induced by secular market changes. Langrish et al (1972), as noted in the literature review, devoted considerable attention to technology-push and demand-pull classification schemes and came to no firm conclusion about the relative importance of each. In one sense consumers take only what manufacturers supply (and it was noted in the literature review that consumers were not particularly imaginative or demanding about new inventions), while on the other hand there were numerous instances of technically satisfactory products failing to appeal to consumers and also of new designs continuing to attract inventions a yet were entirely without prospective sales - the Homodyne receiver was one example.

Economic influences therefore have a considerable effect upon various aspects of product invention and these should be included in any comprehensive theory of invention.

7.2.9 Consumer Influences On Product Invention

The review of the literature on the designer-consumer relationship showed that this issue remained a controversial one. Criticisms had been made of demand-pull concepts in innovation models which had, it was said, failed to show that innovation had been a response to demand and that no satisfactory evidence had been produced to show that invention had been responsive to demand forces. Yet market research and studies of the patterns of international trade had both indicated that ′non-price′ factors were important, and these included consumer perceptions of product design. The analyses of product inventions in the bicycle and radio receiver industries gave clear instances of designs being altered, often at the expense of technical performance, in order that the operation of these products could be made simpler for the consumer, or made to a higher technical specification for more discerning consumers, or even the provision of gimmicks simply because consumers wanted them. These changes often involved complex inventions.

The utility of a new or improved product depended upon the consumers′ attraction in the face of competition from alternative or substitute products and this affected the reception accorded to new products and new variations.

The previous section described the major difficulties of new varieties and how a technologically satisfactory new product or variant might be commercially unsuccessful. The obverse side of this can be seen when "the novelty wears off" and instances were noted of this decline in interest leading to further technical improvements, the gramophone pick-up attachment for radio was one example. The history of the bicycle industry showed clearly how a once popular product could obtain a "down-market" image for its utility form and then for a new leisure demand from the middle classes who demanded higher quality models and were prepared to pay more for them.

At a more specific level the history of radio receiver design showed how consumer influences affected product design. The desire for simpler tuning led ultimately to "single knob" control and this involved considerable product invention. This can be generalised to a construct in which the consumer desire for a product of easy operation leads to inventions to achieve this desire. The development of three (or multi-speed) bicycle gearing systems is one example, while Accessory invention is another. The consumer desire for greater reliability is also part of the same complex. These apparently simple consumer desires could lead to complex technical problems and solutions and though they tend to be second-order phenomena they nonetheless impinge upon product invention and product design. Factors affecting exports were not considered in the bicycle and radio receiver industries although it may be noted here that the Product Life Cycle Hypothesis by Vernon (1966) and subsequently developed by others, posits that a country which has led in the development of a new product or technology will have a world monopoly in exports until the importing countries catch up. The British bicycle industry would fit this concept but the British radio receiver would not.

7.2.10 Conclusion About Theories of Product Invention

This discussion of the theoretical aspects of product design has shown that many different theories have been suggested and that while no individual theory can be regarded as entirely satisfactory, each has broadly captured some facet of product invention contained in either bicycle or radio receiver design.

This points to the complex nature of product invention and the multiplicity of factors involved. It is suggested that the model presented in the previous chapter gives a better representation of the process of product invention and technological development.

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7.3 Process Invention and Economic Theories

This study did not concentrate on Process invention but the results of the brief examination of bicycle and radio receiver production improvements indicated that the pattern of process change conformed closely to Utterback and Abernathy's model. Some differences were noteworthy; one was that firms did not seem over concerned about product prices in the early commercial years of the new industries so that this may account for some of the delay in improving production efficiency. Another point was that the origin of the transition to mechanised production mainly began with the Component suppliers once the product design had stabilised and the quantities demanded reached a level sufficient to make it economically worthwhile to invest in capital equipment. Another feature was that the pattern of process performance appeared to reach a practical limit relatively soon after mechanisation occurred and that there was a tendency for long run Real Prices of the products to remain constant. The results of this study also showed that process technology was frequently transferred from older industries and to newer ones and were often international transfers.
Process invention shared much the same pattern as product invention and was stimulated by periods of economic depression as well as booms.

These observations can be usefully discussed in relation to economic theories of growth incorporating invention (technical progress). The following points are of especial interest; measurement problems, invention and product prices and the production function concept.

7.3.1 Measurement Difficulties

It was noted briefly in the literature review that considerable difficulty surrounded measures of economic growth. Leaving aside all problems connected with national accounting methods it was noted that a number of researchers had attempted to gain more accurate measures of the importance of new products in microeconomic growth and various unorthodox methods had been used by D. Usher (1980), Ironmonger (1972) and Pickering (1977). The general conclusion of each of these researchers was that new products were more important in growth than orthodox growth measures indicated. However these unorthodox measures shared a similar problem to that of Schumpeter's (or Schumpetarian) growth theory, namely that they omit the contribution which product invention makes to established (non-new) industries whose products have also been improved. Another related issue had been discussed by some innovation theorists which showed that process inventions could effectively be product inventions in another industry so that in practice it is not easy to maintain a distinction between product and process invention. The analyses of the bicycle and radio industries also showed that technology transfers were an important feature in technological development and this too of often ignored in orthodox models.

Another measurement difficulty which applies particularly to new industries is the accuracy of measures of output value when product prices are falling rapidly. Gustafson (1962) had drawn attention to this, showing that the annual values of output of a given industry would be distorted if its product prices were falling rapidly. This did not apply to any great extent in the bicycle and radio receiver industries (though it has done in more recent industries, the pocket calculator being one example), but what did become apparent in the bicycle and radio receiver industries was that the range of products increased as the industry matured with a greater spread of product prices even although the average product prices fell relatively slowly and by small amounts.

While no complete solutions can be offered to overcome all the problems about the measurement of invention or the value of total output of any industry, it is suggested that the most sensitive measure of the effects of product and process invention can only be obtained at the disaggregated (microeconomic) level.

7.3.2 Process Invention and Product Price Trends

One major assumption contained in all economic theories of invention and growth is that invention has a prime aim to reduce the costs of production and that it does so linearly and proportionately upon the factors of production (labour and capital). If labour becomes relatively dearer than capital, then labour-saving inventions will result. This concept assumes that costs of production will fall as (process) invention continues.

The product price trends in the bicycle and radio industries show that during the first commercial years (in the Early Growth stage) manufacturers did not appear to be unduly concerned about low product prices, but once the industry became either competitive or were threatened by lower priced imports, manufacturers made a decided effort towards lowering prices. This was achieved by a combination of product invention, process invention and non-technological changes which usually caused a relatively rapid product price fall. After this transition period the Real prices remained remarkably constant.

Invention can reduce prices in many ways; Brassey (1873) in his chapter (five) which was concerned with the relation between invention and labour costs, gave some interesting early examples and observations of cost-cutting inventions. Brassey noted that in France the high costs of coal made French railway designers consider these fuel costs and "that before the drawings of any piece of machinery were completed, the question of the quantity of fuel necessary to be used in producing it was a consideration, and frequently the form or the method of construction originally proposed, underwent an entire modification, with a view to economize coal" (p.132). Brassey also noted that American railway engineers considered raw material costs as well as labour costs, and had reduced both by developing very strong cast iron wheels for railway locomotives and carriages and noted that these techniques had spread to other industries so that they made cast iron rainwater pipes scarcely one eighth of an inch thick whereas British ones were five times as thick. The

Americans used a great of wood because it was cheaper than metal and for this reason were able to produce cheap goods and they led in the design and use of automatic woodworking machinery. Brassey then had shown how product prices could be lowered by product design to economise on raw material and fuel costs in addition to his other observations about traditional labour-saving effects of (process) inventions.

However by the mature stage, product and process inventions had become inter-related, or to use Utterback and Abernathy's term - 'systemic' - so that it is not possible to quantify the independent contribution which each type of invention made.

Gold (1973), as noted in the literature review, was not able to adequately explain why prices remained constant while productivity continued to rise. He thought that the primary problem lay in the theoretical concepts and that the limitation of input factors to 'capital' and 'labour' excluded others which were equally or more important in terms of costs, he cited Materials and Energy as two examples. Rosenberg (1976, chapter 11) also dealt with this topic and quoted Enos's finding that price falls due to new refining inventions were most marked a few years after the innovation. Rosenberg also cited North's finding that long run changes in shipping costs were hardly affected by inventions but that non-technological factors were of greater importance. Rosenberg concluded that price falls were not all due to technological change and other factors such as economies of scale, plant utilisation levels, learning by doing, improved 'quality' of inputs (especially improved labour 'quality' due to better education and training), better organisation and better marketing were very important too. Thus the effects of invention were joined to non-technological improvements one of the most widely quoted being the 'learning' (or experience) curve which has empirically established that if the quantity of production is doubled then the unit cost is reduced by about 25%. Satterthwaite (1980), in an examination of integrated circuit prices in America during the 1960s found that they indeed broadly conformed to the learning curve but that the real price reductions ultimately ceased.

What Does Process Invention In The Mature Stage Do ?

This relative constancy of real prices in the Mature stage of an industry raises the question of the effects of economic effects of invention at that stage. Harlow (1977) in his study of the relation between innovation and productivity growth in five British nationalised industries has provided an insight into the matter. One great benefit of nationalised industries is that annual data are available to a degree which is seldom met with in the private sector. Harlow's prime objective was to enquire into the causes and effects of technological change in the British Electricity, Gas, Telephone, Coal and Airline industries. Some of the inventions involved were Product ones, as for example improved aircraft, some were product inventions which had process effects such as new telephone switchgear, and some were wholly Process inventions as in the Gas industry. Some of these inventions were created within the nationalised industries themselves and some came from outside suppliers.

