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Innovation And Diffusion: A Conceptual Framework And An Empirical Example, The Boulton And Watt Steam Engine In Britain, 1775-1800

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INNOVATION AND DIFFUSION:
A CONCEPTUAL FRAMEWORK AND AN EMPIRICAL EXAMPLE, THE BOULTON AND WATT STEAM ENGINE IN BRITAIN, 1775-1800

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ABSTRACT

This dissertation is concerned with the process of innovation and diffusion. The work falls into two general parts. First, a conceptual framework for the innovation and diffusion process is developed. This provides a basis for the second part of the study which is empirical and investigates the diffusion of the reciprocating and rotary motion steam engines patented by James Watt in the latter part of the eighteenth century.

Innovation and diffusion is a complex event and the purpose of the conceptual framework is to clarify this process. A discussion of some of the characteristics of the innovation process is followed by an examination of the diffusion process. In conceptualizing innovation diffusion four subprocesses are identified relating to (1) information spread, (2) the adoption-decision, (3) acquisition of the innovation and (4) implementation of the decision to adopt at some particular locality. In addition, the role of an organization,

in diffusion is discussed. However, which of the above sub-processes operate in a particular situation will depend on the nature of the innovation and the environment in which the diffusion takes place.

The empirical part of the study, after providing some general background information on the innovations, examines four inter-related aspects of the diffusion. First, the timespatial pattern of spread of the innovations is investigated. Second, among and within industry variations in adoption of the innovations are discussed. Third, information flow processes are examined, and fourth, the way in which the firm of Boulton and Watt directed the course of the diffusion is analysed. It is shown that the diffusion situation consists of a complex changing relationship between the nature of the innovation, the mechanisms of spread, and the characteristics of the environment in which the diffusion takes place.

The study concludes by assessing the importance of the findings in terms of current work on innovation and diffusion and suggests areas where future research might profitably concentrate.

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INTRODUCTION

Preliminaries

In general terms, the aim of this study is to further our understanding of the process of innovation and diffusion. The ultimate aim of such research is that laws and theories appropriate to the analysis of this phenomenon be developed and empirically tested.[1]

The study of innovation and diffusion has long been the concern of many disciplines. In most studies, however, the spatial aspect of what is, by its very nature, a timespatial process has either been implicit or neglected. A small number of individuals, especially geographers but including students in other fields, have explicitly considered

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[1]For a review of some of the problems associated with fulfilling this goal see, L. Guelke, "Problems of Scientific Explanation in Geography," _The Canadian Geographer_, XV (1971), pp. 38-53.

innovation diffusion as both a temporal and a spatial event.[1]

In geography, the current wave of interest in this topic has its origins in the work of the Swedish geographer Hagerstrand in the early 1950's.[2] The topic, though, is one of traditional interest for the discipline.[3]

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[1]See, for example, M. T. Hodgen, "Geographical Diffusion as a Criterion of Age," American Anthropologist, XXXXIV (1942), pp. 345-368; M. S. Edmonson, "Neolithic Diffusion Rates," Current Anthropology, 11 (1961), pp. 71-102.

[2]For a selection of Hagerstrand's work see, T. Hagerstrand, The Propagation of Innovation Waves, Lund Studies in Geography: Series B, Human Geography, No. 4 (Lund: Gleerups, 1952); T. Hagerstrand, Innovation Diffusion as a Spatial Process, translated by A. Pred (Chicago: University of Chicago Press, 1967); T. Hagerstrand, "Quantitative Techniques for Analysis of the Spread of Information and Technology," in Education and Economic Development, ed. by C. A. Anderson and M. J. Bowman (Chicago: Aldine, 1965), pp. 244-280.

[3]For some brief comments on this see, D. Harvey, "Models of the Evolution of Spatial Patterns in Human Geography," in Models in Geography, ed. by R. J. Chorley and P. Haggett (London: Methuen, 1967), pp. 550-551. L. A. Brown and E. G. Moore, "Diffusion Research in Geography: A Perspective," in Progress in Geography, Vol. 1, ed. C. Board, et al. (New York: St. Martins Press, 1969), pp. 121-123 also discuss this topic. They attempt to distinguish two main approaches to the study of innovation diffusion by geographers, namely, a landscape, or Sauer, school and a locationalist, or Hagerstrand, school. According to these authors the former school is essentially empirical-inductive attempting to ". . . explain its observed spatial distribution as the outcome of a process unfolding over space and time" while the latter, deductive-theoretical, school examines ". . . the generative processes by which the observed locational pattern of a given phenomenon comes into existence." It would appear, however, that such a distinction is not a meaningful one in terms of the criteria the authors use.

Much of the research undertaken by geographers in the last twenty years on the subject of innovation diffusion has favoured a particular approach to investigating the problem. This approach, pioneered by Hagerstrand, is concerned with the use of Monte Carlo simulation methods as a means of examining the properties of certain processes relating to innovation diffusion.[1] Such research is characterized by a procedure which involves, typically, choosing a particular process (type of behaviour) which empirical evidence suggests is important in innovation diffusion. Next a device is developed (Hagerstrand's mean information field) to describe the process in question and this is used in a simulation model to produce hypothetical patterns of diffusion of some innovation. A comparison between the simulated pattern and a 'real-world' pattern of diffusion is then undertaken in order to 'test' the validity of the initial behavioural assumptions.

Such an approach does seem to be a valuable way of examining the properties of certain kinds of fairly simple behaviour and as such is one way of attempting to fulfill what some see as a vital need in geography, that is, relating

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[1]S. Gale, "Some Formal Properties of Hagerstrand's Model of Spatial Interactions," Journal of Regional Science, 11 (1972), pp. 199-218.

patterns to the processes which produced them.[1] It can be argued, however, that emphasis on this approach has led to a neglect of detailed empirical investigation of innovation diffusion. This fact should be viewed in the light of the danger associated with using the Hagerstrand-type simulation approach. Specifically that the researcher may replicate the system being studied without gaining insights into it.[2] Also, being able to produce a degree of similarity between a simulated and an observed pattern by means of input in the form of certain behavioural assumptions does not mean that the actual process which produced the observed pattern has been identified. It seems that often the only way of determining whether the initial assumptions about the nature of human behaviour are realistic in terms of a given problem is by detailed empirical investigation of that problem.[3]

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[1]D. W. Harvey, "Pattern, Process, and the Scale Problem in Geographical Research," Transactions of the Institute of British Geographers, XXXXV (1968), pp. 71-78; J. Eichenbaum and S. Gale, "Form, Function, and Process: A Methodological Inquiry," Economic Geography, XXXXVII (1971), pp. 525-544.

[2]For this and similar comments see, A. Pred. "Postscript," in Innovation Diffusion as a Spatial Process by T. Hagerstrand (Chicago: Chicago University Press, (1967), pp. 308-310.

[3]For related comments see, F. Lukermann, "Geography: de facto or de jure," Minnesota Academy of Science Journal, XXXII (1965), pp. 189-96.

A similar problem is related to the danger of assuming that because one type of behavioural mechanism (process) appears to be of importance in some cases of diffusion, then the same kinds of processes will be important in others. In fact, it seems that geographers have deliberately chosen to investigate 'simple' instances of diffusion using such criteria as those employed by Hagerstrand (good documentation, capability of adoption by large numbers of persons in the study area etc.), and as such have only sampled a particular kind of diffusion situation.[1] It is possible with different innovations that different processes become important.[2] For example, Brown has shown that where the innovation is acquired (purchased etc.) via an agency then what he calls 'market factors' become very important.[3] Similarly, recent work by Pred, although not based directly on empirical findings, suggests that other processes than those concerned

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[1]T. Hagerstrand, Innovation Diffusion as a Spatial Process, translated by A. Pred (Chicago: University Press, 1967), pp. 11-12.

[2]Apart from information flow processes, that is.

[3]L. A. Brown, "Diffusion Dynamics: A Review and Revision of the Quantitative Theory of the Spatial Diffusion of Innovation," (unpublished Ph.D. dissertation, Northwestern University, 1966), 2-4, 42-49.

with 'information spread' may be important, especially in the diffusion of industrial and commercial innovations.[1] No work by geographers has, however, as far as the author is aware, specifically examined the spread of industrial innovations.

It is apparent from the preceeding discussion that only a limited attempt has been made by geographers to develop testable generalizations based on empirical investigation of innovation diffusion processes.[2] It can be argued, however, that detailed empirical investigation of the activities of man, in all its complexity, is the basic point of reference for research. Such investigation can, however, be very much aided and strengthened by an organized body of concepts, or generalizations. There should of course be a constant interplay between the empirical and the general levels in the study of innovation and diffusion.

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[1]A. Pred, Behavior and Location, Part 2. Lund Studies in Geography Series B, No. 28 (Lund: Gleerup, 1969), pp. 72-74.

[2]L. Guelke, op. cit., pp. 50-51 in his analysis of recent geographical methodology suggests that one of the shortcomings of much work is that it has failed to develop 'theories' and models which are amenable to testing and therefore capable of denial. In addition internally consistent models have been constructed at the expense of losing touch with reality.

Current Needs in Innovation Diffusion Research

If one of the aims of geography is:

> . . . to develop geographic process theories that yield the spatial structure as deductive consequences of the theories.[1]

then it can be argued that research must be concerned with detailed empirical investigation of these processes.[2] Such investigation will be, at least in part, concerned with decision-making at the level of the individual, since any pattern of diffusion is an aggregate manifestation of such decisions. Thus, empirical investigation will provide insights into just what processes are at work in the innovation and diffusion situation, and as a consequence, aid the development of a more viable set of concepts related to

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[1]L. J. King, "The Analysis of Spatial Form and its Relation to Geographic Theory," Annals of the Association of American Geographers, LIX (1969), p. 593 and pp. 593-95 for a brief review of work along these lines.

[2]F. Lukerman, Geography: de facto or de jure, op. cit., p. 194. Argues that: "Only in accepting process as an integral part of empirical investigation in geography do we finally make possible the relation of the particular to the general. It is in carrying through this relation that we really attain what may be properly called an explanation that directly involves the factual content of the dicipline. In combining the object-level description and model-level explanation in a speculative but probabilistic schema, geography achieves what is best described as a discourse-level narrative."

this.[1]

Such a task will involve the study of the spread of a variety of types of innovation including those complex diffusion situations where the changing relationships between the innovation, its spread, and the environment is apparent. Such studies should, however, be closely related to the existing generalizations and concepts (theory?) developed by both geographers and workers in other disciplines in relation to innovation and diffusion.[2] The role of such a body of 'theory' is not to replicate reality, but to act as a useful device for further observation. As Lukermann states:

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[1]The need for a 'more noble set of concepts related to diffusion of innovation' is noted by L. A. Brown, and K. R. Cox, "Empirical Regularities in the Diffusion of Innovation," Annals of the Association of American Geographers, LXI (1971), pp. 551-59. This could be achieved, in part, they argue ". . . were more attention now given to the behavioral events and their characteristics, rather than to the empirical regularities themselves."

[2]Extensive work has been undertaken by social scientists on the diffusion of innovations. This is especially true of the sociologists. For a review of this work see, E. M. Rodgers, Diffusion of Innovation (New York: The Free Press, 1962).

> Hypotheses and models are not to be viewed as reality, they are not substitutes for reality, they are not analogues of reality, but rather they are logical (linguistic and mathematical) constructs selected ad hoc to clarify and communicate the observation, measurement, recording, and classification of empirical events.[1]

The Relationship Between Process and Structure

At this stage it is thought necessary to clarify the use of several terms. Implicit in much of the previous discussion and in much of geographical writing, is the notion that process is temporal and structure (form or pattern) is in essence spatial and that process contributes a 'history' to the spatial pattern.[2] This is misleading. Processes operate in both time and space (timespace) just as

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[1]F. Lukermann, "The Role of Theory in Geographical Inquiry," The Professional Geographers, XIII (1961), pp. 3-4. Similar arguments are also put in F. Lukermann, "On Explanation, Model, and Description," The Professional Geographer, XII (1960), pp. 1-2. Such concepts and generalizations can be a valuable source of the kinds of questions which are a precondition for systematic observation see, F. A. Hayek, "The Theory of Complex Phenomena," in The Critical Approach to Science and Philosophy, ed. M. Bunge (London: Free Press of Glencoe, 1964), p. 332.

[2]This idea is expressed, for example, in D. W. Harvey, "Pattern, Process, and the Scale Problem in Geographical Research," Transactions of the Institute of British Geographers, XXXXV (1968), pp. 71-72.

patterns -- certain observable manifestations of processes -- unfold in timespace. As Blaut notes:

> Relative space is inseparably fused to relative time, the two forming what is called the space-time manifold, or simply process. Nothing in the physical world is purely spatial or temporal; everything is process.[1]

The implications of this point of view are also made explicit:

> Modern science and scientific philosophy have adopted, almost unanimously, what has been termed a process philosophy. The object concept - discrete, concrete entities interacting across some "hardly real" medium by means of indefinable empirical relationships - has been replaced by a process model. Most now talk of systems of interacting, interpenetrating part-processes. A system is a relativistic, processal object. It is discrete and bounded only to the extent that boundary processes are unimportant in relation to internal processes, or irrelevant to a given inquiry.[2]

This means that all things are processes acting in timespace, including what is usually termed 'spatial structure'. It is up to the researcher to identify those particular processes (systems) in which he is interested.

Diffusion is movement relative to some frame of

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[1] J. M. Blaut, "Space and Process," The Professional Geographer, XIII (1961), p. 2.

[2] J. M. Blaut, "Object and Relationship," The Professional Geographer, XIV (1962), p. 2.

reference. For many practical purposes this will be an arbitrary timespace coordinate system. The real frame of reference, however, must be the environment or structure in which the innovation and diffusion takes place. This structure or environment (synonymous terms in this study) is distinguishable because:

> The majority of real-world events include both rapidly changing and slowly changing processes, and it is usually convenient to separate the two conceptually, . . .
>
> The relatively static events are often referred to as 'structure'; the relatively mobile ones as 'process' or 'function'.[1]

It should be noted however, that the background processes we have arbitrarily called 'structure' may actually be rapidly changing. For example, diffusion may take place through a 'structure' which is itself a diffusing item.

It is usual for the diffusion of innovations to be monitored by the use of a series of maps which show the pattern of adopters of the innovation for times t_1, t_2, . . . t_n. It should be remembered, however, that the process is reality and not the static timespace slice called the map, which is a means to an end and not an end in itself.

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[1]J. M. Blaut, "Space, Structure and Maps," Tijdschrift Voor Economische en Sociale Geografie, LXXII (1971), p. 19.

Aims of the Study

Pursuing the implications of the previous statements, the aim of this research is twofold. First, to synthesize various statements, findings, generalizations etc., relating to the innovation and diffusion process and its timespatial manifestation, in order to provide a conceptual framework within which empirical examples of the process can be viewed. Second, to demonstrate the general utility of such a framework and some of its more specific aspects with regard to a particular empirical case of innovation and diffusion.

In the first part of the study ideas are drawn from a wide range of geographical and other sources and integrated to form a conceptual framework. Special attention is given to conceptualizing the role of the organization (diffusion agency) in the spread of innovation. Such a framework is potentially of great value in empirical investigation for:

> . . . spatially unstructured concepts would appear to be the most useful general tools that the geographer possesses. Concepts like "hinterland," threshold," and "range of a good," have the necessary flexibility to be applied to countless individual cases while not requiring that data be forced into preconceived geometrical or spatial patterns. At the same time one is able to make full account of the particular aspects of any given situation, which is necessary if an

> adequate explanation of a geographical phenomenon is to be provided.[1]

The empirical aspect of the research looks at the development and diffusion of an innovation of major importance, the stationary steam engine as improved by James Watt. This particular innovation was chosen for two main reasons, 1) it was thought that the spread of an innovation of major importance might involve processes which are not significant when minor innovations are examined, and 2) it is extremely well documented. This study, however, really examines two innovations; the reciprocating engine initially patented in 1769 and first produced in 1775; and the rotary motion engine which was patented in 1781. The period of study, 1775 to 1800, represents the length of time for which Watt's patents were in force, and during which time the firm of Boulton and Watt had, in theory, a monopoly of production of such engines.