Harlow found that Cost Reduction was the most important immediate cause of technological change in these nationalised industries and especially a rise in the cost of input factors. However Harlow found no consistent trend in the movement of capital and labour costs and that rises in Materials costs were often far more important in stimulating change. The evidence obtained did not support the Classical view that labour productivity was increased by Factor Substitution or that factor substitution was a main cause of productivity growth. Harlow felt that the explanation of factor productivity changes involved Scale Economies, Technological Change and to a lesser extent Factor Substitution and that some degree of inter-relationship existed among these three although technological change was most important because it changed techniques.

Harlow concluded that "it would (be) misleading to suggest that relative changes in the prices of input factors are a sufficient condition for the introduction of new techniques to an industry. In the industries studied here, although cost control was the objective of the programme of innovation, demand conditions were more influential in bringing about the introduction of new techniques into the capital equipment." (p.240). (A discussion of Demand and Growth will be given in a later section of this chapter).

7.3.3 The Production Function Concept

Rosenberg (1976, chapter 4) has noted that the production function concept is the basic analytical apparatus of production theory and specifies in a rigorous way the relationship between inputs and outputs. Rosenberg considered that this concept had been useful in addressing certain kinds of problem but that it was poorly suited to the study of technical change, and had in many respects served to obscure rather than illuminate the process of technological innovation.

The production function concept distinguished between two types of change, factor substitution and technical progress.

Factor substitution was conceived as a movement along the production function curve in response to changes in factor prices and generally involved a substitution of capital for labour. This substitution, Rosenberg said, was generally presumed not to involve technological change and he considered that a great deal of technological change was involved in substitution.

The second type of Production Function concept was the "outward shift" of the production function curve, which, it is generally assumed, gives a measure of Technical Progress (process invention) and indicates the growth not due to increases in input factors. Rosenberg felt that technological change "entered the economy through many doors" and that the twofold distinction between Substitution and Technical Progress overlooked much of the day to day cumulative technological changes which took place and that the Technical Progress 'outward shift' concept was better suited to Basic (pioneer) innovations which affected a wide range of technologies and tended to ignore the specific incremental innovations of a particular industry.

One weakness, shown by the results of econometric analyses, is that only very weak statistical explanations are produced by the specified inputs to production function equations. Another weakness of the production function concept is that it does not give a clear picture of the dynamic pattern of change. The description of the change in bicycle manufacturing methods showed why mechanised production techniques led to cheaper products than could be obtained by hand production methods. Two key factors prompted the change to mechanised methods of production. One was increased demand, the other was competitive product pricing. Both led to efforts to reduce manufacturing costs, and the description of the change to mechanised bicycle production showed how the use of expensive machinery ensured that its associated capital costs were spread over the larger quantities produced so that unit capital costs were small and the mechanical methods produced bicycles and bicycle components much more quickly than using hand methods, for example a press tool took only seconds to make a part which could take a man hours. The result was that the prices of products and component parts were reduced and that this sequence of improvements continued for a number of years but in due course process technology reached a satisfactory level after which only marginal process improvements were made (and indeed could be rejected as the post-1945 British bicycle industry showed).

It was found that non-technological process improvements to reduce product prices became more important in the later years of the mature stage; this aspect accorded well with Utterback and Abernathy's model, and indeed with Classical theories of production which detailed the inter-related effects of process invention and non-technological improvements such as better organisation or economies of scale. The importance of process (and product) invention is not so much that it leads to direct economies of production but that it makes possible the later inter-related economies, which, in their turn, reach some satisfactory or practical limit after which there is little change.

However this implies that all process invention was economically induced but, as the development of the printed circuit board or other similar methods of receiver assembly showed, process invention-push also occurred.

The production function concept does not take this complex pattern of process invention and non-technological changes into account, and of course omits any cost reduction due to product invention.

One minor point remains; it concerns the validity of the Residual as a measure of technological change. It was noted in the literature review that Matthews

(1964) had given instances where a negative value has been obtained and Wragg and Robertson (1978) similarly found negative residual values as well for some modern British industries. Wragg and Robertson explained that this occurred when the output of these industries had fallen rapidly while there had been a lag in the reduction of the inputs and that the negative value came about because of this relationship. However it is generally the case that technical performance is ever rising, at a decreasing rate, up to some limit, so that the Residual is not a good measure of the effects of process inventions and non-technological changes (technical progress).

These observations about the production function concept suggest that a more suitable way should be found in order to assess the effects of invention which would include product invention as well.

7.3.4 Process Invention And Demand

However changes in demand also controlled process invention and Harlow (1977) has described this in detail with reference to modern British nationalised industries. Harlow showed that the extent of demand primarily determined whether or not it would be economic to invest in expensive new plant or new products and that consideration of factor costs was much less relevant.

Harlow (1977) considered that "the growth of demand must be regarded as the predominant cause of the introduction of factor saving techniques" (p.241). He described how increased demand alone made the changes to new products or techniques economical. For example BEA could not have introduced larger aircraft unless they were certain that there would be sufficient demand to make them pay; again it was the greatly increased demand for electricity which made it possible to create more advanced generators and distribution systems yet keep unit costs low. Similarly the modernisation of the telephone system depended upon a rapid rate of growth of demand so that the need to find a new technique to supersede the Strowger equipment became an urgent matter. The obverse side of this was seen in industries which had experienced either periods of no growth or declining demand; the gas industry stagnated between 1949 and 1960 and although experiments were conducted on new gas processes, these were not installed as there would be insufficient return on the investment due to a lack of demand but after 1960 when gas demand increased many new processes were developed and installed. The coal industry was exceptional in that demand remained static or fell over the thirty years Harlow considered that this made it less likely that new equipment, embodying the latest technology, would be installed.

Harlow's account reveals that process invention is only adopted when the economic circumstances are suitable and implies that in times of economic hardship an industry will be less likely to adopt new technology.

A very clear implication arising from the results was that invention acts as a trigger which brings later non-technological economies into effect. This compound sequence begins with product invention (which creates the new product and the new industry), which is then followed by new process inventions which in turn are followed by various non-technological process improvements to give associated 'learning curve' cost reductions which continue until the market saturates, thereafter only minor changes occur to real product prices.

Production function concepts should be altered to take these sequences into account – or perhaps be abandoned altogether.

7.4 Product Invention And Demand

The basic assumption in most economic theories of growth is that invention is a direct cause of growth and acts in a linear and proportional way. This is clearly seen in Emerson's 'better mousetrap' argument where invention is said to improve product performance and hence create additional demand. In reality product performance improvements were difficult for technically trained persons to measure let alone unsophisticated consumers though by a combination of consumer education and experience the benefits were eventually appreciated as the commercial history of the superhet showed. Nevertheless the key question can be posed: "Did sales grow fastest at times of most rapid improvement in product performance."?
The answer is not entirely clean cut; the 1890s bicycle boom was partly due to

the development of the better Modern Safety design but the later, much greater increase in bicycle sales, in the period 1930 to 1950, owed nothing to improved bicycle performance but was due to demand-side changes. Similarly the period of greatest increase in homesales of radios took place in the years 1929 to 1932, if the rate of annual change of the number of receiving licences is accepted as the most accurate index of consumer use, when receiver performance was slowing down and consumer purchasing power was rising. The sluggish consumer acceptance of F.M. in the 1950s was another illustration that demand was not determined mainly by technical performance. Yet modern market research has shown that consumers tend to 'trade up' when their economic circumstances (either in terms of increased income or falling product prices) permit them to buy more product 'performance' for the same outlay. This again illustrates that consumers use a composite criterion; price-performance-quality, when purchasing products.

Another finding which emerged from the bicycle and radio receiver industries was that in the post-saturation period of the mature stage, product invention could curtail demand because it had created new substitute products which consumers preferred. In the case of the bicycle industry, consumers were attracted to mopeds (initially pedal cycles with 'clip-on' engines) but by the mid-1950s these mopeds had developed into competing products. About the same time the British (and European) motor car manufacturers used product design to create 'bubble cars' which were intended to attract lower income consumers. These bubble cars were not particularly well designed and consumers preferred the new cheap but economical models such as the Austin A30 and the Standard Eight as well as the Morris Minor and the rapid growth of demand for these was accompanied by the decline of the bicycle as a utility vehicle and the change to leisure cycling. The 'wireless' experienced similar competition; initially this came from television which grew rapidly during the 1950s while demand for radio receivers declined. However, bicycle and radio manufacturers were forced to use product inventions to offset the decline in demand, and these updated and revolutionary new models have already been described.

Jome (1929) has commented upon the long run effects of new product inventions. He noted that any new product industry eventually had to contend with ´opposites and complementaries´; for example the wired telegraphy industry had to contend first with the telephone then with radio telegraphy; gas lighting had to contend with paraffin then electric lighting, the gramophone and home entertainment (musical instrument) industries had to contend with the introduction of radio broadcasting which also affected public entertainment industries; the introduction of the automobile affected public transport industries. In all these cases, Jome said, the pattern was one of initial displacement followed by a settled market in which the new product established a market niche which depended upon its most suitable market application and that the total service provided by the cluster of competing products was greater than before the new product had been introduced. Jome concluded that product invention, in spite of displacement at the introductory phase, contributed to growth. As the bicycle and radio receiver industries show, the net effects can be variable; later bicycle sales have never reached the pre-1950 peaks, while radio receiver demand has more than doubled. Product invention can thus curtail demand for a given industry by creating a new competing product although it generally prolongs the original industry life-cycle.