The major source of data for the study of the diffusion of James Watt's steam engine innovations is the Boulton and Watt Collection of manuscripts.[2] This consists of the

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[1]L. Guelke, op. cit., p. 50. Care should be taken, however, that the use of concepts like 'threshold' does not force the process into a preconceived mold.

[2]These are located in the Birmingham Reference Library, Birmingham, England.

records of the firm of Boulton and Watt, an organization which was established to sell the improved steam engines. In addition to providing information on the date of adoption, the location, and the use of the engine, etc., the records of the firm include an extensive body of correspondence between the business organization and its customers. This provides a large amount of information, of a type which is generally not available to researchers, pertaining to the diffusion of the innovations. This contemporary information is used especially to provide insights into both the adoption-decision process and the role of the above mentioned firm in the spread of the innovations.

Organization

This dissertation is divided into two main parts, the first of which provides the conceptual framework (chapter one), and the second of which presents the results of the empirical investigation (chapters two to six).

The latter five chapters deal with various aspects of the innovation and diffusion of the steam engine. The first of these presents general background information. The other four chapters are separated into 1) the general diffusion pattern, 2) among and within industry use of the innovation,

3) information flow processes, and 4) the organization and the diffusion. These chapters are closely interrelated and where appropriate the links between them and the conceptual framework are made explicit. The conclusion draws together the elements of the study and presents some suggestions for further study.

CHAPTER 1

A CONCEPTUAL FRAMEWORK FOR THE INNOVATION AND DIFFUSION PROCESS

Introduction

> The concept of population as a set of objects with births into it and deaths out of it is highly general and applies not only to biological species but also to social species such as artifacts, organizations, and even to ideas and to the structure of knowledge.[1]

Into the total population of human knowledge new ideas (innovations) are constantly being born in the minds of individuals located at specific points in timespace. Depending on conditions these ideas may spread to other individuals at other locations and ultimately to the total human population. Both the process by which new ideas come about and the process by which they, and their concrete manifestations, spread are examined in this chapter.

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[1]K. E. Boulding, A Primer on Social Dynamics: History as Dialectics and Development (New York: The Free Press, 1970), p. 11.

More specifically the object of this chapter is to place in one context a variety of concepts, findings, etc., to provide a conceptual framework for the innovation and diffusion process. This will provide a basis for the examination of complex empirical situations in which many factors interact and in which these factors cannot be isolated and their effects measured separately. Since the process of innovation and diffusion is a complex one the framework presented here breaks it down into various sub-parts, or sub-processes, for purposes of clarity. First, innovation is examined and some of the key factors, or variables, thought to be important in the process are identified. Similarly, innovation diffusion is examined and four major sub-processes are discussed as well as the role of the agency, or organization, in the overall diffusion process.

The framework presented here is not well established theory but an ad hoc collection of concepts representing the best insights and information available at the time. As such it is tentative and subject to modification as further insights and data become available.[1]

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[1]O. Helmer, Social Technology (New York: Basic Books, 1966), pp. 5-6.

The Innovation Process

The Concept of Innovation

Barnett defines innovation as follows:

> . . .any thought, behavior, or thing that is new because it is qualitatively different from existing forms.

He continues by stressing that:

> Strictly speaking, every innovation is an idea, or a constellation of ideas; but some innovations by their nature must remain mental organizations only, whereas others may be given overt and tangible expression.[1]

An innovation, then, represents a new organization of prior knowledge (things already known) in the mind of an individual, resulting from what Usher calls an 'act of insight' and Koestler calls an 'act of creation'.[2] It is, in Boulding's terminology, a restructuring of ones image of the world; a situation which he sees as similar to the mutation process

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[1]H. G. Barnett, Innovation: The Basis of Cultural Change (New York: McGraw Hill, 1953), p. 7.

[2]A. P. Usher, "Technical Change and Capital Formation," in The Economics of Technical Change, ed. by N. Rosenberg (Harmondsworth, England: Penguin Books, 1971), pp. 46-7. A. Koestler, The Act of Creation (London: Hutchinson, 1964).

in biology.[1]

It should be noted, however, that there is some confusion with regard to the terminology used by the various writers on innovation. For instance, Usher, writing mainly from a technological point of view, uses the term 'invention' to describe the 'act of insight' and 'innovation' to describe the first use of the new item.[2] We can agree with Ruttan, however, that invention is a less general term than innovation and as such best reserved for that sub-set of innovations it is possible to get a patent for.[3] In this study the term 'innovation' will be used to describe the act of insight by which a new idea is created. Invention may be used to describe patented innovations. The term 'diffusion' refers to the spread of the innovation.

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[1]K. E. Boulding, A Primer on Social Dynamics: History as Dialectics and Development (New York: The Free Press, 1970), p. 58. The similarity to the mutation process has also been noted by S. Toulmin, "Innovation and the Problem of Utilization," in Factors in the Transfer of Technology, ed. by W. H. Gruber and D. G. Marquis (Cambridge, Mass.: M.I.T. Press, 1969), p. 25.

[2]A. P. Usher, op. cit., pp. 43-71.

[3]V. Ruttan, "Usher and Schumpeter on Invention, Innovation and Technological Change," Quarterly Journal of Economics, LXXIII (1959), p. 605.

The above definition of innovation leads to the observation that newness in the realm of human ideas is quite a common phenomena. In this context, it should be pointed out that the concept of something new and the mental processes which give rise to it should really be considered as independent of consequences. The latter should, however, be stressed. Barnett writes:

> Many ideas are stillborn, and countless others are ephemeral and perish without trace. Some are only casual thoughts; others become cornerstones of faith. Some affect only the innovator himself; others millions of individuals.[1]

From the point of view of the way society is organized in time and space (timespace), it can be seen, therefore, that new ideas will vary greatly in their significance. Some will have a major impact on this organization others practically none at all. To use the words of Marshall McLuhan:

> . . . the 'message' of any medium or technology [innovation] is the change of scale or pace or pattern that it introduces into human affairs.[2]

Of course, it is generally the case that the 'message' of any innovation is only fully appreciated in retrospect.

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[1]H. G. Barnett, op. cit., p. 91.

[2]M. McLuhan, Understanding Media: The Extensions of Man (New York: McGraw Hill, 1964), p. 8.

The Process of Innovation

Probably the best known and most widely accepted model of the innovation process is that formulated by A. P. Usher.[1] He suggests that four main stages in the process can be identified:

1) Perception of an unsatisfactory pattern
2) Setting the stage
3) The primary act of insight
4) Critical revision and development

A problem situation usually emerges when an individual perceives some inadequacy in current modes of action or knowledge (stage 1). This is followed by a period (stage 2) in which the elements of data necessary for a solution are brought together through some particular configuration of events or thought. The solution to the problem is found when the primary act of insight occurs (stage 3), however, it should be pointed out that acts of insight occur at other stages of the process. The final stage of the process (4) is one in which the solution found in stage 3 is fully

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[1] A. P. Usher, A History of Mechanical Invention (Harvard: University Press, 1954), pp. 65-72. For a review of this in relation to previous theories see, V. Ruttan, op. cit., pp. 596-606.

appreciated, perfected and placed in context.[1] This latter period is often called the research and development phase or the 'lag' time between initial conception and first use of an innovation.[2] As shown below in chapter 2, this period can often extend for several years and be very much influenced by the availability of financial and moral support.

In Usher's view invention, or innovation, results from the above process. He points out, however, that any major innovation represents a 'cumulative synthesis' of many individual break-throughs. Although this model does aid in understanding the process of innovation, a word of warning should be introduced. As with all 'stage models', there is a tendency to simplify and divide up what is in all probability a continuous and complex process with 'feedback

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[1]This formulation, by Usher, appears to be similar to that suggested for the problem solving process, in J. G. March and H. A. Simon, Organizations (London: Wiley, 1958), p. 179. They distinguish three stages: (1) Problem formulation, (2) Search for alternatives, and (3) Evaluation of the alternatives (solution). For a brief review of similar models used by other authors see, J. W. Haefele, Creativity and Innovation (New York: Reinhold, 1962), pp. 12-17.

[2]For an elementary discussion of 'lags' see, A. Toffler Future Shock (New York: Bantam Books, 1971), pp. 26-28. See also, J. L. Enos, "Invention and Innovation in the Petroleum Refining Industry," in The Rate and Direction of Inventive Activity: Economic and Social Factors, National Bureau of Economic Research (Princeton: Princeton University Press, 1962), pp. 299-321.

mechanisms' involved in it.[1]

Causes and Conditions

The process of innovation as outlined above involves a restructuring of existing knowledge to form a novel solution to a perceived problem -- a process in which information is both an input and an output. This description of how the process occurs provides clues for a discussion of the causes of, and conditions conducive to, innovation. Most work has been done at the aggregate level (societal) and in connection with patented industrial innovations (inventions). Comments should, however, be applicable to innovation in general and to the basic unit of innovation, the human mind.

Problem Situations

Innovation does not take place in a vacuum but is a response to particular problems which arise in the environment.[2] These problems arise out of changes in the 'state'

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[1]For a detailed discussion of the complex nature of the process see, Barnett, op. cit., pp. 181-289.

[2]Even when an innovation could be said to have occurred 'by accident' it is still a product of the existing state of knowledge and it is required that some observer of the incident perceives the innovation and either recognizes its potential for fulfilling some need or is prepared to utilize it. It should also be noted that a given innovation can be made independently by different persons at different timespatial locations. It is, therefore, possible that the innovation may diffuse from multiple origins.

of the environment or cultural milieu.[1] In general, a problem situation is one in which there is a degree of stress, tension, or anxiety, and one way in which this can arise is from a failure to immediately adjust to change. One way of explaining this is in terms of aspiration and achievement levels and of the gap between these two.[2] A graph to show one possible form of this relationship is shown in figure 1. Environmental changes, in such an instance, would result in an increase in the gap between aspiration and achievement levels and this creates a stressful or problem situation. An example of this would be where sales potential for a product increases due to market expansion (rising aspiration level) while, at the same time, the ability to produce the item remains static (fixed achievement

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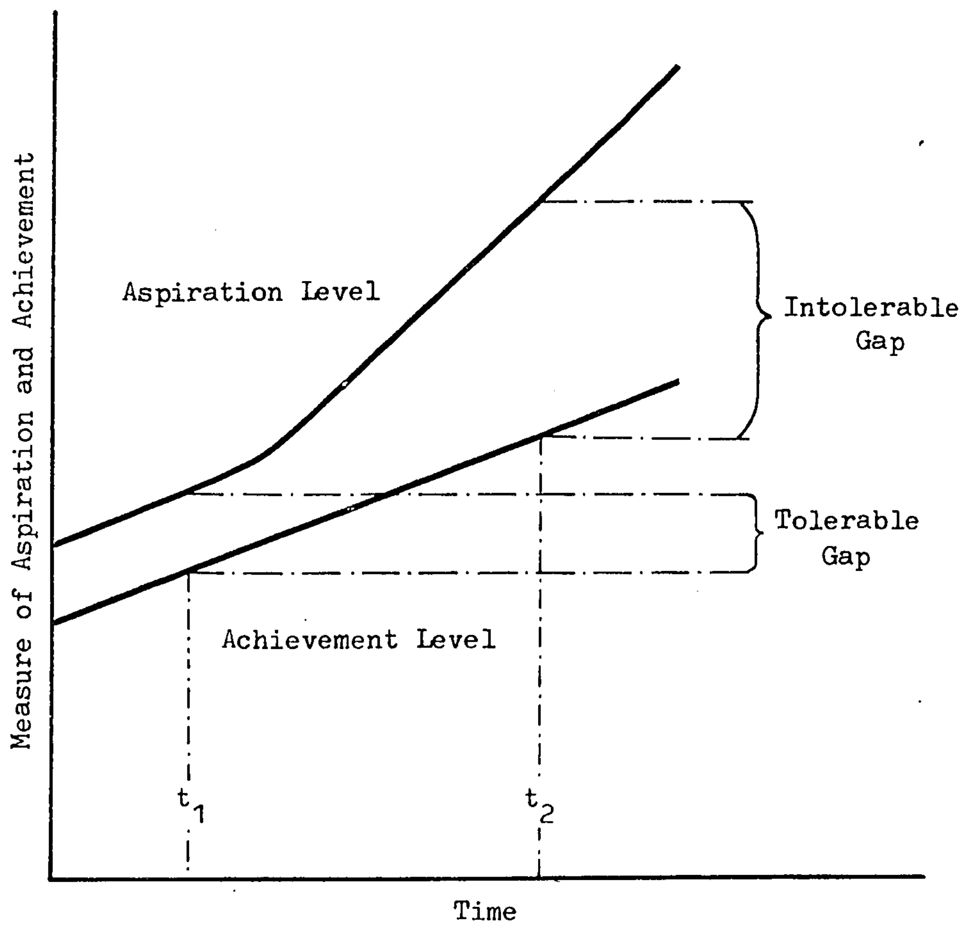
[1]This idea has been expressed by many writers on innovation and invention. See, for example, S. C. Gilfillan, The Sociology of Invention (Cambridge, Mass.: M.I.T. Press, 1970), pp. 5-13; J. Schmookler, Invention and Economic Growth (Cambridge, Mass.: Harvard University Press, (1966), pp. 11-12, and p. 73; J. G. March and H. A. Simon, Organizations (London: John Wiley, 1958), pp. 183-184.

[2]A similar formulation has been used to 'explain' the occurrence of revolutions. See, J. C. Davis, "Towards a Theory of Revolution," American Sociological Review, XXVII (1962), pp. 5-19.

FIGURE 1. CHANGING RELATIONSHIP BETWEEN ASPIRATION AND ACHIEVEMENT.



Source: see text

level). An innovation would enable the gap between the two levels to be reduced. A need or want for innovation is therefore created and it is this that the potential innovator reacts to. Conditions in the environment change for a good many reasons, for example, population growth or decline, urbanization, war, etc. It is in periods of change, especially rapid change, that demand for innovation is greatest.[1] In economic terms Schmookler states:

> . . . it seems probable that expected profits from invention, the ability to finance it, the number of potential inventors, and the dissatisfaction which invariably motivates it - are all likely to be positively associated with sales.[2]

This is due to the fact that invention, like so many activities, is often motivated by a desire for gain and this varies for many activities with the expected sales of goods embodying the innovation.

This whole notion might be usefully expressed in terms of the emergence of a general energy or information field relating to perceived and stated needs of individuals. The intensity

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[1]An expanding market is especially favourable to innovation and diffusion since this facilitates adding new equipment without scrapping the old.

[2]J. Schmookler, "Economic Sources of Inventive Activity," Journal of Economic History, XXII (1962), p. 18.

and extent of the 'field' would, of course, vary with the intensity and generality of the perceived change in the environment.

One of the main causes of change in environmental conditions, not yet discussed, is that of innovation itself. Like many circular systems involving feedback, once discovered a new idea, or technique, may illuminate further unsatisfactory ways of doing things which in turn call for additional innovative solutions.

Given that a 'demand' situation (energy field) exists with regard to unique solutions to perceived problems, it can be assumed that potential innovators must be aware of these problems before they can find solutions to them. This means that flows of information (communications factors) are important in the innovation process. Demand must, therefore, be communicated to the potential innovator and, since information like any other commodity is not moved without 'cost', this means, in general terms, that the 'nearer' (in the broadest sense of the word) an individual is to the source of information (problem area) the more likely he is to be aware of the problem and the potential rewards associated with finding a solution.

Search For Solutions

Just as problems emerge out of the changing state of the existing cultural milieu, so, in finding a solution for a perceived problem, an innovator draws on societies' intellectual heritage or cultural inventory.[1] It follows that the accumulated knowledge of society sets a limit on what innovations are possible at a given time in the same way that the environment determines which are desirable. Since the cultural materials that provide the basis for a new conception must come to focus in the mind of some individual, access to information pertinent to finding a solution is a vital consideration in the second stage of the Usherian Model. 'Setting the stage' is in essence a period of search in which information of relevance to problem solution is brought together. A great many factors in society can affect an individual's access to information. These will consist of the person's individual characteristics as well as general societal characteristics which might speed or heed effective flow of information.[2] This topic

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[1]Schmookler, Invention and Economic Growth, p. 11; Barnett, op. cit., p. 10; p. 40.