The implication of these findings is that technological growth theories should include these changes as well.

7.5 Role of Invention In Growth

Most economic growth theories concentrate upon changes to supply-side variables but the results of the bicycle and radio industries showed that demand-side factors had a profound influence upon changes of output in each industry. The analyses classified these according to a variation of Katona´s two factor theory involving the economic ´ability to buy´ factor and the socio-pyschological ´willingness to buy´ factor.

Economic Factors

One main source of growth was the ´trickling down´ of new demand to lower income groups. Although this was partly due to product price reductions it was shown that changes in income-related variables were much more important in creating the new ability to buy. In the period up to 1939, when homesales of both bicycles and radio receivers grew most rapidly and reached saturation point, changes to income-related variables for lower income groups together with product price changes largely explained (in the statistical sense) the growth of homesales to this point. It was noted in the case of the bicycle that the average real price of British bicycles had not changed very much in the years of most rapid increases in demand and that changes to income-related variables were much more important. In the case of British radio receivers the rapid growth of demand partly coincided with a period of rapid product price reductions but that changes to income-related variables were still very important. Growth then is vitally dependent upon changes to income-related variables.

Income-Related Variables

The review of pertinent literature suggested that consumer durable purchases were associated to some degree not only with increased earnings but with savings too and this led to the inclusion of real net savings per depositor. When Net Savings were combined with earnings and product price changes a very high coefficient of determination was obtained. The net savings figure was taken to represent the additional purchasing power (discretionary income) which low income groups especially obtained because of the changes in either the terms of trade or movements in world prices. A full discussion of this complex issue would involve monetary theories and will not be undertaken here. Matthews et al (1982) have discussed this aspect of British demand and the factors which which affected general price changes in the period 1856 to 1973. In their chapter 10 they noted that during the interwar period, changes in world prices had a major impact upon British domestic prices. In chapter 14 they extended their analysis of the cause of general domestic price movements and noted that during the interwar period the Terms of Trade were exceptionally favourable reaching a level which was not attained either before or after that time. Thus British consumers, especially the lower income groups, benefitted from lower food and product prices which allowed them to save more and spend more - especially on consumer durables. Brassey (1873) noted a similar feature in Britain for the period 1849-1869 when the cost of ′the necessaries of life′ (especially food) had contributed to a higher standard of living (together with increased wages and cheaper products due to invention). Brassey attributed the fall in costs to the "enlightened policy of Free Trade --- and the improved communications by both sea and land" (p.163).

This source of effective increase in purchasing power is not often considered though its magnitude was apparently exceptional in Britain during the 1930s, a time when homesales of bicycles, radios rose rapidly. The very rapid growth in the ´great depression´ years 1930-1932 was surprising; one possible explanation was that both the bicycle and radio receiver were ´inferior´ goods as Landes (1969) had suggested. On the other hand it could be said, as Richardson (1967) and others had; that the British economy in the 1930s was filled with paradoxes. However reference to aggregate annual consumers expenditure upon consumer durable goods[1] showed that this had risen continuously in those depression years so that the bicycle and radio industries had shared in the general growth. References were quoted in the literature review to show how lower income groups had especially gained from the reduction in world prices and hence their new found ability to buy consumer durables.

The post-1945 home market for bicycles and radios was essentially a post-saturation one in which changes in income and income-related variables bore no relation to home demand as profound changes had occurred in the ´willingness to buy´ factor, which will be discussed below.

The essential feature is that growth can adequately be explained with reference to consumers´ ability to buy up to the market saturation point and thereafter the trend of demand bears no relationship to consumers´ economic ability to buy. Although the amount of this effective increase in purchasing power was small it made an enormous difference to lower income groups and, as PEP (1945) noted, lower income households in the 1930s had very little to spare for the purchase of consumer durables, so that the small increase led to large numbers of new buyers.

[1] Given in The British Economy: Key Statistics 1900-1970 (n.d. c1974)

Product Price Changes

A characteristic average price curve for both the bicycle and radio receiver which accorded with the pattern found by others; namely that real product prices fell sharply a little after the commercial start of the industry to some low level after which they stabilised.

This means that in the Mature stage of most industries, when real product prices remain relatively constant, the changes in demand (homesales) are much more sensitive to changes in macroeconomic variables -such as world prices or the terms of trade - than to changes in product prices; and as the possibilities of manufacturers to make further product price reductions is very limited (because technological opportunities have been exhausted), there is very little that the manufacturer can do to create demand by process invention and other price reduction measures but manufacturers do use market-driven product invention to add sales appeal to their products in the later years of the industry life-cycle.

This non-linear price trend also provides a reason for the lack of any long run correlation between invention and growth and the evidence from the bicycle and radio receiver industries showed that the greatest growth occurred after product and process technological developments had matured and that the main cause of this growth lay on the demand-side, not invention.

7.5.1 Consumer Demand Factors

Consumer demand factors have long been recognised as difficult to define and often impossible to quantify yet they have important influences upon demand. One very important factor at the commercial start of any new industry is the novelty appeal of the new product and both the bicycle and radio were exceptional as these products had world wide appeal and consequent rapid acceptance by consumers, though as Maizels (1965) had shown, the very rapid market penetration of radio receivers was exceptionally fast.

This dimension of demand can change and it was found that novelty soon gave way to a more discriminating consumer who demanded better quality or performance from the product and lower first and running costs as well. The influence of this change upon invention was indicated. Once the saturation point is reached, consumers can reverse their regard for the product and in a sense turn against it. This was seen in the down-market image adults had for bicycles in the 1950s and also about the same time they tended to regard "steam" radio as old fashioned and not status enhancing. All these non-economic demand factors may be linked with economic ones but the implication of these findings is that theories of demand should not include a linear and ever rising trend term to represent changes in consumers' preferences as these can change from positive to negative.

Conclusion

The primary aim of this whole research was to obtain a fuller understanding of the factors affecting technological development and its life-cycle pattern and to attempt to assess the economic effects of product invention and design. In addition a number of associated topics were examined including the relationship between science and product design, the relative importance of pioneer and incremental inventions, the role of consumer influence upon design and the complexity of the whole design process. Some elaboration of this last topic may fittingly form the substance of this conclusion.
The findings and the theoretical discussion given in this chapter have shown that although there have been many different theories no single factor or single sets of particular factors associated with any one theory have been sufficient to give a satisfactory explanation of the trends of development and growth.

It is tempting to paraphrase Galbraith (1965, originally 1956)[2] and say, bluntly, that all the simple concepts of invention (and invention and growth) have been tested and found unpersuasive. To say this would merely repeat the many expressions about the complexities which have been observed to underlie invention, innovation and invention-and-growth. Numerous references were made to these in the literature review. Jewkes et al (1969) as early as the 1950s,

2 "Most of the cheap and simple inventions have, to put it bluntly and unpersuasively, been made" (p.86).

drew attention to the to the complexity of the subject and it is fitting to finish with a brief extract from their concluding comments which were more fully quoted in the literature review. "The interactions between science, technology and economic growth are much more complicated than was ever imagined --- Our main conclusion is, therefore, a simple one, that the path of invention is always thorny, that there are no short cuts to success, no infallible formulae".

Yet the assertion that the topic is complex adds nothing to understanding. The model, presented in the previous chapter, goes some way towards isolating the various factors, showing the temporal patterns of change and generally depicting how invention responds to technological, economic, and non-economic demand factors which can be regarded as a starting point for further research.

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8. CHAPTER EIGHT: STATISTICAL APPENDIX

8.1 General

Note: General economic data used for further compilation was mainly taken from Feinstein (1976) except where otherwise specified. For example Average Weekly Wage Earnings (for manual employees) was taken from his Table 65, Col. 2; his index of Retail Prices (1913=100), Table 65, Col. 3, was used to deflate all current prices, while per capita values were obtained using his annual estimates of population for Great Britain Table 55, Col. 4. The "per capita" figure for net saving was obtained using the annual number of (active) depositors for the Post Office & Trustee Savings Banks given in the Annual Abstract Of Statistics Section V11l "Savings Banks". Otherwise data was obtained from the primary or secondary sources quoted below.

British Patent Annualisation Numbers 1915-1966

1915 = 1-18225	1933 = 385258	1950 = 633754
1916 = 100001	1934 = 407311	1951 = 650021
1917 = 102812	1935 = 421246	1952 = 667061
1918 = 112131	1936 = 439856	1953 = 687841
1919 = 121611	1937 = 458491	1954 = 704741
1920 = 136852	1938 = 477016	1955 = 724991
1921 = 155801	1939 = 497409	1956 = 745421
1922 = 173241	1940 = 512178	1957 = 768941
1923 = 190732	1941 = 530617	1958 = 791071
1924 = 208751	1942 = 542024	1959 = 809321
1925 = 226571	1943 = 550067	1960 = 829181
1926 = 244801	1944 = 558091	1961 = 861801
1927 = 263501	1945 = 566191	1962 = 889571
1928 = 282701	1946 = 574006	1963 = 918311
1929 = 302941	1947 = 583360	1964 = 949031
1930 = 323171	1948 = 595746	1965 = 982551
1931 = 340201	1949 = 614704	1966 = 1019390
1932 = 363615		

(Source: Chas. Hude, Copenhagen, no date.)
(The number quoted is the first patent in year of issue.)