[2]Communications factors have been considered important in innovation at least since the work of Gabriel Tarde in the 1890's, see, T. N. Clark, ed., Gabriel Tarde: On Communication and Social Influence (Chicago: University of Chicago Press, 1969), p. 26.

will, however, be explored in more detail in the section of this chapter dealing with information flows and the innovation diffusion process. The theme of information flows is also a recurring one in the empirical section of the dissertation. It is dealt with especially in chapter five.

Availability of Innovators

At both the societal and individual levels there are factors which may affect the availability of persons willing and able to engage in innovative activities. These factors influence whether persons (a) perceive the problems, (b) are willing to attempt solutions, and (c) have both the information and ability to find solutions to the perceived problems. Access to relevant information has already been mentioned as significant for both (a) and (c), however, other factors such as financial resources (important in information seeking), education, and ability may be of consequence at the individual and societal levels. In addition, of great importance in influencing the degree to which persons are willing to attempt solutions is the societal attitude to innovative behaviour.[1] Devising new ways of

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[1]This is in addition to the 'pull' factors associated with the perceived rewards connected with innovation in a particular instance. 'Rewards' as a term is used broadly and these are entirely subjectively determined.

doing things often involves the individual in partially rejecting traditional modes of operation. This has been viewed by some writers as devient behaviour and as such may not be generally acceptable to certain societies. On the other hand under certain conditions this type of behaviour may be tolerated or even rewarded.

There may always be a few individuals in society who have the personality characteristics of innovators, however, under certain conditions it is possible that well defined groups may emerge which, although having deep and acknowledged roots in the society, are characterized by the perception 'that their purposes and values in life are not respected by groups in society whom they respect and whose esteem they value'.[1] The difficulty of gaining status in the accepted way leads, through a complex chain of events, to the channeling of efforts into other directions. This results in the emergence of innovative traits in the groups in question.[2]

Similar conclusions have been arrived at by McClelland.[3]

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[1]E. E. Hagen, _On the Theory of Social Change: How Economic Growth Begins_ (Homewood, Illinois: Dorsey Press, 1962), p. 185.

[2]_Ibid._, pp. 185-236.

[3]D. C. McClelland, _The Achieving Society_ (Princeton, New Jersey: Van Nostrand, 1964), pp. 210-258, and pp. 336-390.

He argues that high need for achievement is correlated with positive attitudes to risktaking, expending energy, willingness to innovate, and readiness to make decisions and accept responsibility. A high level of achievement motivation is developed, McClelland posits, by childhood influences, and he sees as crucial attitudes to child rearing which involve emphasis on self-reliance and mastery. Both Hagen and McClelland place great emphasis on the role of the emergence of such innovative minority groups in economic development and cultural change. Such group attitudes combined with conditions of easy access to information (education and dissemination of information, easily available information storage systems) and a demand can lead to a high rate of innovation. The applicability of this idea to late Eighteenth Century Britain is discussed in the following chapter.

The Timespatial Pattern of Innovative Activity

The specific pattern of innovation for a given activity will be a manifestation of both the processes previously outlined and the existing 'state' of the environment in question. The elements of importance in the process include the specific pattern of demand which may in turn be related to the rate of growth or change in various activities. Given constraints on the movement of information, it may be in areas where the demand is greatest that problem awareness is greatest and possibly that information relevant to solutions is most abundant. In such an instance it would follow that the pattern of innovation would mirror the pattern of the critical phenomenon.[1]

Traditionally, the centers of change in many societies have been said to be cities.[2] Although, obviously, this is not true of all activities. The reasons suggested for the concentration of innovative activity in urban places are related to the discussion outlined above. As Webber notes, the unique commodity that the city has to offer is accessibility.[3] In essence, urban nodes are massive communications systems, he suggests:

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[1]See, S. C. Gilfillan, The Sociology of Invention (Cambridge, Mass.: M.I.T. Press, 1970), p. 8.

[2]For comments on this idea see, R. Redfield, and M. B. Singer, "The Cultural Role of Cities," Economic Development and Cultural Change, III (1954), pp. 70-73.

[3]M. M. Webber, "The Urban Place and the Nonplace Urban Realm," in Explorations into Urban Structure, ed. by M. M. Webber (Philadelphia: University of Pennsylvania Press, 1967), p. 85.

> . . . actively involved in the business of producing and distributing the information that is the essential stuff of civilization - the accumulated wisdom, descriptive accounts, ideas and theories, reports of human events, laws, contracts, records of transactions, gossip, and the ideational products of the arts and sciences.[1]

The importance of cities as points of 'high' accessibility and the relation of this to flows of information is summed up in the following statement by Meier:

> The flow of information, ideas, concepts, artifacts and their human carriers from one context to another can be accelerated under conditions of high accessibility. The city is not only a crossroads, a place for outsiders to meet and trade, it is a living repository for culture - high, low, and intermediate.[2]

Cities, therefore, facilitate exchange of ideas and information as well as provide access to accumulated stores of information. In addition to this, many activities in most societies are primarily concentrated in urban places and it is often that in such places the rate of change is greatest. This is true as well of many commercial activities and industrial undertakings: a trend which became increasingly

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[1] Ibid., p. 36.

[2] R. L. Meier, "The Organization of Technological Innovation in Urban Environments," in The Historian and the City, ed. O Handlin and J. Burchard (Cambridge, Mass.: M.I.T. Press, 1966), p. 75.

obvious during the industrial revolution.

Although little work has been done on the timespatial patterns of innovative activity, the general impression is that in those societies which have some degree of urbanization then innovation becomes essentially an urban phenomena. Pred's exploratory work on United States inventive activity during the nineteenth century suggests a high correlation between invention and urbanization.[1] He writes:

> . . . inventive activity is apt to concentrate in urban environments where manufacturing is sizable and where the repertory of know-how accumulates most rapidly.[2]

and

> . . . the larger the city, the larger the number of intentionally and unintentionally overlapping information fields of laborers and other industrial personnel, the larger the volume of influential short-distance information flows, and the greater the awareness of specific technical problems and existing production process improvements.[3]

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[1]A. Pred, The Spatial Dynamics of U.S. Urban-Industrial Growth, 1800-1914; Interpretive and Theoretical Essays (Cambridge, Mass.: M.I.T. Press, 1966). This relationship is also suggested by W. R. Thompson, "Locational Differences in Inventive Activity and their Determinents," in The Rate and Direction of Inventive Activity: Economic and Social Factors, National Bureau of Economic Research (Princeton: Princeton University Press, 1962), pp. 253-271.

[2]Ibid., p. 95.

[3]Ibid., p. 129.

Evidence supplied by Smith does offer some support for the above ideas. He shows that Birmingham, England had a higher per capita rate of patented inventions for the mid-nineteenth century than would have been expected from examining national figures.[1] A recent article by Feller has however, critisized Pred's findings.[2] Many of the problems associated with this type of analysis appear to derive from the use of aggregate patent data and could be solved to some extent by more detailed investigation. Nevertheless, it is possible to say that there does appear to be a correlation between innovative activity and urbanization, and it is highly likely that this relationship is particularly strong in the periods of rapid urban-industrial growth associated with industrial revolution. This would appear to bear out the energy (information?) field hypothesis of aggregate mental activity as a generator of innovation.

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[1] B. M. D. Smith, "Patents for Invention: The National and Local Picture," Business History, IV (1962), pp. 109-119.

[2] I. Feller, "The Urban Location of United States Invention, 1860-1910," Explorations in Economic History, VIII (1971), pp. 285-303.

The Innovation Diffusion Process

Monitoring Adoption of Innovation

Once an innovation occurs, the process by which it spreads in timespace and is accepted by individuals, or other adopting units, is usually termed 'diffusion'. Adoption of an innovation takes place when an individual or group becomes committed to the new idea and accepts it. The act of adoption may be difficult to monitor in some respects, however, and usually a surrogate for the 'decision' is needed. This will be, in most cases, a change in behaviour which adopting the innovation induces. For example, non-material innovations like political ideologies may involve changed voting behaviour, with innovations such as television, the factory system, or a new breed of cow, the decision to adopt may be monitored by acquisition of the item in question. It should be noted, however, that even when a decision to adopt has been made it may not always be possible to immediately obtain the innovation (see below).

The Diffusion Process

Given a population of potential adopters of an innovation and a measure of when and where adoption takes place, how can variations in the time and place of adoption be accounted for? For the purpose of clarity, the diffusion process can be divided into four sub-processes and these are shown in figure 2:

1) An information spread process
2) An adoption-decision process
3) An acquisition process
4) An implementation process

It should be noted, however, that although separated, they are in reality part of a larger context as shown in figure 2 and hence very closely inter-related. This larger context may involve the role of an organization in the diffusion process, and this can relate to all the sub-processes identified above.

Information Spread Process

The basic mechanism of innovation diffusion is one which accounts for the way in which information concerning the innovation reaches the potential adopter. This is fundamental since a person cannot adopt without knowing about the innovation.[1]

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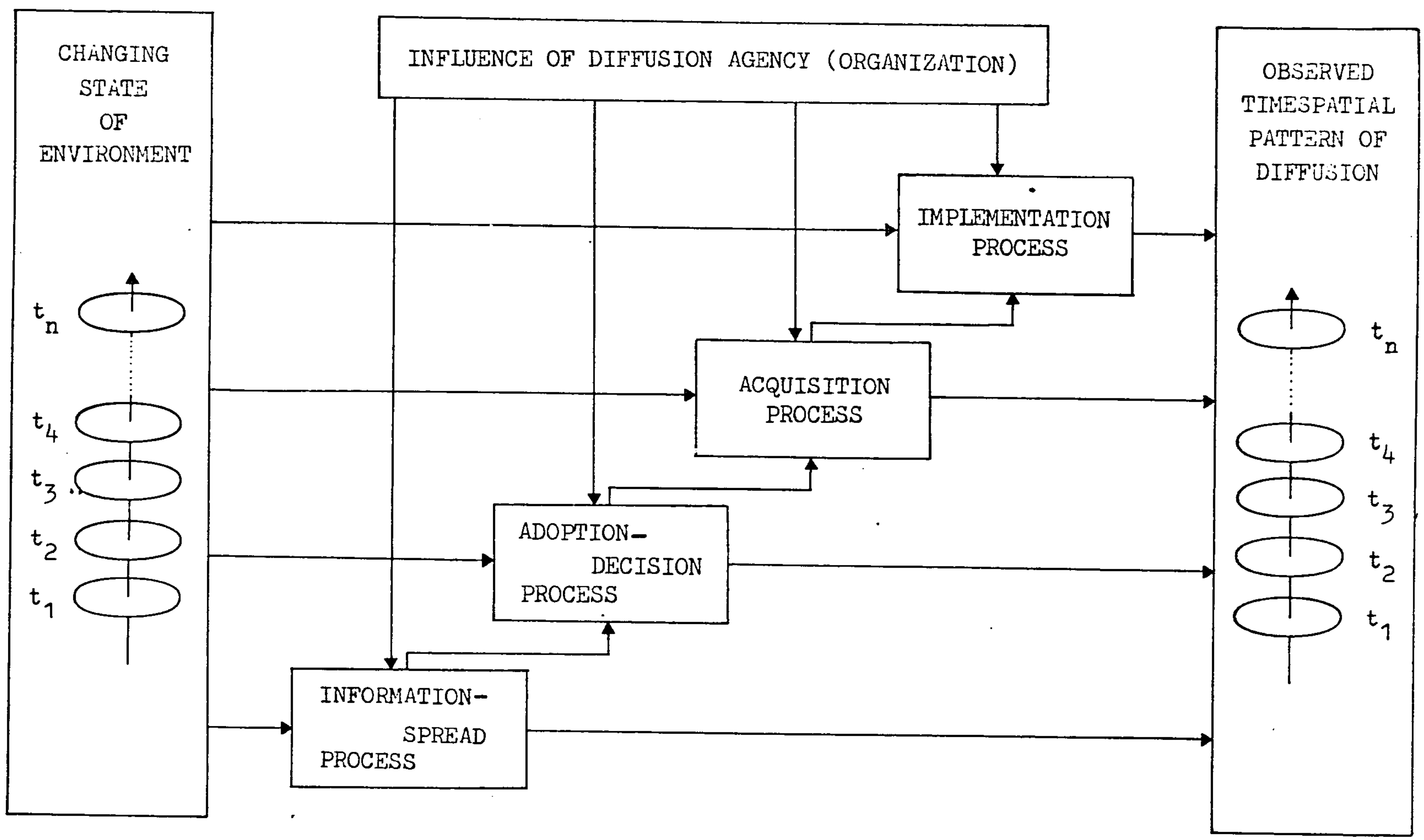
[1]A person can, of course, find that an innovation has been adopted on his behalf without knowing about it and a good example of this might be the adoption of fluoridation for city water supplies. In such a case, however, the adopting unit can usually be viewed as the city administration rather than the individual.

FIGURE 2. CONCEPTUALIZATION OF THE INNOVATION DIFFUSION PROCESS.



Source: author

The pattern of potential adopters in timespace provides the basic structure within which the diffusion takes place.[1] The ultimate pattern of innovation spread will be constrained by this structure -- a fact which can be of great importance when the group defined as potential adopters is not randomly distributed throughout the total population of the environment.[2]

Given a population of individuals, each with a location in timespace, they can be viewed as elements or nodes on a graph. It follows that at any one time (t_1, t_2, t_3, . . . t_n) some of the nodes (individuals) may possess information concerning the innovation and some will not.[3] The process by which information is communicated between the nodes can be described simply by using a version of a model suggested

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[1]The definition of potential adopters may present a problem in certain diffusion situations. In some cases this 'population' may be defined a priori, but in others it must be assumed to be the 'total population'.

[2]An example of this might be where the potential adopters are associated with a particular type of industry or farming enterprise.

[3]See, L. A. Brown, Diffusion Processes and Location. Bibliographical Series No. 4 (Philadelphia: Regional Science Research Institute, 1968), pp. 9-38.

by Weaver.[1] In this, a source-node (S) selects a message it wishes to communicate. This message passes by means of a communication channel (C) to a receiver-node (R). In terms of graph theory, the establishment of a link (C) between two nodes (S and R) represents a path of relationship, influence, or movement which is termed an edge. Such graphs are dynamic in that the pattern of nodes (S and R) and edges changes over time.

The communications process outlined above can now be discussed in terms of the characteristics of source nodes, receiver nodes, and the relationships (channels, flows or edges) between them.

a) Source Nodes

What are the sources of information concerning innovations and what are the characteristics of these? Two main classes of sources can be identified:

1) Previous adoptors of the innovation

2) Organizations or individuals which, although not adoptors, have an interest in promoting the spread of the innovation

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[1]W. Weaver, "The Mathematics of Communication," in Communication and Culture, ed. by A. G. Smith (New York: Holt, Rinehart & Winston, 1966), p. 17.

The fact that previous adopters of innovations are important sources of information has been recognized by many researchers, and in the diffusion models of Hagerstrand these individuals form the only sources of information. Other researchers have, however, recognized the important role played by promotional agencies and other individuals (carriers) in spreading information about innovations.[1] It appears, therefore, that innovation promotion can be either formal, as with a government agency or firm, or informal, as with individuals who spread information for a variety of personal motives. In the former instance, the information sources are likely to be controlled by some central decision-making authority which directs action.[2]

Sources of information are not all alike with regard to the quantity and quality of information emitted. The propensity of source nodes to send messages concerning an innovation may vary for many reasons, for example, Karlsson

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[1]For some comments on 'middlemen' or 'carriers' see, F. Redlich, "Ideas, Their Migration in Space and Transmittal Over Time," Kyklos, VI (1952), pp. 301-22.

[2]This is what K. E. Boulding, A Primer on Social Dynamics: History as Dialectics and Development (New York: The Free Press, 1970), p. 3, calls a teleological process. Such organizations are discussed below in this chapter.

emphasizes the importance of motivation to communicate.[1] This motivation may be influenced by factors such as the sources' perception of the importance of the message to the group with which communication is to take place. Other researchers have emphasized that certain individuals tend to be much more likely to be sources of information on particular topics.[2] These persons usually called 'opinion leaders' or 'key communicators' are often receivers of a greater quantity and variety of information, which they may process or interpret before they pass it on to receiver nodes. This situation has been identified with regard to the 'two-step' flow of mass-media information via opinion leaders to receiver nodes.[3] It is, however, possible to generalize the concept of 'influentials' so that they exist not just as processers of mass-media information, but as receivers and interpreters of information from a wide

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[1] G. Karlsson, Social Mechanisms (New York: The Free Press, 1958), pp. 29-32.