Post Office Savings Bank Data

Year	Active Accounts	Deposits	Withdrawals	Net Saving	Net Saving per depositor
1920	12741581	101323000	107425000	-6104000	-0.19633
1921	10526652	83300000	91945000	-8645000	-0.36993
1922	10636032	87491000	89770000	-2279000	-0.11970
1923	10544573	83561000	85095000	-1534000	-0.08507
1924	10670810	81056000	80358000	+698000	0.03803
1925	10672801	82986000	84641000	-1655000	-0.08963
1926	10427546	73877000	82518000	-8641000	-0.49033
1927	09985871	75660000	81440000	-5780000	-0.35293
1928	09783442	77778000	80636000	-2858000	-0.17921
1929	09834716	77421000	87952000	-10531000	-0.66509
1930	09855817	76120000	77694000	-1574000	-0.10303
1931	09538515	72025000	79821000	-7796000	-0.56366
1932	09482532	90347000	81105000	+9242000	0.69122
1933	09030309	92756000	79385000	+13371000	1.08078
1934	09322828	104153000	84144000	+20009000	1.55524
1935	09702295	116218000	89653000	+26565000	1.95572
1936	10148794	128156000	96019000	+32137000	2.19901
1937	10631455	136015000	108764000	+27251000	1.68634
1938	11127856	144422000	117427000	+26995000	1.58555

Trustee Savings Bank Data

1920	2247632	40939000	39522000	+1417000	0.25837
1921	2211966	32995000	36733000	-3738000	-0.76121
1922	2211507	36101000	35142000	+959000	0.24225
1923	2237841	35635000	33703000	+1932000	0.50487
1924	2282090	35687000	34887000	+800000	0.20381
1925	2327280	38662000	39519000	-857000	-0.21285
1926	2354685	33755000	37065000	-3310000	-0.83177
1927	2412050	36736000	39304000	-2568000	-0.64917
1928	2460072	38810000	40475000	-1665000	-0.42300
1929	2492073	39166000	43413000	-4247000	-1.05851
1930	2345379	39368000	41487000	-2119000	-0.58288
1931	1972065	39317000	42359000	-3042000	-1.06382
1932	1983004	42017000	41799000	+218000	0.07796
1933	2024067	50401000	43634000	+6767000	2.44034
1934	2076791	49422000	45661000	+3761000	1.31229
1935	2142676	51971000	41568000	+10403000	3.46795
1936	2221688	56557000	46510000	+10047000	3.14044
1937	2320095	61073000	53077000	+7996000	2.26737
1938	2420358	63862000	56090000	+7772000	2.09875

(Source: Annual Abstract Of Statistics;)

Savings Banks Data

Combined P.O.S.B. & T.S.B. Net Saving per depositor at Constant Prices

1920 = 0.03102	1927 = -0.50105	1933 = 1.76056
1921 =-0.56557	1928 = -0.30111	1934 = 1.43376
1922 = 0.06127	1929 = -0.86180	1935 = 2.71184
1923 = 0.20989	1930 = -0.34296	1936 = 2.66972
1924 = 0.12092	1931 = -0.81374	1937 = 1.97685
1925 =-0.15124	1932 = 0.38459	1938 = 1.84215
1926 =-0.66105		

(Source: Annual Abstracts Of Statistics; these figures are arithmetic means of combined P.O.S.B. & T.S.B. annual net saving).

8.2 Bicycle & Bicycle Industry Data

British Patent Abridgements/Patents Granted for Class 136 Velocipedes & Later Equivalents

1855= 3	1891= 249	1927= 198
1856= 1	1892= 316	1928= 166
1857= 2	1893= 389	1929= 106
1858= 0	1894= 426	1930= 118
1859= 1	1895= 508	1931= 107
1860= 0	1896= 1304	1932= 113
1861= 1	1897= 1341	1933= 80
1862= 3	1898= 811	1934= 124
1863= 4	1899= 542	1935= 134
1864= 0	1900= 354	1936= 82
1865= 1	1901= 377	1937= 82
1866= 0	1902= 321	1938= 108
1867= 2	1903= 308	1939= 121
1868= 5	1904= 253	1940= 120
1869= 28	1905= 258	1941= 101
1870= 7	1906= 283	1942= 20
1871= 6	1907= 253	1943= 20
1872= 0	1908= 234	1944= 20
1873= 1	1909= 241	1945= 71
1874= 7	1910= 255	1946= 71
1875= 6	1911= 243	1947= 56
1876= 21	1912= 225	1948= 56
1878= 28	1913= 207	1949= 137
1878= 41	1914= 148	1950= 117
1879= 40	1915= 120	1951= 114
1880= 69	1916= 21	1952= 114

(Cycle Patent Abridgements, Class 136 continued)

1881= 76	1917= 109	1953= 97
1882= 74	1918= 93	1954= 99
1883= 75	1919= 145	1955= 94
1884=216	1920= 255	1956= 94
1885=181	1921= 293	1957= 78
1886=125	1922= 215	1958= 56
1887=152	1923= 234	1959= 59
1888=159	1924= 198	1960= 55
1889=158	1925= 199	1961= 40
1890=186	1926= 188	1962= 46

(Source: 1855-1904, 22nd. Annual Report Of Comptroller, 1904, p.9; 1905-1930 Patent Abridgements Class 136. 1931-1962 Annual Reports of the Comptroller of Patent Office).

8.2.1 British Bicycle Production, Exports & Imports

Year	Production	Exports	Imports
1885	40000	-	-
1895	800000	-	-
1900	350000		
1901	375000		
1902	400000		
1903	425000	-	4777
1904	450000	-	1587
1905	475000	47604	2345
1906	500000	78948	1288
1907	(623800)*	102399	698
1908	420000	99378	772
1909	350000	105135	521
1910	350000	129364	433
1911	350000	146698	351
1912	(467000)*	136993	387
1913	400000	147661	422
1914	400000	108978	288
1915	250000	64224	69
1916	50000	59009	24
1917	50000	49512	6
1918	100000	8015	2
1919	400000	62959	345
1920	385000	159640	2627
1921	410000	39117	854
1922	435000	69244	1441
1923	460000	121817	2799
1924	(681347)*	200781	1143
1925	510000	276468	1088
1926	535000	280052	1251

(Bicycle Production Continued)

Year	Total Prodn.	Exports	Imports
1927	560000	283358	1054
1928	725000	338908	1058
1929	840000	367866	1347
1930	814449	247147	1121
1931	1000000	172950	1267
1932	1100000	164084	59
1933	1418000	204610	438
1934	1836000	282222	-
1935	1957000	377104	-
1936	2150000	519173	-
1937	2057000	831065	-
1938	1900000	576454	-
1946	2113000	1073391	-
1947	2492000	1449662	-
1948	2939000	1803908	-
1949	3518000	2210432	-
1950	3528000	2109864	-
1951	4033000	2737780	-
1952	3624000	2788672	-
1953	2994000	1986325	-
1954	3297000	2056160	-
1955	3562000	2350760	-
1956	2873000	2005963	-
1957	2548000	1550230	-
1958	2156000	1324587	-
1959	2213000	1260820	-
1960	2278000	1467865	-
1961	1980000	1314365	-
1962	1927000	1302711	-
1963	2050000	1474448	-
1964	1740000	1036234	
1965	1683000	955000	-
1966	1423000	750000	-
1967	1437000	761000	5000
1968	1504000	773000	13000
1969	1624000	857000	11000
1970	1605000	891000	27000
1971	1806000	1099000	45000
1972	2019000	1280000	47000
1973	2059000	1303000	74000
1974	1930000	1176000	174000
1975	1952000	1084000	236000
1976	1859000	1009000	250000
1977	1746000	1005000	173000
1978	2095000	1221000	260000

(Sources; 1885 & 1895 - Literature cited; 1900-1919 - Prest (1954), p.138. 1920-1938 - Stone & Rowe (1966), Tables 24 & 25, pp. 58-59. Exports & Imports

1905-1938 - Trade & Navigation Accounts annually. Items marked * are Census Of Production data (Motor & Cycle Trade). 1946 - 1972 from Annual Abstracts of Statistics & Business Monitor Series PA367.).

8.2.2 Bicycle Export Prices

Year	Current Prices	Constant Prices	Year	Current Prices	Constant Prices
1905	6.45	7.16	1932	3.16	2.24
1906	5.46	6.00	1933	2.83	2.06
1907	4.96	5.33	1934	2.76	2.00
1908	4.64	5.09	1935	2.79	1.99
1909	4.39	4.77	1936	2.68	1.86
1910	4.19	4.45	1937	2.80	1.84
1911	4.09	4.30	1938	2.90	1.79
1912	4.25	4.33		- -	
1913	4.14	4.14	1946	6.00	2.54
1914	4.09	4.04	1947	6.92	2.77
1915	4.42	3.65	1948	7.07	2.63
1916	4.85	3.39	1949	6.98	2.53
1917	5.82	3.36	1950	7.15	2.52
1918	7.24	3.63	1951	7.71	2.47
1919	9.69	4.59	1952	8.51	2.51
1920	9.65	3.95	1953	9.06	2.59
1921	9.74	4.38	1954	8.85	2.49
1922	6.97	3.89	1955	8.90	2.39
1923	5.79	3.38	1956	9.29	2.38
1924	5.09	2.95	1957	9.23	2.28
1925	4.73	2.73	1958	9.60	2.30
1926	4.31	2.55	1959	9.77	2.33
1927	4.19	2.55	1960	9.46	2.24
1928	4.00	2.45	1961	8.81	2.01
1929	3.77	2.34	1962	8.74	1.92
1930	3.82	2.46	1963	8.69	1.86
1931	3.51	2.42	1964	9.19	1.91

(Sources: Current Prices from Trade & Navigation Accounts; constant prices computed using the Retail Price Index by Feinstein (1976)).

8.2.3 Bicycle Demand Analysis

SPSS Regression Program

```
FILE .BIKE:STAT9 TO &DATA/FB
SPSS PROGRAM %H! DATA =&DATA OUTPUT = .OUTPET
PAGESIZE 66
VARIABLE LIST YEAR,PCCONS, PCQTY,PRICE, REARN, NETSAV/
INPUT MEDIUM DISK
INPUT FORMAT FIXED (F4.0, F11.8,F11.8,F5.3,F7.3,F10.6)
NEW REGRESSION VARIABLES=PCQTY,PRICE,REARN,NETSAV/
CRITERIA=TOLERANCE(0.0000001)/
DEPENDENT=PCQTY/
ENTER = PRICE/
DEPENDENT = PCQTY/
ENTER = PRICE, REARN/
DEPENDENT = PCQTY/
ENTER = PRICE, REARN, NETSAV/
DEP= PCQTY/
TEST (PRICE,REARN,NETSAV)/
RESID = DURBIN/
READ INPUT DATA
!
```

Bicycle Regression Input Data

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
1920	0.0588789	0.0090673	6.51	113.9	0.031020
1921	0.0693698	0.0095763	7.20	117.1	−0.565573
1922	0.0647286	0.0100921	6.42	116.7	0.061276
1923	0.0593026	0.0106144	5.61	112.8	0.209899
1924	0.0545158	0.0111093	4.94	113.9	0.120921
1925	0.0527373	0.0116433	4.50	114.4	−0.151245
1926	0.0509345	0.0121651	4.14	114.2	−0.661058
1927	0.0523346	0.0126871	4.08	120.1	−0.501058
1928	0.0509801	0.0131961	3.86	119.0	−0.301112
1929	0.0501890	0.0137288	3.66	121.1	−0.861802
1930	0.0533285	0.0142284	3.80	124.5	−0.342961
1931	0.0722714	0.0184693	3.93	130.3	−0.813746
1932	0.0847307	0.0226466	3.75	131.2	0.384598
1933	0.0983169	0.0267995	3.64	134.3	1.760570
1934	0.1308341	0.0342283	3.84	134.7	1.433770
1935	0.1315876	0.0353093	3.71	135.0	2.711840
1936	0.1196375	0.0343412	3.47	134.7	2.669730
1937	0.1156320	0.0333637	3.48	130.9	1.976860
1938	0.1157808	0.0324186	3.59	135.2	1.842150

(Where Col. 1 is Year; Col. 2 is <u>per capita</u> consumer expenditure on bicycles from Stone & Rowe (1966), deflated using Retail Price Index by Feinstein (1976); Col. 3 is quantity of bicycle homesales from Stone & Rowe (1966) reduced to <u>per capita</u> data using population estimates by Feinstein

(1976); Col. 4 is the average constant price of an average British bicycle each
year from data given by Stone & Rowe (1966) deflated using Feinstein (1976). Col. 5 is Average Weekly Wage from Feinstein (1976). Col. 6 is combined Net Saving given in Savings Bank Data above.

Regression Results For Bicycle Homesales

```
2 VARIABLE LIST YEAR,PCCONS, PCQTY,PRICE, REARN, NETSAV/
3 INPUT MEDIUM DISK
4 INPUT FORMAT FIXED (F4.0, F11.8,F11.8,F5.3,F7.3,F10.6)
WARNING - A NUMERIC VARIABLE HAS A WIDTH GREATER THAN 7. SMALL
ROUNDING/TRUNCATION ERRORS MAY RESULT.
5 NEW REGRESSION VARIABLES=PCQTY,PRICE,REARN,NETSAV/
6 CRITERIA=TOLERANCE(0.0000001)/
7 DEPENDENT=PCQTY/
8 ENTER = PRICE/
9 DEPENDENT = PCQTY/
10 ENTER = PRICE, REARN/
11 DEPENDENT = PCQTY/
12 ENTER = PRICE, REARN, NETSAV/
13 DEP= PCQTY/
14 TEST (PRICE,REARN,NETSAV)/
15 RESID = DURBIN/
*WARNING* 3 LOW TOLERANCE ( 0.100E-06) RESULTS MAY BE ODD
16 READ INPUT DATA
VARIABLE LIST NUMBER 1. LISTWISE DELETION OF MISSING DATA.
EQUATION NUMBER 1.
DEPENDENT VARIABLE.. PCQTY
BEGINNING BLOCK NUMBER 1. METHOD: ENTER PRICE
VARIABLE(S) ENTERED ON STEP NUMBER 1.. PRICE
MULTIPLE R 0.63905 ANALYSIS OF VARIANCE
R SQUARE 0.40839 DF SUM OF SQUARES MEAN SQUARE
ADJUSTED R SQUARE 0.37359 REGRESSION 1 0.00074 0.00074
STANDARD ERROR 0.79523D-02 RESIDUAL 17 0.00108 0.00006
F = 11.73511 SIGNIF F = 0.0032
------------------ VARIABLES IN THE EQUATION ------------------
VARIABLE B SE B BETA T SIG T
PRICE -0.00558 0.00163 -0.63905 -3.426 0.0032
(CONSTANT) 0.04394 0.00743 5.910 0.0000
FOR BLOCK NUMBER 1 ALL REQUESTED VARIABLES ENTERED.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
EQUATION NUMBER 2.
DEPENDENT VARIABLE.. PCQTY
BEGINNING BLOCK NUMBER 1. METHOD: ENTER PRICE REARN
VARIABLE(S) ENTERED ON STEP NUMBER 1.. REARN
2.. PRICE
MULTIPLE R 0.92474 ANALYSIS OF VARIANCE
R SQUARE 0.85514 DF SUM OF SQUARES MEAN SQUARE
ADJUSTED R SQUARE 0.83703 REGRESSION 2 0.00155 0.00078
STANDARD ERROR 0.40562D-02 RESIDUAL 16 0.00026 0.00002
F = 47.22541 SIGNIF F = 0.0000
```

```
------------------ VARIABLES IN THE EQUATION ------------------
VARIABLE B SE B BETA T SIG T
REARN 0.00103 0.1461D-03 0.89689 7.025 0.0000
PRICE -0.35783D-03 0.00111 -0.04101 -0.321 0.7522
(CONSTANT) -0.10632 0.02172 -4.894 0.0002
FOR BLOCK NUMBER 1 ALL REQUESTED VARIABLES ENTERED.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
EQUATION NUMBER 3.
DEPENDENT VARIABLE.. PCQTY
BEGINNING BLOCK NUMBER 1. METHOD: ENTER PRICE REARN NETSAV
VARIABLE(S) ENTERED ON STEP NUMBER 1.. NETSAV
2.. PRICE
3.. REARN
MULTIPLE R 0.96321 ANALYSIS OF VARIANCE
R SQUARE 0.92777 DF SUM OF SQUARES MEAN SQUARE
ADJUSTED R SQUARE 0.91333 REGRESSION 3 0.00169 0.00056
STANDARD ERROR 0.29580D-02 RESIDUAL 15 0.00013 0.00001
F = 64.22701 SIGNIF F = 0.0000
------------------ VARIABLES IN THE EQUATION ------------------
VARIABLE B SE B BETA T SIG T
NETSAV 0.00541 0.00139 0.47275 3.884 0.0015
PRICE -0.27911D-03 0.8127D-03 -0.03199 -0.343 0.7360
REARN 0.58878D-03 0.1550D-03 0.51455 3.797 0.0018
(CONSTANT) -0.05742 0.02024 -2.838 0.0125
FOR BLOCK NUMBER 1 ALL REQUESTED VARIABLES ENTERED.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
EQUATION NUMBER 4.
DEPENDENT VARIABLE.. PCQTY
BEGINNING BLOCK NUMBER 1. METHOD: TEST PRICE REARN NETSAV
VARIABLE(S) ENTERED ON STEP NUMBER 1.. NETSAV
2.. PRICE
3.. REARN
HYPOTHESIS TESTS
SUM OF
DF SQUARES RSQ CHG F SIG F SOURCE
3 0.00169 0.92777 64.22701 0.0000 PRICE REARN NETSAV
3 0.00169 64.22701 0.0000 REGRESSION
15 0.00013 RESIDUAL
18 0.00182 TOTAL
------------------------------------------------------------------
MULTIPLE R 0.96321 ANALYSIS OF VARIANCE
R SQUARE 0.92777 DF SUM OF SQUARES MEAN SQUARE
ADJUSTED R SQUARE 0.91333 REGRESSION 3 0.00169 0.00056
STANDARD ERROR 0.29580D-02 RESIDUAL 15 0.00013 0.00001
F = 64.22701 SIGNIF F = 0.0000
------------------ VARIABLES IN THE EQUATION ------------------
VARIABLE B SE B BETA T SIG T
NETSAV 0.00541 0.00139 0.47275 3.884 0.0015
PRICE -0.27911D-03 0.8127D-03 -0.03199 -0.343 0.7360
REARN 0.58878D-03 0.1550D-03 0.51455 3.797 0.0018
(CONSTANT) -0.05742 0.02024 -2.838 0.0125
```

FOR BLOCK NUMBER 1 ALL REQUESTED VARIABLES ENTERED.
* *
RESIDUALS STATISTICS:

	MIN	MAX	MEAN	STD DEV	N		MIN	MAX	MEAN	STD DEV	N
*PRED	0.0080	0.0357	0.0192	0.0097	19	*RESID	-0.0041	0.0057	0.0000	0.0027	19
*ZPRED	-1.1631	1.7010	0.0000	1.0000	19	*ZRESID	-1.3978	1.9106	0.0000	0.9129	19
*SEPRED	0.0009	0.0020	0.0013	0.0003	19	*SRESID	-1.5341	2.1045	-0.0081	1.0179	19
*ADJPRED	0.0077	0.0359	0.0193	0.0097	19	*DRESID	-0.0055	0.0069	-0.0001	0.0034	19
*MAHAL	0.8653	7.2675	2.8421	1.7245	19	*SDRESID	-1.6141	2.4219	-0.0003	1.0728	19
*COOK D	0.0000	0.3970	0.0660	0.0988	19						

TOTAL CASES = 19
DURBIN-WATSON TEST = 2.10367
END OF JOB.
0 ERRORS WERE DETECTED.