[2] H. F. Lionberger, Adoption of New Ideas and Practices (Ames, Iowa: Iowa State University Press, 1960), pp. 55-66.

[3] E. Katz, "The Two-Step Flow of Communication: An Up-to-date Report on a Hypothesis," Public Opinion Quarterly, XXI (1957), pp. 61-78.

variety of interpersonal sources as well, the processed information being passed on, often selectively, to receivers. The role of such persons is especially important in the diffusion of the innovations dealt with in this study, especially in chapter 5.

b) Communications Channels

The links between source nodes and receivers of information in innovation diffusion are channels of communication. One generally accepted classification of these channels is into 1) interpersonal, and 2) mass-media, the main characteristics of these being summarized by Rogers as follows:[1]

	Interpersonal	Mass-media
1. Direction of Message Flow	Two-way	One-way
2. Speed to Large Audiences	Slow	Rapid
3. Accuracy of Message to Large Audiences	Low	High
4. Ability for Source to Select Receiver	High	Low
5. Ability to Overcome Selectivity Process	High	Low
6. Amount of Feedback	High	Low
7. Possible Effect	Attitude Change	Increased Knowledge

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[1]E. M. Rogers, _Modernization Among Peasants: The Impact of Communication_ (New York: Holt, Rinehart, 1969), p. 125.

The above classification presents several criteria for distinguishing between the two types of communications channels, and the distinction does seem to be appropriate for certain purposes and situations. For example, there is an obvious distinction between the electronic mass-media of today and interpersonal contacts, according to Rogers' criteria. As Karlsson notes, however, it is in many instances difficult to distinguish between the two types of channels.[1] In between the two extremes, for instance, fall such phenomena as meetings and demonstrations, which have some of the characteristics of both the types of channels discussed above. It is also doubtful whether, in a historical context, much weight can be attached to the term 'mass media' as a description of newspapers, etc.[2]

Given a population of individuals (nodes), what is the likelihood of communication (interaction) occurring between two nodes (a source and a receiver)? A useful conceptual basis for the discussion of this has been suggested by Anatol Rappoport, who outlines a series of biases, which

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[1]G. Karlsson, op. cit., p. 18.

[2]See below, chapter 5.

affect the probability of interaction between nodes.[1] If, in a population, the probability of interaction (message flow) between any two nodes is equal then this is termed a random network. In such a situation, it will not be possible to predict the direction of interaction or communication, however, this type of network is seldom, if ever, found in reality, and a whole range of biases modify the randomness of the network. Several such biases will be briefly mentioned here.

Distance Bias: In this, the probability of communication between nodes is a function of the distance between them. For geographers, this usually means distance measured in euclidean space. Such a distance bias was utilized by Hägerstrand in developing the notion of the mean information field (M.I.F.), which features so prominently in his simulation models.[2] The value of using such techniques in simulation models is limited, however, as such devices are

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[1]A. Rappoport, "Contributions to the Theories of Random and Biased Nets," Bulletin of Mathematical Biophysics, XIX (1957), pp. 257-277.

[2]For details of M.I.F.'s see, Hägerstrand, Innovation Diffusion as a Spatial Process, pp. 235-257.

'. . . contingent on the characteristics of the system in which they are measured', and, as such, are not rules of spatial behaviour which are independent of the particular structural elements of spatial system.[1] Nevertheless, the idea of a euclidean distance bias does have its attractions since it is based on the notion that individuals usually have a relatively fixed location in timespace around which they move, and, given this focal point, contacts tend to decrease with distance. The range of contacts, however, is influenced by many factors other than euclidean distance, for example migration and length of residence at a particular spot.[2]

It is clear that Rappoport's distance bias is not just concerned with euclidean distance, but with distances measured in other spaces, for example, social space with its '. . . peculiar metrical and topological properties'.[3]

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[1]G. Rushton, "Analysis of Spatial Behavior by Revealed Space Preference," Annals, Association of American Geographers, LIX (1969), pp. 342-3. A rule of spatial behaviour should, he argues, be place independant and capable of producing different patterns in different structural contexts.

[2]J. Wolpert, "Behavioral Aspects of the Decision to Migrate," Papers, Regional Science Association, XV (1965), pp. 163-165.

[3]A. Rappoport, "The Diffusion Problem in Mass Behavior," General Systems Yearbook, 1 (1956), p. 50.

Social distance between nodes (individuals) is based on differentials in factors such as income, education, status, etc. The more alike people are, measured in this space, the shorter the distance between them. It is, of course, possible to think of distances measured in other spaces.[1]

Acquaintance Circle Bias: The probability of interaction between nodes in this case is a function of their being in the same acquaintance circle. Acquaintance circles, or cliques as they are often called, are not mutually exclusive, however, and some individuals may be members of more than one circle. In this way, interaction both within and between cliques is possible, although the probabilities of this may differ. One important point to note is that this kind of bias has obvious overlap with the distance biases mentioned above. Acquaintances or friends are likely to be close in both euclidean and social distance.

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[1]For a discussion of some of these see, J. W. Watson, "Geography - A Discipline in Distance," The Scottish Geo-Graphical Magazine, LXXI (1955), pp. 1-13; D. Harvey, Explanation in Geography (London: Edward Arnold, 1969), pp. 191-229. Anthropologists also recognize various kinds of distance, see, W. W. Howells, "Population Distances: Biological, Linguistic, Geographical, and Environmental," Current Anthropology, VII (1966), pp. 511-540.

Force-field Bias: In this bias, certain nodes are more likely to either send or receive information due to what is called 'popularity' or 'drawing power'. Some nodes, for example those located in large urban places, are much more likely to receive certain messages earlier and in greater quantities than others. This is due to biases in the circulation of much private and public information.[1]

Another example of this type of bias would be, using urban places as the nodes, the effect of size (measured in population) on interaction. The well-known 'gravity model' incorporates a force-field bias in its 'mass' term and it also uses a distance bias (usually euclidean). This raises an interesting question related to measures of distance; can it be measured in terms of population differences? If so then it would seem that the distance biases begin to duplicate the force-field ones.

Although the discussion has emphasized the effects of various factors (biases) on interpersonal communications, such biases also exist with regard to so-called mass-media

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[1]This topic has been explored recently for pre-electronic U.S.A. by A. Pred, "Urban Systems Development and the Long-Distance Flow of Information through Preelectronic U.S. Newspapers," Economic Geography, XXXXVII (1971), pp. 498-524. His map (p. 508) shows the hierarchical flow of information.

information flows. For example, where a message source is a newspaper or radio in town X then the probability of individuals being in the message audience of the source will be in part related to some distance measure(s).

Thus far it has been assumed that the nodes in our network have been relatively static, that is, although they move in order to interact, they have a fixed center around which they oscillate. This means that the path they trace in timespace shows no major discontinuities. In reality, however, individuals migrate, that is, they change the focus around which they oscillate. This is one way of spreading information concerning innovations, and the movement of ideas by this means has been recognized as of great importance.[1]

Receiver Nodes: It cannot be assumed that the node which receives information from a source by means of a particular communications channel passively awaits to be contacted. Potential receivers may be actively searching

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[1]F. Redlich, op. cit., pp. 302-303; W. C. Scoville, "The Huguenots and the Diffusion of Technology," Journal of Political Economy, LX (1952), pp. 294-311.

for information on particular topics,[1] and may select individuals whom they perceive to be sources of relevant information or whose opinion they respect (influentials or opinion leaders).

Receivers are, similarly, selectively exposed to mass-media and, apparently, different types of media attract different types of persons.[2] Some of the more important socio-economic factors affecting this selectivity are education, age, sex, income, and occupation. Similarly, the importance attached to messages will depend on the receiver's perception of the message quality, credibility or reliability and relevence (ability to place the information in a meaningful context).[3]

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[1]Many factors influence the extent and vigour of 'search' for information. Individual or group resources may be important, since acquisition of information costs time and money.

[2]S. Wade and W. Schramm, "The Mass Media as Sources of Public Affairs, Science, and Health Knowledge," Public Opinion Quarterly, XXXIII (1969), pp. 197-209; S. Greenberg and B. Dervin, "Mass Communications Among the Urban Poor," Public Opinion Quarterly," XXXIV (1970), p. 224-235.

[3]Rogers, Modernization, pp. 184-186.

The Adoption Process

Thus far it has been assumed that as soon as a receiver node becomes informed about an innovation then the individual adopts the innovation. In fact, evidence supports the notion that adoption of an innovation is a complex decision-making process involving a continuum from first awareness to final acceptance. It has been found useful by many researchers to break down this complex process into a series of stages, each having different kinds of behaviour and sources of information associated with it. Both Rogers and Lionberger suggest that five distinct stages can be identified.[1]

1) Awareness: A person first learns about an innovation. This may be the result of a more or less chance contact with information from any source or it may be the result of a general search in an area of interest.

2) Interest: A person becomes interested in the potential use of an innovation and begins to actively search (purposive) in a specific way for information concerning the innovation from a variety of sources.

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[1]E. M. Rogers, Diffusion of Innovation (New York: The Free Press, 1962), pp. 79-86; and H. F. Lionberger, Adoption of New Ideas and Practices (Ames, Iowa: Iowa State University Press, 1960), pp. 21-32. Note the general similarity between these stages and those in the innovation process.

3) Evaluation: In this stage the information collected concerning the innovation is weighed. Lionberger calls this the 'mental trial stage'. The influence of peers may be especially important.

4) Trial: Where this is possible the individual may first use the innovation on a small scale to determine personally its value. Information sought in this stage will be mainly concerned with the specifics of obtaining and utilizing the innovation.

5) Adoption: After the initial trial period a decision is made as to whether to maintain use of the innovation and make full use of it, or whether to reject it. Personal experience is most important here.

Although individuals in a population will generally go through part or all of the above process, it is possible to see from the arguments presented in discussing information spread, that some persons are unlikely to become aware of an innovation or at least the length of time elapsing before they do so will be great. Even when persons become aware, the length of time between this and adoption (trial) may vary enormously and some individuals never reach the adoption stage. The different lengths of time associated with the process can be explained in terms of variations in 'resistance' to the innovation. The use of this 'umbrella' term assumes that individuals have a negative attitude, at least initially, to new things. This is probably related to their uncertainty concerning the nature and potential of the innovation, which in turn is related to the information they have about the item. The diagram in figure 3, expresses this notion graphically.

In a given population, what kinds of factors determine when individuals will adopt an innovation? Biases in the time at which information is received have already been discussed. Other biases include attitudes to change and taking risks and in this context cosmopoliteness (the degree to which a person is orientated outside his particular social system),[1] age, income, size of organization (farm, business, etc.), etc., may all be important.[2] Of course all these factors may be closely interrelated. Many of the social factors identified suggest that the early adopter is in some senses a 'social deviant' or 'misfit', that is, one who does not conform to the norms of society.[3]

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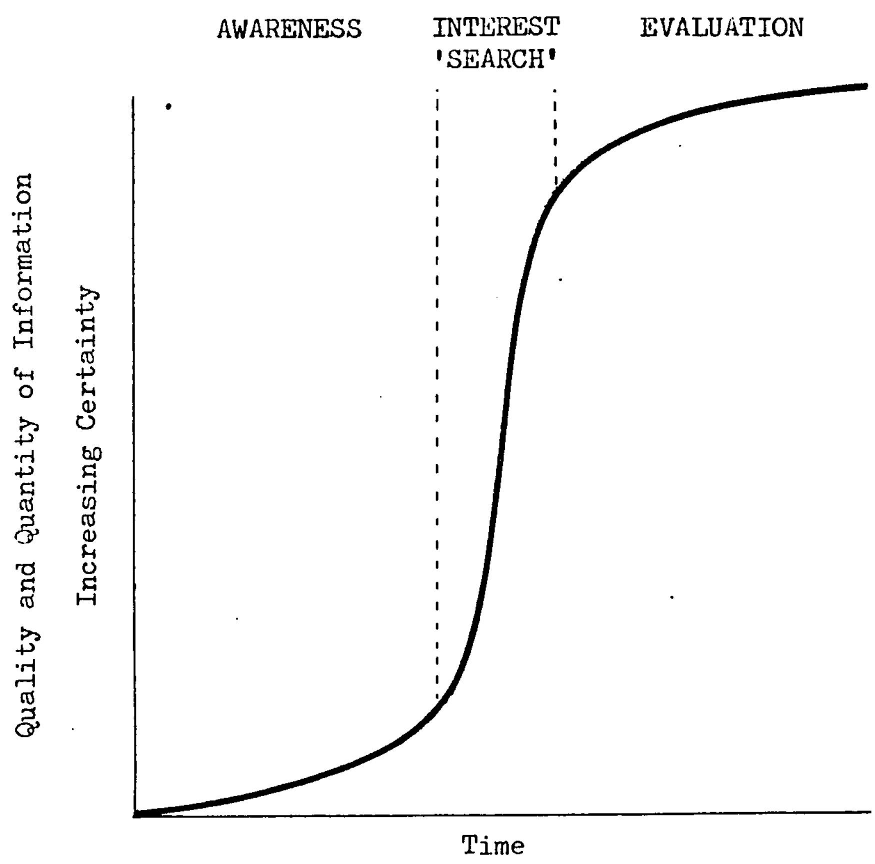
[1]The idea that early adopters may be more cosmopolite than others suggests that their patterns of communication or contact may be timespatially more extensive than is general. This would raise further questions about the validity of using the notion of a 'mean' information field.

[2]For a review of some of these factors see, E. M. Rogers, Diffusion of Innovation, pp. 185; and see below chapter 4.

[3]This has already been discussed in connection with 'innovators'. See, E. M. Rogers, Diffusion of Innovation (New York: The Free Press, 1962), pp. 193-207, for additional comments.

FIGURE 3. INFORMATION, UNCERTAINTY, AND THE ADOPTION–DECISION PROCESS.



Source: author

A factor of a slightly different nature, in its effect on spread of adoption, is that relating to the perceived applicability of the innovation with regard to the needs of the individual/group.[1] This involves the perceptual meshing of the characteristics of the innovation with the individual's needs, and in the case of industrial innovations, this may be related to the existing 'state' of technology in the industries which are potential users. This kind of factor is given empirical expression in chapter 4 of this study. Not unrelated to this is the idea that dissatisfaction on the part of individuals (see discussion of aspiration and achievement levels earlier) may lead to a search for innovations. In such instances, this might affect the speed of adoption of an innovation which is seen to be profitable in terms of reducing dissatisfaction.[2]

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[1]For a study which emphasizes the compatibility of an innovation with the norms and values of different groups see, S. Graham, "Class and Conservatism in the Adoption of Innovations," Human Relations, IX (1956), pp. 91-100.

[2]The idea that the speed of adoption of an innovation is related to profitability has been discussed extensively, for example see, E. Mansfield, "Technical Change and the Rate of Imitation," Econometrica, XXIX (1961), pp. 741-66; and Z. Griliches, "Hybrid Corn and the Economics of Innovation," Science, CXXXII (1960), p. 275-80.

The Acquisition Process

In many instances of innovation diffusion, making a decision to adopt a new idea and the acquisition of the physical manifestation of the idea may be viewed as separate elements in the process. This means that once a person has decided to adopt he must then involve himself in activities related to the acquisition of the innovation (where this has concrete expression and is supplied by persons other than the adopter).[1] However, the availability of the innovation may not be the same for all adopters, and here it is important to discuss what Brown has called 'market factors'.[2] He suggests availability is related to two principle factors 1) the distribution policy of the promoters (or sellers) of an innovation,[3] and 2) the 'shopping'

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[1]It is possible that a person will not adopt an innovation because of perceived difficulties associated with acquisition, even where these difficulties do not exist in reality.