8.3 Radio

8.3.1 Radio Patents

Unless otherwise stated, all the following radio patents have been taken from the Series 'A' File List at the Patent Office.

Radio Patents, Sub-Class H3Q1E, Crystal Sets

1913 = 1	1931 = 1	1949 = 0
1914 = 0	1932 = 0	1950 = 0
1915 = 0	1933 = 0	1951 = 0
1916 = 0	1934 = 1	1952 = 0
1917 = 0	1935 = 0	1953 = 0
1918 = 0	1936 = 0	1954 = 0
1919 = 0	1937 = 0	1955 = 1
1920 = 1	1938 = 0	1956 = 1
1921 = 1	1939 = 0	1957 = 0
1922 = 0	1940 = 0	1958 = 0
1923 = 5	1941 = 0	1959 = 0
1924 = 8	1942 = 0	1960 = 0
1925 =15	1943 = 0	1961 = 0
1926 = 3	1944 = 0	1962 = 1
1927 = 2	1945 = 0	1963 = 0
1928 = 2	1946 = 0	1964 = 0
1929 = 1	1947 = 0	1965 = 0
1930 = 0	1948 = 0	

Radio Patents, Sub-Class H3Q7B6, Crystal Detectors

1911 = 2	1930 = 2	1949 = 3
1912 = 6	1931 = 5	1950 = 1
1913 = 3	1932 = 3	1951 = 1
1914 = 3	1933 = 7	1952 = 2
1915 = 2	1934 = 2	1953 = 4
1916 = 0	1935 = 5	1954 = 0
1917 = 0	1936 = 2	1955 = 2
1918 = 3	1937 = 5	1956 = 3
1919 = 2	1938 = 3	1957 = 3
1920 = 7	1939 = 2	1958 = 1
1921 = 2	1940 = 6	1959 = 2
1922 = 2	1941 = 4	1960 = 2
1923 = 2	1942 = 1	1961 = 4
1924 = 3	1943 = 0	1962 = 0
1925 = 7	1944 = 2	1963 = 4
1926 = 7	1945 = 0	1964 = 5
1927 = 8	1946 = 2	1965 = 4
1928 = 5	1947 = 1	
1929 = 4	1948 = 1	

Radio Patents, Sub-Class H3Q7G1 Crystal & Like Detectors

1913 = 2	1931 = 2	1949 = 0
1914 = 0	1932 = 1	1950 = 0
1915 = 0	1933 = 7	1951 = 1
1916 = 0	1934 = 0	1952 = 1
1917 = 0	1935 = 0	1953 = 1
1918 = 0	1936 = 0	1954 = 0
1919 = 0	1937 = 0	1955 = 0
1920 = 4	1938 = 0	1956 = 0
1921 = 1	1939 = 0	1957 = 0
1922 = 1	1940 = 0	1958 = 0
1923 = 1	1941 = 0	1959 = 0
1924 = 1	1942 = 0	1960 = 0
1925 = 0	1943 = 0	1961 = 1
1926 = 2	1944 = 0	1962 = 0
1927 = 1	1945 = 0	1963 = 0
1928 = 1	1946 = 1	1964 = 0
1929 = 0	1947 = 0	1965 = 1
1930 = 0	1948 = 0	

Radio Patents, Sub-Class H3Q7A8A, Neutralising Arrangements

1915 = 1	1931 = 1	1946 = 0
1916 = 0	1932 = 0	1947 = 0
1917 = 1	1933 = 0	1948 = 0
1918 = 0	1934 = 1	1949 = 1
1919 = 0	1935 = 0	1950 = 0
1920 = 0	1936 = 0	1951 = 0
1921 = 0	1937 = 1	1952 = 1
1922 = 0	1938 = 0	1953 = 0
1923 = 0	1939 = 0	1954 = 0
1924 = 1	1940 = 0	1955 = 0
1925 = 4	1941 = 0	1956 = 0
1926 = 2	1942 = 0	1957 = 0
1927 = 1	1943 = 0	1958 = 0
1928 = 0	1944 = 0	1959 = 0
1929 = 0	1945 = 0	1960 = 1
1930 = 0		

Radio Patents, Sub-Class H3Q1K, Layout Screening

1918 = 1	1934 = 6	1950 = 1
1919 = 0	1935 = 2	1951 = 0
1920 = 2	1936 = 6	1952 = 2
1921 = 5	1937 = 7	1953 = 0
1922 = 4	1938 = 5	1954 = 5
1923 = 1	1939 = 4	1955 = 2
1924 = 2	1940 = 2	1956 = 1
1925 = 8	1941 = 2	1957 = 0
1926 = 9	1942 = 2	1958 = 0
1927 = 4	1943 = 0	1959 = 1
1928 = 8	1944 = 0	1960 = 2
1929 =12	1945 = 2	1961 = 3
1930 =13	1946 = 0	1962 = 1
1931 = 4	1947 = 0	1963 = 1
1932 =12	1948 = 0	1964 = 4
1933 = 6	1949 = 0	1965 = 1

Radio Patents, Sub-Class H3Q7A7, Neutrodyne Screening

1920 = 3	1934 = 0	1948 = 1
1921 = 0	1935 = 1	1949 = 0
1922 = 0	1936 = 0	1950 = 1
1923 = 0	1937 = 1	1951 = 2
1924 = 5	1938 = 1	1952 = 0
1925 = 3	1939 = 1	1953 = 0
1926 = 1	1940 = 0	1954 = 3
1927 = 0	1941 = 0	1955 = 0
1928 = 0	1942 = 0	1956 = 1
1929 = 0	1943 = 0	1957 = 0
1930 = 0	1944 = 1	1958 = 0
1931 = 0	1945 = 0	1959 = 0
1932 = 0	1946 = 0	1960 = 0
1933 = 1	1947 = 0	1961 = 3

Radio Patents, Sub-Class H3Q7G4, Super-regenerative Circuits

1920 = 1	1936 = 8	1951 = 9
1921 = 1	1937 =11	1952 =10
1922 = 1	1938 = 2	1953 = 2
1923 = 2	1939 = 2	1954 = 2
1924 = 2	1940 = 2	1955 = 2
1925 = 5	1941 = 0	1956 = 2
1926 = 3	1942 = 3	1957 = 0
1927 = 3	1943 = 0	1958 = 0
1928 = 2	1944 = 2	1959 = 0
1929 = 2	1945 = 1	1960 = 0
1930 = 2	1946 = 4	1961 = 1
1931 = 7	1947 =10	1962 = 0
1932 = 9	1948 =12	1963 = 0
1933 =13	1949 = 1	1964 = 2
1934 = 5	1950 = 7	1965 = 0
1935 = 6		

Radio Patents, Sub-Class H3Q7G7, Supersonic Heterodyne Circuits

1914 = 1	1932 = 16	1949 = 7
1915 = 0	1933 = 15	1950 = 13
1916 = 0	1934 = 13	1951 = 8
1917 = 0	1935 = 16	1952 = 5
1918 = 0	1936 = 9	1953 = 4
1919 = 3	1937 = 18	1954 = 8
1920 = 6	1938 = 20	1955 = 3
1921 = 3	1939 = 7	1956 = 2
1922 = 3	1940 = 10	1957 = 4
1923 = 2	1941 = 7	1958 = 6
1924 = 3	1942 = 3	1959 = 4
1925 = 7	1943 = 5	1960 = 5
1926 = 11	1944 = 2	1961 = 2
1927 = 10	1945 = 3	1962 = 2
1928 = 7	1946 = 8	1963 = 6
1929 = 2	1947 = 4	1964 = 1
1930 = 3	1948 = 8	1965 = 2
1931 = 8		

Radio Patents, Sub-Class H3Q7G5, Heterodyne Circuits For Beats

1913 = 1	1931 = 0	1949 = 1
1914 = 2	1932 = 4	1950 = 0
1915 = 3	1933 = 0	1951 = 0
1916 = 2	1934 = 2	1952 = 0
1917 = 1	1935 = 3	1953 = 1
1918 = 1	1936 = 0	1954 = 1
1919 = 3	1937 = 0	1955 = 0
1920 = 22	1938 = 2	1956 = 0
1921 = 9	1939 = 0	1957 = 1
1922 = 13	1940 = 3	1958 = 1
1923 = 8	1941 = 0	1959 = 0
1924 = 7	1942 = 1	1960 = 0
1925 = 3	1943 = 1	1961 = 0
1926 = 3	1944 = 1	1962 = 0
1927 = 1	1945 = 1	1963 = 0
1928 = 4	1946 = 0	1964 = 0
1929 = 1	1947 = 0	1965 = 0
1930 = 0	1948 = 1	

Radio Patents, Sub-Class H3Q7G6, Homodyne Circuits

1916 = 3	1933 = 2	1950 = 2
1917 = 1	1934 = 4	1951 = 5
1918 = 0	1935 =14	1952 = 5
1919 = 2	1936 = 8	1953 = 1
1920 = 4	1937 =13	1954 = 2
1921 = 1	1938 = 4	1955 = 2
1922 = 1	1939 = 8	1956 = 2
1923 = 2	1940 =13	1957 = 4
1924 = 1	1941 = 9	1958 = 5
1925 = 0	1942 = 4	1959 = 3
1926 = 2	1943 = 1	1960 = 5
1927 = 3	1944 = 3	1961 = 3
1928 = 0	1945 = 1	1962 = 2
1929 = 2	1946 = 3	1963 = 4
1930 = 1	1947 = 1	1964 = 4
1931 = 2	1948 = 3	1965 = 0
1932 = 4	1949 = 7	

Radio Patents, Sub-Class H3R9R5, F.M. Receiving Circuits

1931 = 1	1943 = 8	1955 = 1
1932 = 0	1944 = 5	1956 = 5
1933 = 0	1945 = 2	1957 = 3
1934 = 0	1946 = 6	1958 = 4
1935 = 0	1947 = 7	1959 = 0
1936 = 1	1948 = 5	1960 = 2
1937 = 1	1949 =10	1961 = 2
1938 = 1	1950 = 4	1962 = 2
1939 = 1	1951 = 4	1963 = 1
1940 = 1	1952 = 9	1964 = 1
1941 = 4	1953 = 0	1965 = 6
1942 = 7	1954 = 2	

Radio Patents, Sub-Class H3R9R1, F.M. Receiving Circuits

1920 = 1	1936 = 1	1951 = 1
1921 = 0	1937 = 2	1952 = 3
1922 = 1	1938 = 1	1953 = 0
1923 = 0	1939 = 4	1954 = 2
1924 = 0	1940 = 1	1955 = 1
1925 = 0	1941 = 0	1956 = 0
1926 = 0	1942 = 2	1957 = 1
1927 = 0	1943 = 2	1958 = 3
1928 = 0	1944 = 5	1959 = 0
1929 = 0	1945 = 4	1960 = 1
1930 = 0	1946 = 3	1961 = 3
1931 = 0	1947 = 4	1962 = 0
1932 = 0	1948 = 2	1963 = 1
1933 = 0	1949 = 7	1964 = 0
1934 = 1	1950 = 2	1965 = 0
1935 = 1		

Radio Patents, Sub-Class H39R3, F.M. Negative Feedback

1938 = 1	1947 = 1	1957 = 0
1939 = 3	1948 = 0	1958 = 1
1940 = 1	1949 = 1	1959 = 0
1941 = 1	1950 = 3	1960 = 2
1942 = 1	1951 = 3	1961 = 0
1943 = 2	1952 = 1	1962 = 2
1944 = 0	1953 = 2	1963 = 1
1945 = 1	1954 = 0	1964 = 0
1946 = 0	1955 = 1	1965 = 0
	1956 = 0	

Radio Patents, Sub-Class H3R9R4, F.M. Re-Combining Circuits

1927 = 1	1940 = 0	1953 = 0
1928 = 2	1941 = 0	1954 = 0
1929 = 0	1942 = 0	1955 = 0
1930 = 0	1943 = 0	1956 = 0
1931 = 0	1944 = 1	1957 = 0
1932 = 0	1945 = 0	1958 = 0
1933 = 1	1946 = 0	1959 = 0
1934 = 3	1947 = 0	1960 = 0
1935 = 0	1948 = 0	1961 = 0
1936 = 1	1949 = 4	1962 = 0
1937 = 0	1950 = 0	1963 = 0
1938 = 2	1951 = 0	1964 = 0
1939 = 2	1952 = 0	1965 = 0

Radio Patents, Class 40(v), Wireless Signaling

1909 = 58	1917 = 43	1925 = 398
1910 = 57	1918 = 21	1926 = 414
1911 = 64	1919 =132	1927 = 340
1912 = 79	1920 =317	1928 = 442
1913 = 91	1921 =239	1929 = 455
1914 = 85	1922 =216	1930 = 292
1915 = 61	1923 =261	
1916 = 27	1924 =360	

(Source: Patent Abridgements Class 40(v).)

Radio Patents, Radio Receivers Only

1931 = 61	1942 = 47	1953 = 62
1932 = 69	1943 = 47	1954 = 55
1933 = 61	1944 = 47	1955 = 74
1934 = 54	1945 = 47	1956 = 57
1935 =127	1946 = 58	1957 = 79
1936 = 81	1947 = 58	1958 = 54
1937 = 81	1948 = 58	1959 = 34
1938 =153	1949 =101	1960 = 27
1939 =166	1950 =108	1961 = 38
1940 =220	1951 = 88	1962 = 26
1941 =156	1952 = 66	1963 = 29

(Source: Annual Reports Of Comptroller)

8.3.2 Radio Industry Prices & Output

Data For Radio Industry

Annual Export Prices of British Radios
(Radio Receivers Only, Excludes Radiograms)

Year	Current Price (pounds)	Constant Price (1913 = 100)
1932	7.61	5.39
1933	6.12	4.46
1934	5.56	4.02
1935	4.87	3.47
1936	5.29	3.67
1937	5.55	3.65
1938	5.20	3.39
1947	11.34	4.55
1948	11.79	4.39
1949	10.04	3.65
1950	9.75	3.19

(Sources: Trade & Navigation Accounts; Annual Abstract of Statistics; Group F, Class III Wireless Apparatus - Receiving Sets Other Than Radiograms excluding Valves.).

Annual Average Export Prices of British (Valve, Mains) Radio Receivers

Year	Current Prices (pounds)	Constant Prices (1913 = 100)
1952	10.27	3.03
1953	10.76	3.08
1954	10.23	2.88
1955	10.09	2.71
1956	9.32	2.39
1957	9.02	2.23
1958	9.17	2.20
1959	10.60	2.53
1960	10.32	2.44
1961	9.99	2.28
1962	9.53	2.09
1963	11.01	2.36
1964	10.69	2.22
1965	10.61	2.10

(Source: Annual Abstract of Statistics)

Average Ex-Factory Prices Of Radio Receivers Made In Britain

Year	Current Price (pounds)	Constant Price (1913 = 100)
1933	5.88	4.29
1934	6.15	4.45
1935	6.07	4.35
1937	6.29	4.13
1948	11.31	4.22
1951	9.75	3.11
1954	8.64	2.43
1958	8.39	2.01
1963	9.97	2.14

(Sources: Census Of Production for all years except 1933, 1934 & 1937 which are from Import Duties Acts reports for Wireless Apparatus - Receiving sets + Radiograms).

Total British Production Of Radios + Radiograms: 1930 - 1938

Year	Quantity (Thousands)
1930	506
1931	850
1932	1,000
1933	1,281
1934	1,757
1935	1,850
1936	1,910
1937	1,918
1938	1,434

(Source: Wilson, in Burn (ed.) (1964), Table 1, p.137)

Consumers' Expenditure on Radio Receivers: 1930-38
(excluding Car Radios & Radiograms)

Year	Current Prices (Million Pounds)	Constant Prices (1913 = 100)
1930	5.43	3.50
1931	10.03	6.91
1932	10.30	7.30
1933	14.24	10.39
1934	16.96	12.28
1935	18.33	13.09
1936	18.71	12.99
1937	17.22	11.32
1938	17.36	11.34

(Source: Wilson, in Burn (ed.) (1964), Table 2, p.138)

Quantities and Prices Of Exports (Radios & Radiograms), 1930 - 1938

Year	Quantity (actual no.)	Value (Pounds) (Current)	unit Price (Pounds) (Current)	Unit Price (1913=100) (Constant)
1930	(n.a.)	(n.a.)	9.01 (est)	5.81
1931	(n.a.)	(n.a.)	8.04 (est)	5.54
1932	20,838	158,640	7.61	5.39
1933	39,319	240,956	6.12	4.46
1934	58,368	324,808	5.56	4.02
1935	56,056	273,436	4.87	3.47
1936	55,644	294,751	5.29	3.67
1937	68,669	381,257	5.55	3.65
1938	84,612	440,605	5.20	3.39

(Source: Trade & Navigation Accounts; With Estimates for 1930 & 1931 by extrapolation.)

Total Production (Qty.) [Radios + Radiograms], and Homesales : 1946 -1970

Year	Total Production (000s)	Homesales (000s)
1946	1380	1035
1947	1982	1578
1948	1630	1322
1949	1345	1051
1950	1809	1530
1951	2089	1610
1952	1234	807
1953	1183	863
1954	2018	1707
1955	2142	1796
1956	1682	1353
1957	1843	1559
1958	1808	1577
1959	1834	1596
1960	2504	2254
1961	3074	2864
1962	2976	2845
1963	2782	2647
1964	2639	2506
1965	1913	1819
1966	1578	1507
1967	1532	1467
1968	1736	1644
1969	1421	1217
1970	1313	1107

(Source: Annual Abstract Of Statistics; Homesales = Total Production - Exports)

Annual Numbers of Radio Receiving Licences Issued to Dec. 31; 1922 - 1938

Year	Licences	Year	Licences
1922	35,774	1931	4,330,735
1923	595,496	1932	5,263,017
1924	1,129,578	1933	5,973,758
1925	1,645,207	1934	6,780,569
1926	2,178,259	1935	7,403,109
1927	2,395,183	1936	7,960,573
1928	2,628,392	1937	8,479,600
1929	2,956,736	1938	8,908,900
1930	3,411,910		

(Source: B.B.C. Yearbook 1939, (p.129).)