[2]L. A. Brown, "Diffusion Dynamics: A Review and Decision of the Quantitative Theory of the Spatial Diffusion of Innovation," (unpublished Ph.D. dissertation, Northwestern University, 1966), pp. 2-4, 42-49.

[3]For more recent comments on this see, L. A. Brown and K. R. Cox, "Empirical Regularities in the Diffusion of Innovation," Annals of the Association of American Geographers, LXI (1971), pp. 55-59; and L. A. Brown, "Diffusion and Growth Poles: Comments on Recent Developments and Inter-Related Work," (unpublished paper, 1972).

behaviour of the adopters. The first of these will be dealt with in more detail below when the special role of promotion agencies in the process of diffusion are considered. The latter of these can be important where the availability of an innovation is limited to certain central places. In such an instance, the shopping trip behaviour of individuals in terms of which central places they interact with and the frequency with which this occurs, can be of great significance. In this regard, work along the lines of that undertaken by de Temple involving a consumer-space preference approach to the diffusion of innovations may be particularly valuable.[1]

The Implementation Process

Once a decision to adopt an innovation has been made, or even before, the adopter may be involved in the problem of implementation.[2] This means that, for a great many kinds

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[1]D. J. de Temple, A Space Preference Approach to the Diffusion of Innovations, Geographic Monograph Series, Vol. 3 (Bloomington, Indiana: Indiana University, Department of Geography, 1971).

[2]A. Pred, Behavior and Location, Part 2. Lund Studies in Geography, Series B, No. 28. (Lund: Gleerup, 1969), pp. 72-74.

of innovations, the adopter must make certain implementation decisions, that is, choose a location or locations, as well as deciding upon the scale of operation, etc. One decision-making body can, in fact, be responsible for the appearance of an innovation at a great many locations.

This process of implementation, which may apply particularly to industrial and commercial innovations of some importance, is involved with the whole question of the nature of the decision makers (adopters) perception (image) of the environment in which his decision is to be acted out.[1] This image (range of alternatives, spatial or otherwise) will be largely based on information which he has, either in storage or as a result of a search, concerning the environment.

Patterns of diffusion may, therefore, involve locational decision-making as well as adoptional decision-making, however, this question will be examined in more detail in the following section where the locational decisions of the propogator of the innovation (organization) are discussed; and in chapter 4 where the adoption of steam power in the

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[1]There is an increasing body of research by geographers which deals with behaviour and the perceived environment. See, for example, T. F. Saarinen, Perception of the Drought Hazard on the Great Plains, Department of Geograph Research Paper, Number 106 (Chicago: Department of Geography, The University of Chicago, 1966).

cotton industry in the 1790's is examined.

The importance of such processes in diffusion of innovations can be readily appreciated, however, by consideration of the fact that many innovations are implemented (diffused) by a central decision-making organization such as government. Examples of this kind of innovation might be institutional; schools, medical centres and the like.[1]

The Role of the Organization as an Agent in Innovation Diffusion

The Organization

In many innovation diffusion situations there exists an organization, such as a government agency or a firm, which has an interest in propagating the innovation. The role of such an agency is conceptualized in figure 4. The organization,

> is in essence concerned with 'trying to gain certain ends by the manipulation of variables at their disposal'.[2]

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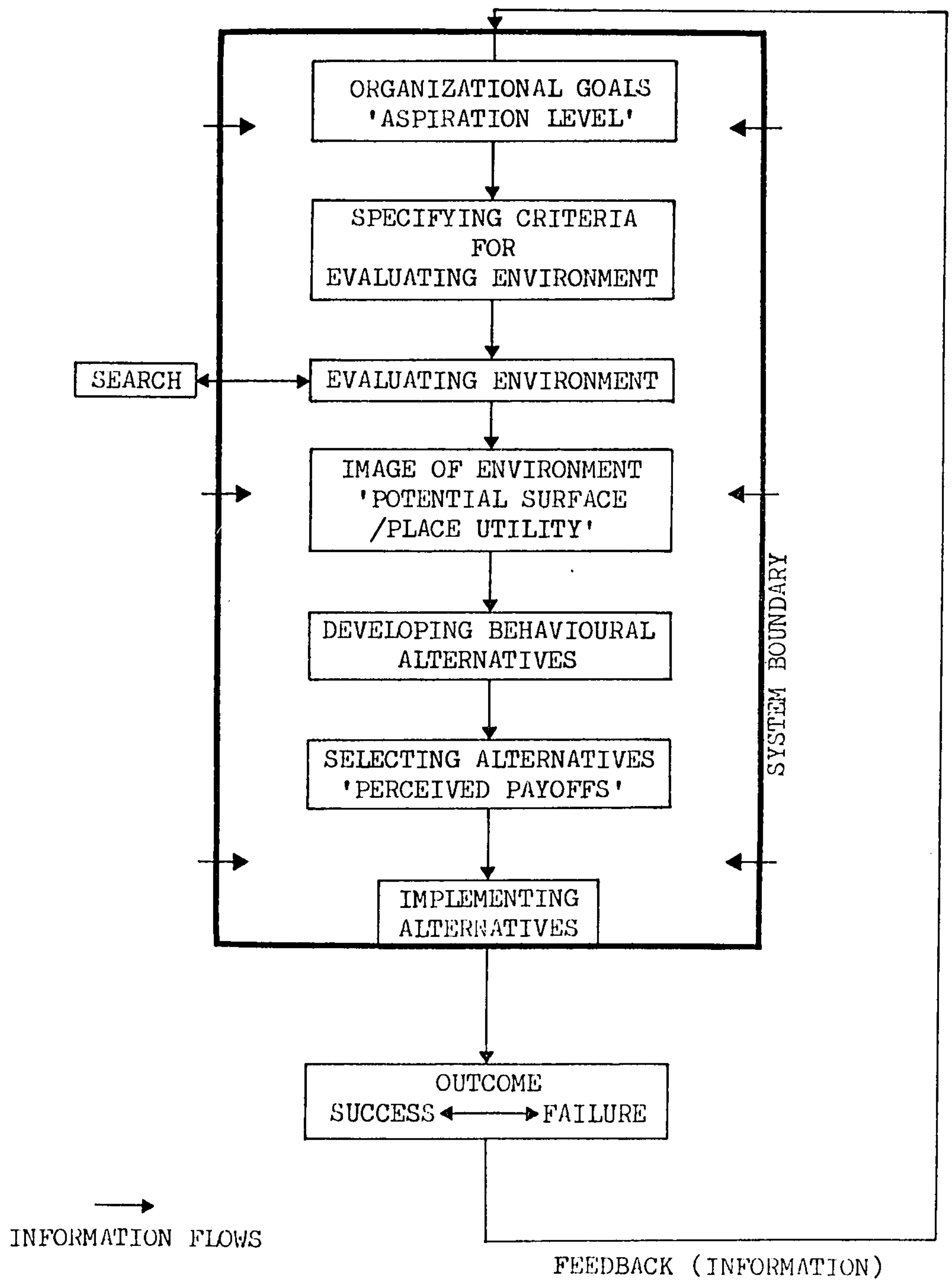
[1]For some comments see, J. B. Riddell, "Mechanisms For Hierarchical Diffusion," Annals, Association of American Geographers, LXII (1972), pp. 152-153.

[2]H. A. Simon, Models of Man (New York: Wiley, 1957), p. 170.

FIGURE 4. CONCEPTUALIZATION OF THE ROLE OF THE ORGANIZATION IN INNOVATION DIFFUSION.



Source: author

Goals

Involved in the above behaviour is the establishment of certain 'ends' or 'goals' for achievement which serve to guide actions and also as a reference point for feelings of success or failure. Traditionally, most organizations and individuals have been assumed to be characterised by one desire: profit maximization. Perfect knowledge of things pertinent to this optimization is also assumed.[1] Recent work has, however, suggested that a more realistic way of examining goals is in terms of aspiration levels.[2] These are defined by Starbuck as subjectively established goals for achievement which are usually formulated on the basis of past experience and perceived future expectations.[3] As such they continually adjust as new experience accumulates and expectations change. Aspiration levels may be defined in many ways, for example, they may be based on short-run

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[1]For a discussion of the 'economic man' concept see, J. Wolpert, "The Decision Process in Spatial Context," Annals of the Association of American Geographers, LIV (1964), pp. 537-558.

[2]R. M. Cyert and J. G. March, A Behavioral Theory of the Firm, (Englewood Cliffs, New Jersey: Prentice Hall, 1963), p. 28.

[3]W. H. Starbuck, "Level of Aspiration Theory and Human Behavior, Behavioral Science, VIII (1963), p. 128.

profit maximization or on maintaining a satisfactory level of profits over a longer period, as well as on the personal motives of entrepreneurs, etc. The goals (aspiration level) of the diffusion agency will provide a framework within which any action is set.

Environmental Evaluation

An organization evaluates the environment in terms of its potential for achieving goals, and specific criteria may be selected for this which are appropriate to a particular diffusion situation. The criteria will be based on both the goals of the agency and the information available concerning the 'state' of the environment. Similarly, the 'image' that the organization has concerning the potentialities for the achievement of its goals will be dependent on the evaluation of the environment in terms of the specific criteria. Information is again a vital input here and it should be emphasized that generally as the quality and quantity of information increases so does the accuracy of the image. Since information acquisition (search) costs money, in most cases, this places emphasis on the importance of the agencies financial resources in increasing the accuracy of the image and thus reducing uncertainty.[1]

The actual nature of the organization's image of the environment may vary, but it will certainly have a spatial element to it. Whether the concept of a market, or other, potential surface is of value here, is a question open to empirical investigation.[2] The notion does, however, seem to be conceptually similar to Wolpert's 'place utility' for migration and might refer to 'the net composite of utilities which are derived . . . at some position in space'.[3]

Behavioural Alternatives

Given that the organization has some image of the environment based on its potential for goal achievement, there may be several (or one) perceived behavioural alternatives by which the goals may be reached. Each course of action will lead to a particular state of affairs and for

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[1]Decisions made where information is incomplete are made in uncertainty, and, since information is never 'total', all decisions contain an element of uncertainty. The more information, the greater the certainty.

[2]L. A. Brown and K. R. Cox, "Empirical Regularities in the Diffusion of Innovation," p. 556 suggest this concept may be valuable.

[3]J. Wolpert, "Behavioral Aspects of the Decision to Migrate," Journal Regional Science Association, XV (1965), p. 162.

each of the 'states' there will be an outcome value or utility (pay-off function) associated with it. Information again plays a basic role in influencing the organization's perception of (a) what the states will be, (b) what the value of the states will be, and (c) the likelihood that particular modes of action will produce a particular state.[1]

Modes of Action

What kinds of behaviour can an organization undertake in order to aid, or contain, the spread of an innovation? It is suggested that action undertaken by an agency can be classified into three sections concerning:[2]

1) The nature of the innovation

2) The spread of information concerning the innovation

3) The availability of the innovation to potential adopters

The first of these is concerned with the potential adopter's 'image' of the innovation. Action can be taken by the agency to make the diffusing item more attractive or

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[1]H. A. Simon, op. cit., p. 244.

[2]M. E. Stern, Marketing Planning: A Systems Approach (New York: McGraw-Hill, 1966), pp. 16-17 and 47-104.

acceptable. The second deals with spreading information about the innovation, and this can fit within the conceptual framework of 'information-spread-processes' presented earlier as well as 'adoption-processes'. An agency can use mass-media, meetings, agents, trials, demonstrations and incentives to spread information of both a general and specific nature. Where the innovation is supplied by a particular organization, then decisions pertinent to making the item available to adopters will be of great importance. This may involve the diffusion of a system of outlets or supply centers, if these do not exist already.[1] It is clear that effectiveness of an agency in affecting the spread of something by the above means will be influenced by the resources available to the organization.

At this point, it seems appropriate once again to emphasize the difference between an organization's (individual's) objective orientation to the real world and its subjective orientation to an incomplete picture of it.[2]

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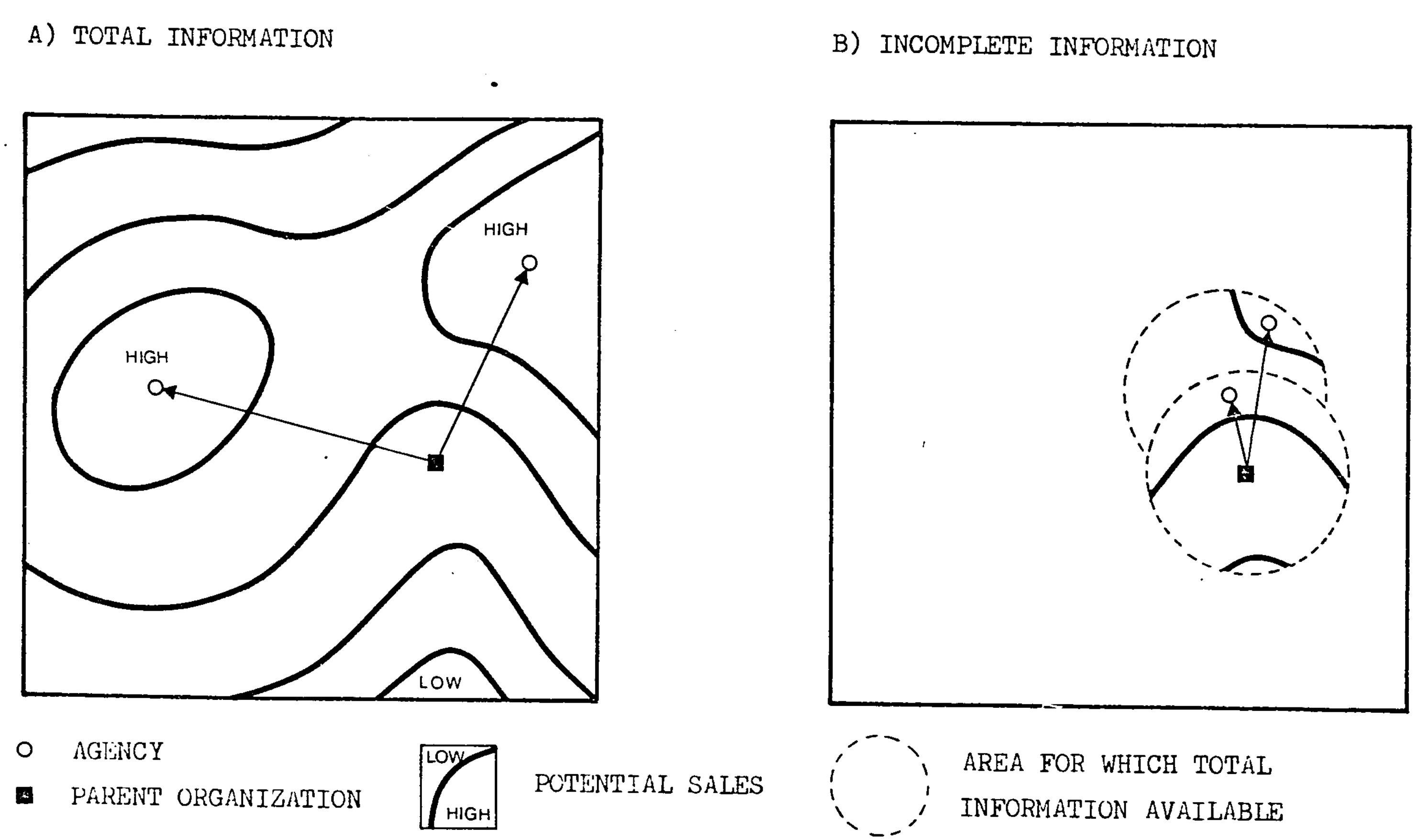
[1] L. A. Brown, "Diffusion and Growth Poles . . ."

[2] H. A. Simon, op. cit., p. 198.

Selection of Alternatives

The choice between modes of behaviour may be made so as to maximize the expected outcome utility. This does not mean that an attempt will necessarily be made to maximize utility in an 'objective' sense. This situation may, nevertheless, be approached where the decision-making organization has almost 'total' information concerning the possible alternatives and can effectively choose between them. In most instances only some of the alternatives will be perceived, and these imperfectly. Notions of maximization may still be appropriate, but only in a subjective sense. In situations where the problem-solver (organization) is searching the environment for alternatives, and perception is sequential (one alternative is 'found' after another) then utility is most likely to be viewed as either satisfactory (+) or unsatisfactory (-) according to some criteria. In such an instance it can be hypothesized that the first alternative encountered which is satisfactory will often be chosen. This places great emphasis on the way in which the environment is searched, since this may determine the outcome. The diagrams in figure 5 illustrate this where (a) is the outcome in a total-information (maximization) situation, and (b) is a search (satisfying) situation.