8.3.3 Radio Demand Analysis

Regression Program For Radio Homesales

```
FILE .THESIS8:RADSTAT1 TO &DATA/FB
SPSS PROGRAM %H! DATA =&DATA OUTPUT = .OUTPET
PAGESIZE 66
VARIABLE LIST YEAR,PCCONS, PRICE, NETSAV, REARN/
INPUT MEDIUM DISK
INPUT FORMAT FIXED (F4.0, F8.5,F5.2,F11.7,F8.3)
NEW REGRESSION VARIABLES=PCCONS,PRICE,NETSAV,REARN/
CRITERIA=TOLERANCE(0.0000001)/
DEPENDENT=PCCONS/
ENTER = PRICE/
DEPENDENT = PCCONS/
ENTER = PRICE, REARN/
DEPENDENT = PCCONS/
ENTER = PRICE, REARN, NETSAV/
DEP= PCCONS/
TEST (PRICE,REARN,NETSAV)/
RESID = DURBIN/
READ INPUT DATA
!
```

Input Data For Radio Homesales Program

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
1930	0.78496	5.81	-0.3429614	124.516
1931	1.54296	5.54	-0.8137459	130.345
1932	1.62030	5.39	0.3845984	131.206
1933	2.29645	4.46	1.7605655	134.307
1934	2.70697	4.02	1.4337694	134.783
1935	2.87144	3.47	2.7118412	135.000
1936	2.83661	3.67	2.6697291	134.722
1937	2.46238	3.65	1.9768595	130.921
1938	2.45551	3.39	1.8421532	135.294

Where Col. 1 is year.
Col. 2 is Constant Consumer Expenditure from Wilson in Burn (ed.) (1964) & Feinstein (1976).
Col. 3 is Constant Export Prices Of Receivers Only, Trade & Nav. Accounts. Col. 4 is Constant per depositor Combined Net Saving from above.
Col. 5 is Constant Average Weekly Earnings from Feinstein (1976).

Regression Results For Radio Homesales

```
2 VARIABLE LIST YEAR,PCCONS, PRICE, NETSAV, REARN/
3 INPUT MEDIUM DISK
4 INPUT FORMAT FIXED (F4.0, F8.5,F5.2,F11.7,F8.3)
5 NEW REGRESSION VARIABLES=PCCONS,PRICE,NETSAV,REARN/
6 CRITERIA=TOLERANCE(0.0000001)/
7 DEPENDENT=PCCONS/
8 ENTER = PRICE/
9 DEPENDENT = PCCONS/
10 ENTER = PRICE, REARN/
11 DEPENDENT = PCCONS/
12 ENTER = PRICE, REARN, NETSAV/
13 DEP= PCCONS/
14 TEST (PRICE,REARN,NETSAV)/
15 RESID = DURBIN/
*WARNING*  3 LOW TOLERANCE ( 0.100E-06) RESULTS MAY BE ODD
16 READ INPUT DATA
VARIABLE LIST NUMBER 1. LISTWISE DELETION OF MISSING DATA.
EQUATION NUMBER 1.
DEPENDENT VARIABLE.. PCCONS
BEGINNING BLOCK NUMBER 1. METHOD: ENTER PRICE
VARIABLE(S) ENTERED ON STEP NUMBER 1.. PRICE
MULTIPLE R 0.92701 ANALYSIS OF VARIANCE
R SQUARE 0.85934 DF SUM OF SQUARES MEAN SQUARE
ADJUSTED R SQUARE 0.83925 REGRESSION 1 3.45553 3.45553
STANDARD ERROR 0.28426 RESIDUAL 7 0.56562 0.08080
F = 42.76525 SIGNIF F = 0.0003
```

```
------------------ VARIABLES IN THE EQUATION ------------------
VARIABLE B SE B BETA T SIG T
PRICE -0.68373 0.10455 -0.92701 -6.540 0.0003
(CONSTANT) 5.16850 0.46742 11.058 0.0000
FOR BLOCK NUMBER 1 ALL REQUESTED VARIABLES ENTERED.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
EQUATION NUMBER 2.
DEPENDENT VARIABLE.. PCCONS
BEGINNING BLOCK NUMBER 1. METHOD: ENTER PRICE REARN
VARIABLE(S) ENTERED ON STEP NUMBER 1.. REARN
2.. PRICE
MULTIPLE R 0.97025 ANALYSIS OF VARIANCE
R SQUARE 0.94139 DF SUM OF SQUARES MEAN SQUARE
ADJUSTED R SQUARE 0.92185 REGRESSION 2 3.78547 1.89273
STANDARD ERROR 0.19819 RESIDUAL 6 0.23568 0.03928
F = 48.18512 SIGNIF F = 0.0002
------------------ VARIABLES IN THE EQUATION ------------------
VARIABLE B SE B BETA T SIG T
REARN 0.09315 0.03214 0.46408 2.898 0.0274
PRICE -0.41442 0.11811 -0.56187 -3.509 0.0127
(CONSTANT) -8.33841 4.67186 -1.785 0.1245
FOR BLOCK NUMBER 1 ALL REQUESTED VARIABLES ENTERED.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
EQUATION NUMBER 3.
DEPENDENT VARIABLE.. PCCONS
BEGINNING BLOCK NUMBER 1. METHOD: ENTER PRICE REARN NETSAV
VARIABLE(S) ENTERED ON STEP NUMBER 1.. REARN
2.. NETSAV
3.. PRICE
MULTIPLE R 0.97415 ANALYSIS OF VARIANCE
R SQUARE 0.94897 DF SUM OF SQUARES MEAN SQUARE
ADJUSTED R SQUARE 0.91835 REGRESSION 3 3.81594 1.27198
STANDARD ERROR 0.20259 RESIDUAL 5 0.20521 0.04104
F = 30.99291 SIGNIF F = 0.0012
------------------ VARIABLES IN THE EQUATION ------------------
VARIABLE B SE B BETA T SIG T
REARN 0.09006 0.03305 0.44866 2.725 0.0415
NETSAV 0.12962 0.15042 0.23177 0.862 0.4282
PRICE -0.26510 0.21119 -0.35942 -1.255 0.2648
(CONSTANT) -8.74983 4.79922 -1.823 0.1279
FOR BLOCK NUMBER 1 ALL REQUESTED VARIABLES ENTERED.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
EQUATION NUMBER 4.
DEPENDENT VARIABLE.. PCCONS
BEGINNING BLOCK NUMBER 1. METHOD: TEST PRICE REARN NETSAV
VARIABLE(S) ENTERED ON STEP NUMBER 1.. REARN
2.. NETSAV
3.. PRICE
HYPOTHESIS TESTS
SUM OF
DF SQUARES RSQ CHG F SIG F SOURCE
```

```
3 3.81594 0.94897 30.99291 0.0012 PRICE REARN NETSAV
3 3.81594 30.99291 0.0012 REGRESSION
5 0.20521 RESIDUAL
8 4.02115 TOTAL
----------------------------------------------------------------
MULTIPLE R 0.97415 ANALYSIS OF VARIANCE
R SQUARE 0.94897 DF SUM OF SQUARES MEAN SQUARE
ADJUSTED R SQUARE 0.91835 REGRESSION 3 3.81594 1.27198
STANDARD ERROR 0.20259 RESIDUAL 5 0.20521 0.04104
F = 30.99291 SIGNIF F = 0.0012
------------------- VARIABLES IN THE EQUATION -------------------
VARIABLE B SE B BETA T SIG T
REARN 0.09006 0.03305 0.44866 2.725 0.0415
NETSAV 0.12962 0.15042 0.23177 0.862 0.4282
PRICE -0.26510 0.21119 -0.35942 -1.255 0.2648
(CONSTANT) -8.74983 4.79922 -1.823 0.1279
FOR BLOCK NUMBER 1 ALL REQUESTED VARIABLES ENTERED.
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
RESIDUALS STATISTICS:
MIN MAX MEAN STD DEV N MIN MAX MEAN STD DEV N
*PRED 0.8788 2.8393 2.1753 0.6906 9 *RESID -0.3187 0.1987 -0.0000 0.1602 9
*ZPRED -1.8772 0.9614 0.0000 1.0000 9 *ZRESID -1.5732 0.9809 -0.0000 0.7906 9
*SEPRED 0.0992 0.1776 0.1329 0.0256 9 *SRESID -2.1853 1.1249 -0.0419 1.1031 9
*ADJPRED 1.1908 3.0705 2.2014 0.6881 9 *DRESID -0.6150 0.3451 -0.0262 0.3264 9
*MAHAL 1.0284 5.2610 2.6667 1.3798 9 *SDRESID -9.2266 1.1642 -0.8168 3.2414 9
*COOK D 0.0033 1.1099 0.3102 0.3939 9
TOTAL CASES = 9
DURBIN-WATSON TEST = 2.00682
END OF JOB.
0 ERRORS WERE DETECTED.
```

9. CHAPTER NINE

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