FIGURE 5. HYPOTHETICAL AGENCY LOCATION UNDER DIFFERING CONDITIONS.



Source: author

Where an organization concerned with innovation diffusion is searching the environment in the way described above, then a factor of great importance for the outcome of the search for alternatives is the idea that many potential 'customers' are not passive, but that they may be, in turn, searching for the innovation of the type in question. As a result the activity of potential adopters may decide which alternatives the agency perceives first.

Adaptive Behaviour

Of major importance in discussing the role of the agency in diffusion is the notion that the organization is purposive, and therefore attempting to adapt its behaviour to changes in the perceived environment. This means that as an organization receives information and learns about the 'state' of the environment, then action is taken to adjust to the changed image that results.[1] The model presented in figure 4 is therefore a dynamic one. A good example of this is provided by examining the way in which an organization's aspiration levels may change as a result

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[1]Changes in the 'image' may reflect actual changes in the 'state' of the environment or they may reflect changes in the quantity and quality of information.

of 'feedback' from the environment. In 'search' conditions where alternatives of a satisfactory nature are easily found, then aspiration levels may rise; where difficult to find, they may fall.

This section has shown how the role of the organization relates to the innovation diffusion process as conceptualized in figure 2. In the empirical study which is presented later in this dissertation (chapter 6), the role of the firm of Boulton and Watt as an organization involved in the spread of the steam engine innovations under study is considered in detail.

Timespatial Patterns of Innovation Diffusion

Theoretical Considerations

Any observed timespatial pattern of diffusion of an innovation will be a manifestation of all, or some, of the processes previously outlined. The actual characteristics of the pattern will however, depend on the relationship between the nature of the innovation being diffused, one or several of the mechanisms or processes outlined above, and the structural elements of the environment in which the diffusion takes place. Of course, all these may change over time. The general diffusion process presented in this chapter is, therefore, capable of producing an almost infinite variety of actual patterns, when the peculiarities of the particular spatial system and variations in the nature of the innovation are taken into account. Deducing the actual pattern from the process, where this is known, would be possible only when the details of the spatial system in question are accurately known. In many cases, especially in a historical context, this condition is not met.

Empirical Regularities

Researchers have reported some regularity with regard to the timespatial patterns of innovation diffusion. Hägerstrand observed that adopters of an innovation tend to cluster in geographical space and that over time the cluster expands step-by-step in such a way that the probability of new adoption appears to decrease with increasing distance from the previous adopters.[1] He suggested the term 'neighbourhood effect' would be appropriate to describe this. In its simplest form this would be manifest as a

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[1]T. Hägerstrand, "Quantitative Techniques for Analysis of the Spread of Information and Technology," in <u>Education and Economic Development</u>, ed. by C. A. Anderson and M. J. Bowman (Chicago: Aldine, 1965), pp. 260-261.

uniform spread from a point, rather like the spread of ripples from a stone thrown into a stream; however, in practice this pattern is seldom found.[1] Support for the existence of 'neighbourhood effects' is not complete. Cliff (using Hagerstrand's Asby data), de Temple, and others report that with statistical tests they failed to detect this pattern.[2] On the other hand and at a much larger scale, Griliches notes a neighbourhood effect in the diffusion of hybrid corn.[3]

The second observation of regularity is in connection with the effects of a system of urban places in diffusion. Urban places appear to cause short-circuits in neighbourhood type diffusions, with the innovation appearing earlier at

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[1]This simple neighbourhood effect would not be expected where, as a result of independent innovation, the item diffuses from more than one point of origin.

[2]A. D. Cliff, "The Neighbourhood Effect in the Diffusion of Innovations," Transactions of the Institute of British Geographers, XLIV (1968), pp. 75-84; D. J. de Temple, op. cit., pp. 11-15. Work on the spread of diseases by epidermiologists also suggests this type of cluster effect may not be present at small scales, but is at large scales, see, K. F. Maxey, ed. Papers of Wade Hampton Frost, M.D.: A Contribution to Epidemiological Method (New York: The Commonwealth Fund, 1941), p. 210, pp. 227-8.

[3]Z. Griliches, op. cit., pp. 275-80.

such places. Similarly, the larger the urban place then the earlier the innovation appears.[1] The 'hierarchical effect', as it is known, is strongly in evidence where the innovation diffusing is a 'central-place function' and the adopting unit is viewed as the urban center itself.[2] This 'hierarchical' or 'short-circuit' effect is also evident in diffusion patterns where urban centers are not important, and in actual patterns usually both these regularities may be identified.[3]

Linking Pattern and Process

Mechanisms accounting for the above empirical regularities in the diffusion of innovation have been postulated. The neighbourhood effect is explained by Hägerstrand in terms of a euclidean distance bias affecting the

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[1]T. Hägerstrand, "Aspects of the Spatial Structure of Social Communications and the Diffusion of Innovation," Papers, The Regional Science Association, XVI (1965), pp. 27-42; P. O. Pedersen, "Innovation Diffusion Within and Between National Urban Systems," Geographical Analysis, II (1970), pp. 203-254.

[2]Data collected by the author on the diffusion of Mechanics Institutes in Southern Ontario, 1831-1895.

[3]For a recent discussion of the consistency between these empirical regularities and the S-shaped curve of adoption see, L. A. Brown and K. R. Cox, "Empirical Regularities in the Diffusion of Innovation," pp. 551-559.

interpersonal flow of information concerning the item. At a larger scale, however, Griliches invokes 'resistance' in the form of profitability to account for the declining rate of adoption with increased distance from the center from which the innovation spread.[1] Where the neighbourhood effect is not in evidence, for example at small scales, biases other than euclidean distance are seen as influencing the flow of information. Similarly, it is suggested that variations in 'resistance' may destroy the simple neighbourhood effect. With regard to central places and the hierarchy effect, biases of the force-field type are seen to be influential.

In discussing the spread of 'urban' innovations through a system of central places we can cite the recent work of Wood.[2] He suggests that the lack of a distinct neighbourhood effect may be due to the nature of the patterns of 'search' conducted by municipalities. It is

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[1]Z. Griliches, "Hybrid Corn: An Exploration in the Economics of Technological Change," Econometrica, XXV (1957), pp. 501-522.

[2]C. J. B. Wood, "Some Characteristics of Searching by Municipal Governments," Geografiska Annaler, Series B, LIII (1971), pp. 138-145.

often the case, he points out, that an urban place does not contact its nearest neighbour which has adopted the innovation previously, but that a place with similar characteristics, for example size, will be sought.

The problem of relating pattern and process results from the fact that a given process can produce different kinds of patterns and a given pattern could have resulted from a variety of processes. For example, distance biases affecting the flow of information can produce a clustered pattern of adoption, but so can variations in resistance, lack of homogeneity in the availability of the innovation (market factors), and the implementation of adoption decisions in a particular locality. Similarly, a pattern of diffusion related to the urban hierarchy could be the result of any of the four main sub-processes of diffusion outlined in this chapter, or combinations of them. The situation might be further complicated, for example, where information spread and adoption processes produce a hierarchical pattern of adoption-decisions which are then implemented to produce a clustered pattern.

When the nature of the innovation being diffused is considered, similar problems arise. Some commercial, industrial, or institutional innovations are 'space competetive' being orientated to a market or to serve an area. In such cases, the characteristics of the diffusion pattern will reflect this.

It can be seen from this brief discussion that there is no such thing as one type of pattern, or process, associated with innovation diffusion. Many similar patterns may be the result of different processes and vice versa. In fact, many patterns may be the result of several processes operating in an interrelated way and each producing a specific element in the general pattern of diffusion. Thus it can be seen as a matter of vital importance to link together both in empirical and theoretical studies the elements of the diffusion situation, that is the item being diffused; the processes in operation (behavioural mechanisms); the structural elements of the environment; and the time-spatial patterns produced. The following chapters which examine the spread of James Watt's steam engine innovations attempt to do this.

Summary

A collection of ideas and concepts are incorporated into a framework or model of the innovation and diffusion process. Sub-processes in this complex phenomenon are identified and discussed. In a given diffusion situation which of the processes will be in operation will depend on both the nature of the innovation and the environment. Some processes will, however, be active in all situations. Likewise the nature of the innovation and the environment will determine whether an agency is involved in the diffusion. The following chapters present a discussion of the innovation and diffusion of the steam engine improvements made by James Watt. Many of the concepts discussed in this chapter are therein given empirical expression.

CHAPTER 2

THE INNOVATION: ANTECEDENTS, CONDITIONS, AND CONTEXT

Introduction

The aim of this chapter is to briefly describe the nature of the Watt steam engine innovations and to trace their antecedents. The innovations are placed in context by means of a discussion of the early industrial revolution. This leads to an examination of the general conditions for innovation in the period and a more specific look at the conditions in which James Watt made his discoveries concerning the steam engine.

The Innovations

In January 1769 James Watt (1736-1819) of Glasgow obtained a patent lasting for fourteen years for "a new method of lessening the consumption of steam and fuel in fire engines".[1] The innovation described in the patent consisted of a modification to the atmospheric or Newcomen engine by the addition of a separate container for condensing steam.[2] Previous to Watt's discovery one cylinder, that containing the piston, was used for condensing the steam to create a vacuum -- the pressure of the atmosphere then moving the piston for the working stroke. Condensation was achieved by means of a jet of cold water which incidentally also cooled the cylinder. By use of the separate condenser the cylinder heat was retained and this resulted in approximately a 75 percent saving in the consumption of fuel. Watt's first patent, therefore, suceeded in producing a more efficient reciprocal engine (up and down motion) without really extending the use to which the machine could be put.[3]

Watt's second major innovation occurred when he

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[1]Patent No. 913, January 5, 1769. The term 'fire engine' is the old way of describing a steam engine. The patent was renewed in 1775 for 25 years.

[2]Most of the comments following are based on H. W. Dickinson, A Short History of the Steam Engine (London: Frank Cass, 1963), pp. 66-70.

[3]The Newcomen engine became known as the 'common engine'.

succeeded in converting the reciprocal (pumping) engine to rotary motion. In 1781 a patent was taken out.[1] Also, in 1782 he succeeded in developing a double acting engine where steam acted on both sides of the piston alternatively. A smooth-working engine was thus produced which was suitable for rotary motion. Watt's other patents included a method of connecting the piston rod to the engine beam (parallel motion) in 1784.

The Antecedents

The history of the steam engine and its antecedents has been discussed in detail elsewhere,[2] however, a brief review of some of this history will assist in placing Watt's innovations in context.

The initial innovation, the separate condenser, was based upon a modification to the Newcomen engine; a device

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[1]Patent No. 1306, 25th October, 1781. For details of Watt's developments concerning rotary motion see, H. W. Dickinson, op. cit., pp. 79-85. The method of producing rotary motion was initially by means of gearing called 'Sun and Planet'. The traditional method of producing such motion by the crank could not be used as it had been patented by Pickard in 1780. This method was used, however, after 1794 when Pickard's patent expired.

[2]H. W. Dickinson, op. cit., This edition has an excellent new introduction by A. E. Musson; L. T. C. Rolt, Thomas Newcomen: The Prehistory of the Steam Engine (London: Macdonald, 1963).

conceived in the 1690's by Thomas Newcomen and first used near Wolverhampton, in the Midlands, in 1712.[1] The engine used low pressure steam to produce a vacuum by condensation, thus allowing the pressure of the atmosphere to drive the piston in a cylinder.[2] Newcomen's great achievement was to build a practical engine by putting to work the findings of such scientists as Papin and Huyghens. He never patented this engine, however, due to the fact that Thomas Savery had patented an engine in 1698 which pre-empted the field.[3] Newcomen and Savery joined together to supply engines under the patent, although the formers' engines proved to be more successful. Engines of both types were used throughout the eighteenth century, even after Watt's improvements. Newcomen's engine was, however, improved greatly in the period, especially by John Smeaton, the engineer, who undertook

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[1]A. P. Usher, A History of Mechanical Inventions (Harvard: University Press, 1954), pp. 338-357.

[2]The idea of a piston in a cylinder almost certainly came from Papin who published it in 1690. Newcomen's link with the idea was probably Dr. Robert Hooke, Secretary of the Royal Society.

[3]Savery was the first to design and make a workable apparatus and sell it to the public. Engines of his type were used throughout the eighteenth century.

careful and systematic measurement and study of the engine.[1]

The General Context: The Industrial Revolution

The purpose of this section is to demonstrate that the steam engine improvements made by James Watt were not just isolated innovations but that they were part of a general trend involving fundamental changes in the British economy and way of life.

General Changes

The context for both Watt's improvements in the steam pumping and rotary motion engines is the early period of what has become known as the Industrial Revolution in Britain. Regardless of the fact that continuities in the developments which led to these changes can be traced back far in time, it is generally evident that the major discontinuity in the rate and nature of economic growth in Britain occurred in the last quarter of the eighteenth century.[2]

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[1]M. Kerker, "Science and the Steam Engine," Technology and Culture, II (1961), p. 385, L. T. C. Rolt, *op. cit*., pp. 125-131.

[2]For the question of discontinuity verses continuity see, P. Deane, *The First Industrial Revolution* (Cambridge: University Press, 1965), p. 4. The actual timing of the discontinuity varies with the measure used. Trade data, see P. Mantoux, *The Industrial Revolution in the Eighteenth Century* (London: J. Cape, 1961), p. 102, indicates 1780. Patent data, see figure 6, indicates the 1760's.

What were the causes of this change in the rate of growth? As M. W. Flinn points out in a recent comprehensive study of the problem, the process of growth is complex and cannot be explained in terms of a single prime mover.[1] Nevertheless, after identifying what he calls pre-requisite factors, ranging from developments in agriculture to increasing population, he points out:

> . . . in the last resort, the decisive factor both in increasing the scale and in changing the methods and location of production was technology. The vast flood of cheap textiles, the coming of the new iron age, the summoning of the power of steam to the aid of industry, the aggregation of large numbers of workers in a single unit of industrial production as a commonplace rather than an exception, and the urban concentration of large-scale industry - all these facets of the Industrial Revolution stemmed from the adoption of new techniques of production.[2]

Technological Change

Technological developments (innovations or inventions) may facilitate economic growth by reducing production costs. There is no doubt that technological output, measured by

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[1]M. W. Flinn, The Origins of the Industrial Revolution (London: Longmans, 1966), p. 93.

[2]Ibid., p. 102.

the number of patents sealed, rises greatly towards the end of the eighteenth century, as shown in figure 6.[1] There was, therefore, a significant rise in the propensity to innovate, and almost certainly in the propensity to adopt innovations, in the period. What accounted for this discontinuity? Dean speaks to this question:

> Over a large part of the century, beginning somewhere before the middle and accelerating in the second half, there seems to have been a tendency for the demand for British manufactures to exceed their supply. The resultant stimulus to technical change was reflected in the wide interest in innovation.[2]

The Increased Propensity to Innovate

The identification of significant 'demand' factors is in accordance with theoretical considerations discussed earlier. This, however, does not account for an increase in the number of persons willing and able to respond to the demand. To provide further insight into this problem, two lines of investigation may be followed. First, 'social

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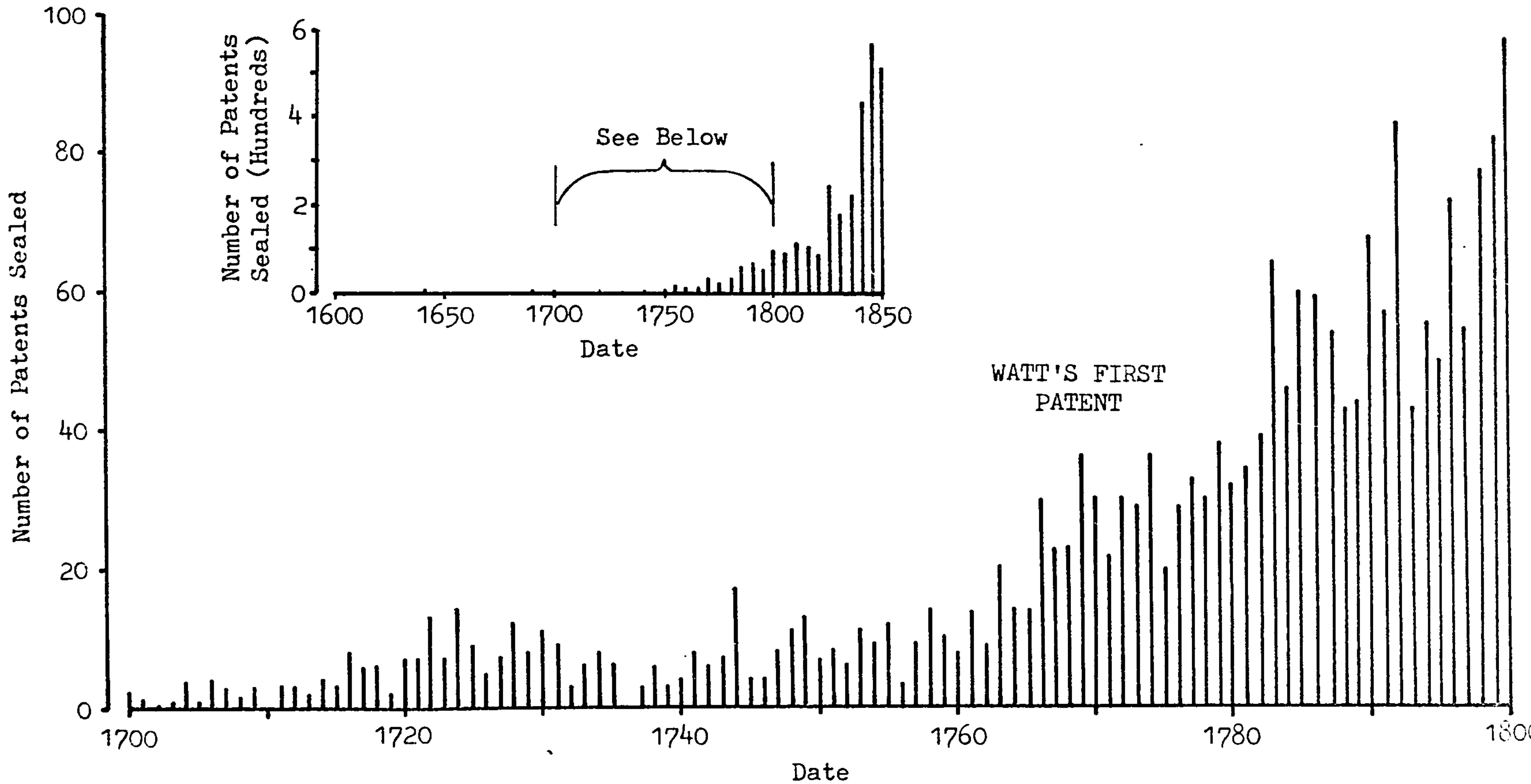
[1]Based on, B. R. Mitchell, Abstract of British Historical Statistics (Cambridge: University Press, 1962), p. 268. Number of patents issued is a crude indicator due to the fact that it gives no indication of their importance.

[2]P. Deane, op. cit., p. 132.

FIGURE 6. BRITISH PATENTS SEALED ANNUALLY FOR THE EIGHTEENTH CENTURY.



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structure' factors will be discussed, and second, the relationship between the Scientific and Industrial Revolutions will be examined. Both these sets of factors are, however, clearly related.

The writers Hagen and McClelland have used social psychological factors to help explain the origins of the Industrial Revolution.[1] Hagen's observation that religious non-conformists, such as Unitarians and Congregationalists, in total about seven percent of the population of England and Wales in the period, formed 41 percent of a sample of principle entrepreneurs and innovators suggests that a disproportionate number of innovators were from dissenting origins.[2] The explanation for this, provided by Hagen, is connected with the idea that the withdrawal of 'status respect' from a minority group leads, through changes in the circumstances of home life and social environment, to the emergence of innovational creativity in that group.

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[1]E. E. Hagen, On the Theory of Social Change: How Economic Growth Begins (Homewood, Illinois: Dorsey Press, 1962), pp.290 - 309; D. C. McClelland, The Achieving Society (Princeton, New Jersey: Van Nostrand, 1961), pp. 132-149.

[2]E. E. Hagen, op. cit., pp. 295-7.

McClelland's argument is similar, relating dissenting attitudes to child rearing to the emergence of 'high achievement motivation'. By the late eighteenth century, therefore, it is argued that there existed in Britain a group who had an incremental propensity to innovate. The importance of such a group of 'innovators' for the diffusion of the innovations examined inthis work is discussed below in chapter 5.

It was during the sixteenth and seventeenth centures in Europe that the Scientific Revolution was in progress. This was characterised by 1) an increasing concentration on physical rather than metaphysical problems, 2) accurate observation of natural phenomena, 3) systematic use of the experimental method, and 4) greater interest in the utilitarian aspects of applied science.[1] As with most new things it is often assumed that diffusion is instantaneous and, for example, that with the establishment of the Royal Society in Britain in 1660 this scientific movement had occurred. If, on the other hand, we view the new-found interest in science as a diffusing phenomenon, both

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[1] A. E. Musson and E. Robinson, Science and Technology in the Industrial Revolution (Toronto: University of Toronto Press, 1969), p. 12.

timespatially and through the various strata of society, this may provide some insight into the increased propensity to innovate in the eighteenth century.

Throughout the seventeenth and eighteenth centuries, London was the center of scientific activity in Britain.[1] A manifestation of this was the number of scientific societies located there.[2] By the early eighteenth century, however, this interest in science was beginning to spread to the provinces. The early concentration of societies which mirror this trend was almost exclusively in the eastern agricultural counties of England. By the latter half of the century the situation was changing and "the economic and intellectual centre of gravity was shifting from the south and east to the midlands and north".[3]

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[1]Glasgow and Edinburgh, in Scotland were also of considerable importance. For some details see, A. Clow and N. L. Clow, The Chemical Revolution (London: Batchworth Press, 1952), pp. 39-42.

[2]See, A. E. Musson and E. Robinson, op. cit., pp. 57-58, 126-127; W. H. G. Armytage, "Education and Innovative Ferment in England, 1588-1805," in Education and Economic Development, ed. by C. A. Anderson and M. J. Bowman (Chicago: Aldine, 1965), pp. 379-81.

[3]A. E. Musson and E. Robinson, op. cit., p. 142.

That the general interests in scientific matters, and in their applications, was becoming more widely diffused in the late eighteenth century is indicated by the springing into existence of Literary and Philosophical Societies in such places as Manchester, Leeds, Newcastle, Derby, Birmingham, Liverpool, etc.[1] Many of these societies were informal gatherings of individuals who were interested in discussing scientific and technical matters and conducting experiments. There were also more specialized societies, for example the Society of Civil Engineers. Other societies were formally constituted, often modelled on the Society of Arts which was formed in 1754. The emergence of small but active bodies of persons interested in science and its applications in the provinces was, therefore, typical of the age and the importance of this will be made explicit in chapter 5. This, together with greater emphasis on teaching science, in academies, particularly dissenting academies and schools, as well as an increase in the output of scientific

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[1]For details of these societies see, R. E. Schofield, <u>The Lunar Society of Birmingham</u> (Oxford: Clarendon Press, 1963); Musson and Robinson, op. cit., pp. 87-199.

and technological publications,[1] in the eighteenth century, must have had ramifications for the rate of innovation. Such factors must have made knowledge pertinent to solution of technical problems more generally available, as well as acquainting more persons with a method of 'problem solving'. It is particularly important to note that it was the religious dissenters who particularly emphasized science, commerce, etc., in education and it was from these sources that many innovators came. The evidence suggests, therefore, that strong links existed between the scientific and industrial revolutions. The role of scientific societies as focii of activity in the spread of the Boulton and Watt engines is explained in some detail in chapter 5.

The Specific Context

Science and the Steam Engine

The evidence of links between science and its application in the case of the steam engine is particularly strong. Both Savery and Newcomen had scientific interests and connections. In addition they came from south-west England

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[1] W. Bowden, Industrial Society in England Towards the End of the Eighteenth Century (London: Frank Cass, 1965), pp. 15-17.

and had associations with mining in that area. Both individuals must have been well aware of the 'demand' for improved drainage facilities and the potential rewards related to such developments. They also had access to information relevant to finding solutions to these problems by virtue of their scientific connections (see previous chapter for theoretical discussion of this). Throughout the eighteenth century the Newcomen engine continued to be improved, especially by John Smeaton. Science again played an important role in this, for it was through systematic measurement that the latter person's improvements were made.

Watt's Innovations

Watt's steam engine innovations, as part of the continuum of improvement, were also clearly linked with scientific work. First, Watt was a methematical instrument maker, 'a truly scientific engineer and chemist, well versed in contemporary scientific knowledge and constantly engaged in scientific experiments'.[1] He was, in his work, based at the University of Glasgow, and as such closely associated with Dr. Joseph Black (a discoverer of the principles of

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[1]Musson and Robinson, op. cit., p. 80.

latent heat), John Robinson, and Dr. John Anderson, Professor of Natural Philosophy at Glasgow. It was the latter who gave him a model Newcomen engine to mend in the winter of 1763-1764.[1] Watt, viewing the Newcomen engine as a piece of scientific apparatus, was struck by the inefficient use of steam. He undertook careful experiments on the engine and subsequently made his discovery.

The general applicability of the Usherian model of innovation (see chapter one) to Watt's discovery has been demonstrated by Scherer and there is no need to repeat it here, except to point out some of the more important later stages in the development of the innovation.[2]

Research and Development

The critical act of insight occurred in 1765 and following this there was an extended period of critical revision or research and development. In this period, to 1768, Watt was supported financially by his friend Dr. Black.

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[1]M. Kerker, "Science and the Steam Engine," Technology and Culture, II (1961), p. 386.

[2]F. M. Scherer, "Invention and Innovation in the Watt-Boulton Steam-Engine Venture," Technology and Culture, VI (1965), pp. 165-187.

Eventually a patron was required for continued support and Dr. Roebuck of the Carron Iron Works filled this role. An acquaintance of both Watt and Black, he was having difficulty in keeping his coal mines clear of water and he saw the improved steam engine as a potential solution to his problems.[1] As a result, an agreement was made between Watt and Roebuck and the first patent was obtained in 1769. The value of the innovation to fulfill a utilitarian need had been recognized.

Watt's connection with Matthew Boulton of Soho, Birmingham had developed before his patent had been obtained.[2] It was through a mutual friend, Dr. William Small, that Watt was first introduced to Soho in 1766, and the following year he met Matthew Boulton, " . . . one of the most successful and best-known of Midland manufacturers".[3] Watt was impressed with Boulton's Soho factory, especially its organization and excellent workmanship which contrasted with

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[1]E. Roll, _An Early Experiment in Industrial Organization_ (London: Frank Cass, 1968), p. 12.

[2]E. Roll, _Ibid_., pp. 13-23.

[3]Roll, _op. cit_., p. 7.

that in Scotland. Matthew Boulton was interested in Watt's engine and partnership negotiations were undertaken. As a result he was made an offer to manufacture engines for the counties of Warwick, Staffordshire, and Derbyshire. He did not find the proposal acceptable, however, and in a lengthy letter to Watt in 1769 sets out both the problems associated with establishing an engine business and his reasons for rejecting the offer.

> By this time, I daresay, you have fully concluded that I am a very queer fellow, I having never answered your last friendly letter of the 20th October nor your last of the 12th December . . . The plan proposed to me is so very different from that which I had conceived at the time I talked with you upon the subject that I cannot think it is a proper one for me to meddle with as I do not intend turning engineer. I was excited by two motives to offer you my assistance which were love of you and love of a money-getting, ingenious project. I presumed that your engine would require money, very accurate workmanship and extensive correspondence to make it turn out to the best advantage, and that the best means of keeping up the reputation and doing the invention justice would be to keep the executive part out of the hands of the multitude of empirical engineers, who from ignorance, want of experience and want of necessary convenience, would be very liable to produce bad and inaccurate workmanship; all of which deficiencies would affect the reputation of the invention. To remedy which and produce the most profit, my idea was to settle a manufactory near to my own by the side of our canal where I would erect all the conveniences necessary for the completion of engines, and from which manufac-

> tory we would serve all the world with engines of all sizes. By these means and your assistance we would engage and instruct some excellent workmen (with more excellent tools than would be worth any man's while to procure for one single engine) could execute the invention 20 per cent cheaper than it would be otherwise executed, and with as great a difference of accuracy as there is between the blacksmith and the mathematical instrument maker. It would not be worth my while to make for three counties only, but I find it very well worth my while to make for all the world.
>
> What led me to drop the hint I did to you was the possessing an idea that you wanted a midwife to ease you of your burthen and to introduce your brat into the world . . . Although there seem to be some objections to our partnership in the engine trade, yet I live in hopes that you or I may hit upon some scheme or other that may associate us in this part of the world, which would render it still more agreeable to me than it is by the acquisition of such a neighbour . . .[1]

During the early 1770's Roebuck's affairs deteriorated and financial support could no longer be given to Watt. In 1773 Roebuck was bankrupt and his share of the engine venture was made over to Boulton to be set off against a debt. Thus Watt moved with his trial engine, the Kinneil engine as it was known, to Birmingham. In 1774 experiments on the engine continued and were successful. However, as six years

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[1]Letter, M. Boulton to J. Watt, Feb. 7, 1769, quoted in L. T. C. Rolt, James Watt (London: B. T. Batsford, 1962), pp. 47-48.

of the original patent had run, an Act of Parliament was secured which gave Watt a monopoly of the manufacture of his engine for 25 years in England, Scotland, Wales and the 'Plantations'(May 1775).[1] Boulton and Watt then became partners.

The firm which was established did not produce engines until 1795, however, and essentially 'sold the idea' of the engine and acted as consultant engineers in its design and erection. Only a few parts demanding special skills were provided by the firm of Boulton and Watt at Soho, Birmingham. John Wilkinson, the Shropshire ironmaster, was usually specified as the supplier of the engine cylinder as his patent method of boring cannon was the only method of production which would give the precise results required by the Soho firm.

The activities of the firm of Boulton and Watt were, therefore, based on the 'sale' of reciprocating (pumping) engines until the mid-1780's when the rotary motion engine was developed. Both types of engines were then produced in the period studied here (to 1800), the firm continued in

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[1]The 'plantations' were the colonies. They have been excluded from this study.

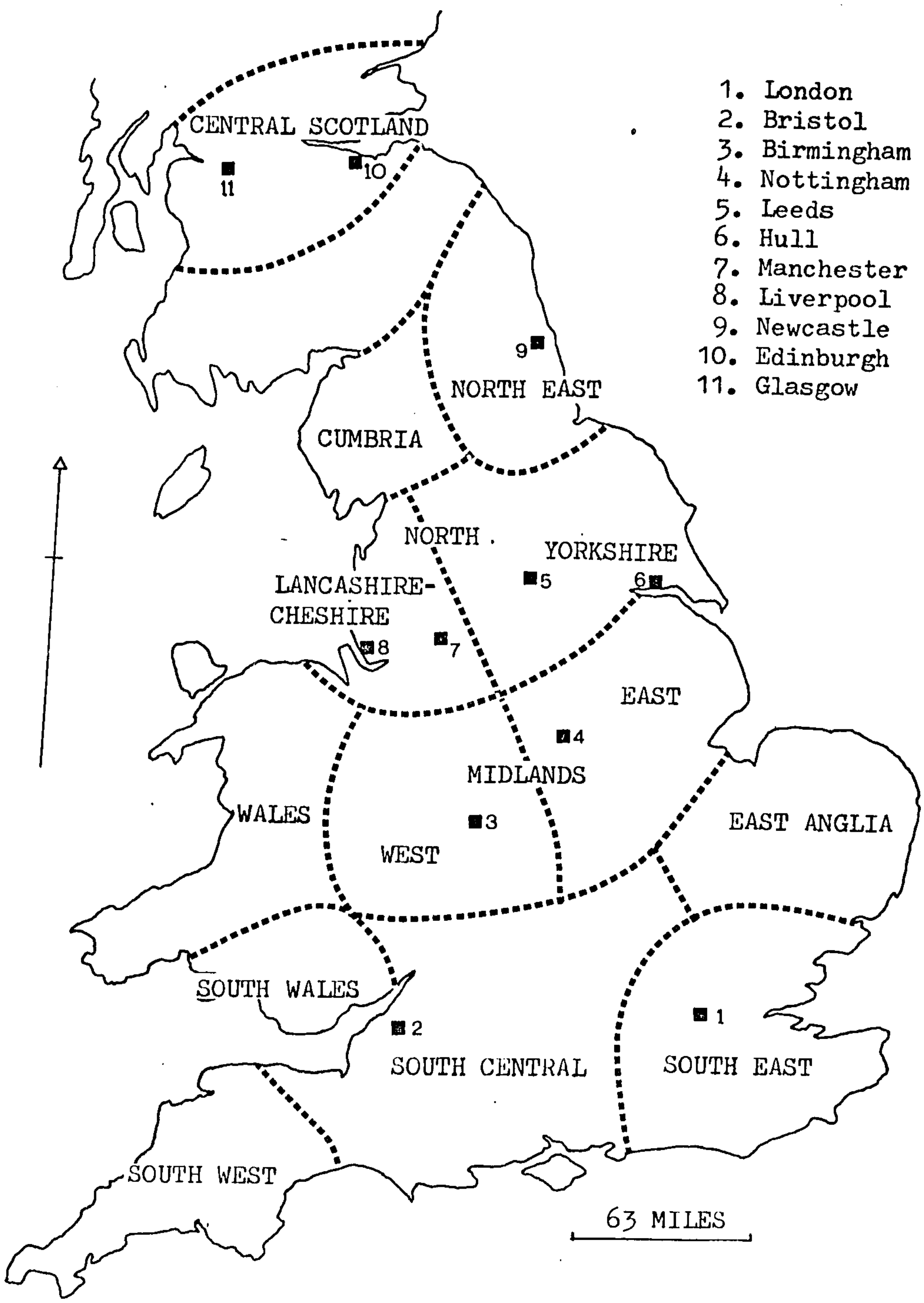
existence, however, after the patent had expired in 1800.

Summary

This discussion has shown that the developments made by James Watt with regard to steam power were part of a much broader context involving major changes in the economic life of Britain. The latter part of the eighteenth century was one of a general increase in the propensity to innovate in Britain and the reasons for this have been traced to the innovative activities of religious dissenters and the impact of the scientific developments of the period. Tracing the history of the steam engine it is clear that close ties existed between the scientific developments and interests of the time and the improvement of steam powered mechanisms.

The latter part of the chapter examines in greater detail the development of Watt's innovation, especially in the period before it began to be produced for 'sale'. This demonstrates some of the difficulties associated with the research and development phase of innovation and the special role that financial and moral support can play in these developments.

FIGURE 7. BRITAIN: REGIONS AND TOWNS.



CHAPTER 3

THE GENERAL PATTERN OF DIFFUSION

We continually search for patterns, but patterns that contain the unexpected.[1]

Introduction

If we accept what Boulding calls 'the D'Arcy Thompson Principle', which states that at any moment the form of something is a result of its laws of growth up to that moment,[2] then the pattern of diffusion of an innovation at any one time will conform to this principle. What then can an examination of the form of the diffusion pattern as it unfolds in timespace tell us about these laws of growth?

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[1] J. Platt, Perception and Change: Projections for Survival (Ann Arbor, Michigan: University of Michigan Press, 1970), p. 82.

[2] K. E. Boulding, Beyond Economics (Ann Arbor, Michigan: University of Michigan Press, 1968), p. 77.

The purpose of this chapter is to examine the time-spatial diffusion pattern of James Watt's two main steam engine innovations 1) the reciprocating engine, and 2) the rotary motion engine. These two innovations are treated separately because of the clear distinction between them in terms of their technical character, the uses to which they could be, and were, put, and their significance to man.

The examination of pattern is guided by a search for the empirical regularities in innovation diffusion which have been identified by other researchers, and which were discussed briefly in chapter one.

Data

Between the years 1775 and 1800 something over one hundred and fifty reciprocating (pumping and blowing) engines of Boulton and Watt's design were erected in Britain.[1] Similarly, in the period after 1781 over three hundred rotary motion engines were erected.

The basic data for the analysis presented in this chapter consists of information concerning these engines and is mainly drawn from the Catalogue of Old Engines which

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[1]The 'Plantations', including Ireland, have been excluded from this study.

forms part of the records of the firm of Boulton and Watt.[1] This document provides what is in all probability a fairly complete list of engines supplied under Watt's patent. In addition, information on the name of the customer, the location at which the engine was erected, and the date-of-first-plan is provided. Although the latter date is not that when the engines were put to use, it is a more accurate indicator of when the 'decision' to adopt was taken. The length of time between this and the date at which the engines were set to work could vary a great deal depending on such factors as the supply of parts, how busy the firm was, transport difficulties etc.

Mapping Technique

Although, initially all adoptions were recorded according to precise spatial location and year, due to the difficulties involved in indicating the location of individual adopters at the scale shown some degree of aggregation is necessary in the maps.[2]

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[1]Boulton and Watt Collection, Birmingham Reference Library, Birmingham, England. All letters quoted are from this source unless otherwise stated.

[2]The removal of engines has not been considered in this study. The pattern is that of adoptions.

Pattern Analysis

Reciprocating Engines, 1775 to 1800

The graphs in figure 8 show, for Britain, the annual number of adoptions of the reciprocating engine and this as a cumulative growth curve. The latter of these provides no evidence of an initial period of slow adoption of the innovation,[1] in fact, the overall trend of the curve approximates a straight line. There are, however, minor deviations from this general trend. One of the most obvious of these is the reduction in the annual number of adoptions for a number of years after 1786. This may be possibly related to 1) the introduction of rotary motion engine production by the firm of Boulton and Watt -- allowing a short lag time -- and 2) the exhaustion of the most extensive market for engines in Cornwall. If the first factor is important then this suggests that the rate of diffusion of the engines after the introduction of the rotary engine may initially have been inhibited by the firm's ability

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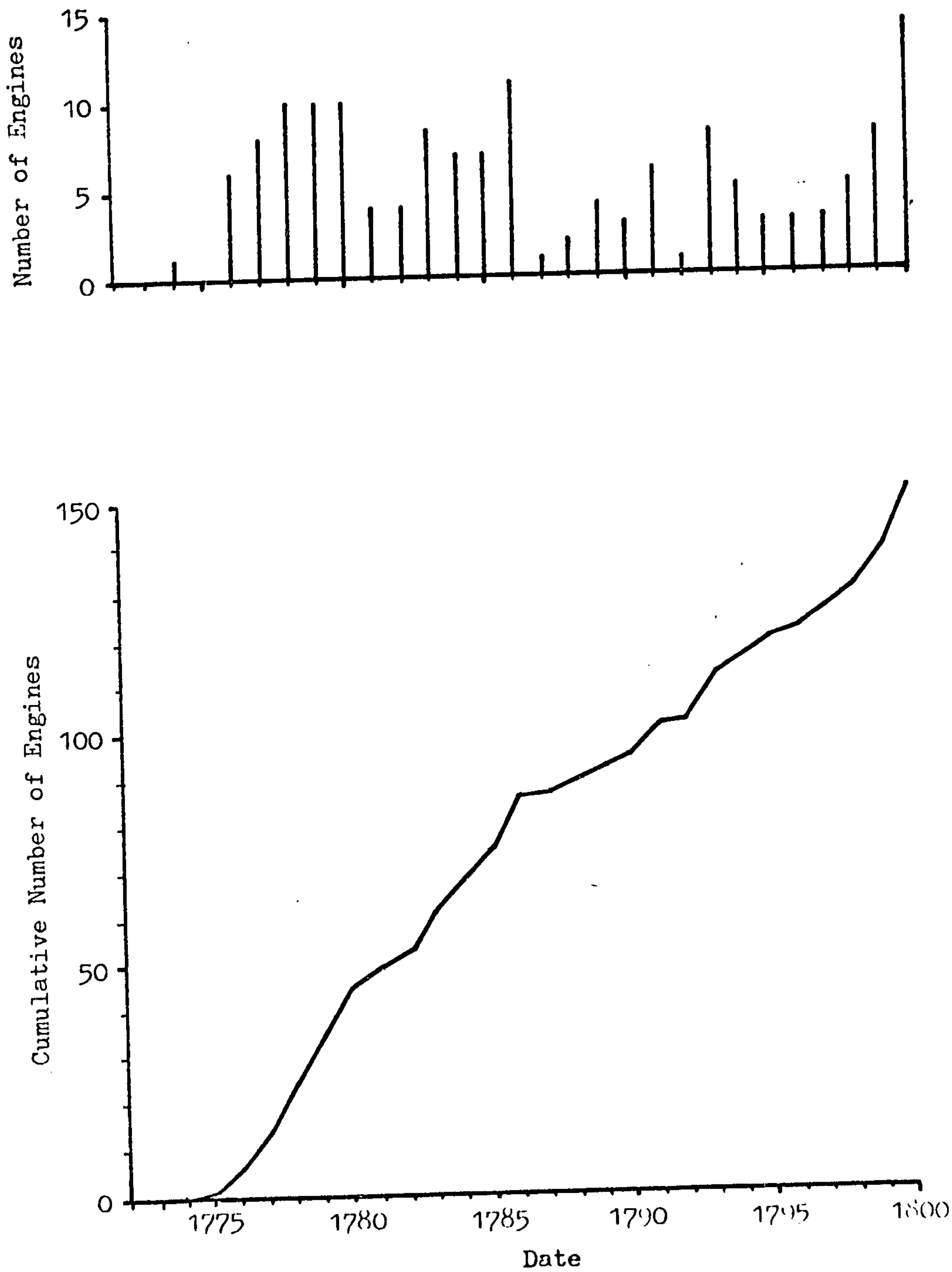
[1]See the comments on the 'S' shaped growth curve in chapter one.

FIGURE 8. RECIPROCATING ENGINES: ANNUAL ADOPTIONS AND GROWTH CURVE.



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to supply its product. Total annual production could have been limited by many factors, for example, lack of skilled workmen. Of course, such a factor may have influenced the rate of adoption even before the 1780's, but it only becomes really apparent with the introduction of rotary motion. The second factor is discussed in some detail in the following chapter.

The timespatial diffusion pattern of the engines is shown by means of the sequence of maps in figure 9. These maps show the cumulative pattern of adoptions for times t_1, t_2, t_3, . . . t_n. The difference between t_1 and t_2 is three years.

The first observation that can be made about the diffusion is that the pattern as it develops is highly focal, or clustered, in nature. A measure of this, apart from visual inspection, is provided by nearest neighbour analysis.[1] This technique describes whether a pattern tends to be aggregated, random, or uniform by means of an index (R) which ranges from 0 (complete aggregation), through 1 (random), to 2.15 (uniform). The index is calculated by

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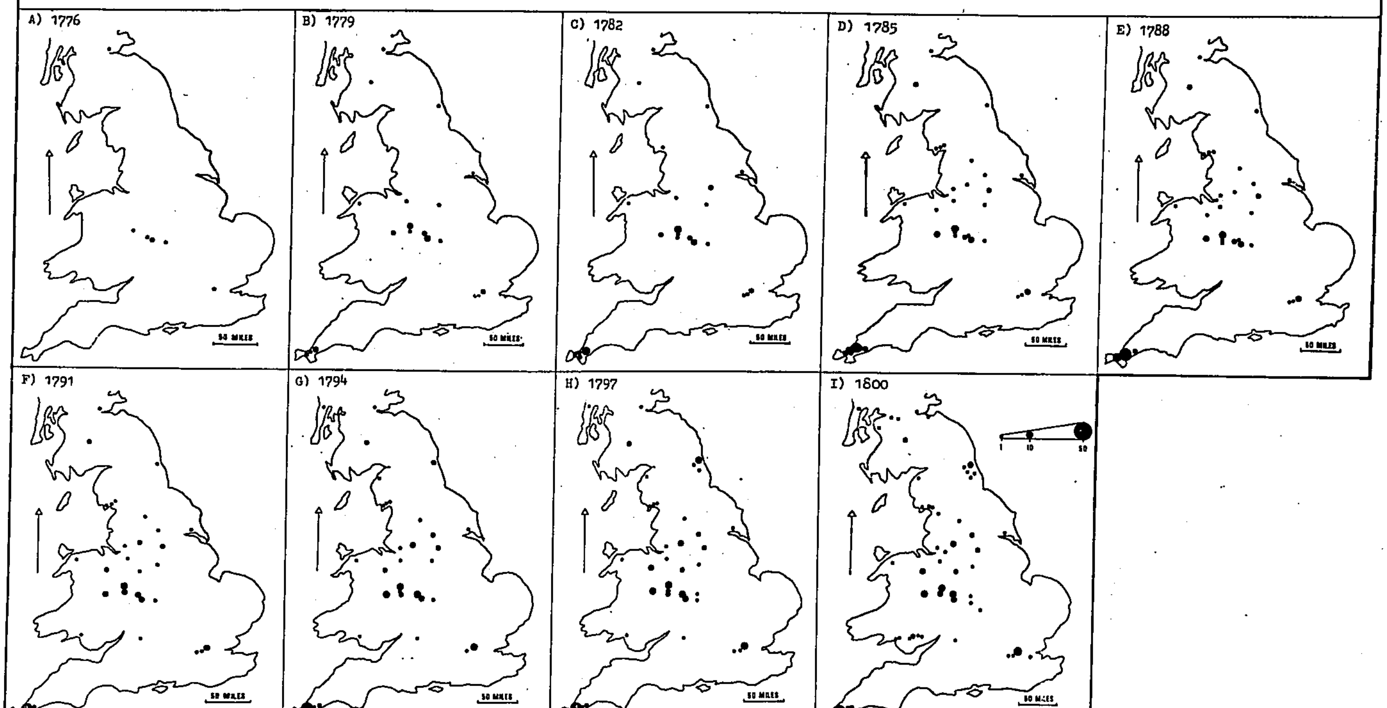
[1]For details of this technique see, H. R. Thompson, "Distribution of distance to nth nearest neighbor in a population of randomly distributed individuals," Ecology, XXXVII (1956), pp. 391-394.

FIGURE 9. RECIPROCATING ENGINES: CUMULATIVE PATTERN OF DIFFUSION.



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comparing the mean distances of points to their n nearest neighbours in the actual distribution with similarly calculated distances in a random distribution. This analysis supports the notion that the pattern of diffusion is highly aggregated, at least as far as the first eight nearest neighbours are concerned.[1]

Does the pattern of diffusion conform to the neighbourhood effect mentioned earlier in terms of a gradual spread from a point of initiation? Inspection of the map sequence in figure 9 suggests not, and this observation is supported by an examination of the distances of adopters, for three year periods, from Birmingham, the point of initiation. A gradual increase in the mean distances of new adopters from this point, over time, is not generally in evidence.[2] It may be possible that there are two 'waves' of diffusion, with the year 1788 as the separating date. The evidence is,

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[1]R statistics for eight nearest neighbours for three years.

	1781			1791				1800			
1st Neighbour	0.13	5th	0.20	1st	0.21	5th	0.19	1st	0.19	5th	0.26
2nd "	0.19	6th	0.20	2nd	0.18	6th	0.25	2nd	0.23	6th	0.27
3rd "	0.16	7th	0.21	3rd	0.19	7th	0.25	3rd	0.25	7th	0.28
4th "	0.14	8th	0.20	4th	0.18	8th	0.23	4th	0.25	8th	0.29

[2]

Date	Mean Distance, from Birmingham				
1776	60.0 miles	1785	123.0 miles	1794	117.0 miles
1779	117.0 miles	1788	188.0 miles	1797	123.0 miles
1782	150.0 miles	1791	51.5 miles	1800	129.0 miles

however, inconclusive.

The most notable feature of the pattern of diffusion is that multiple focii, or regional clusters, develop. The main concentrations which can be identified are, and here the reader may find it useful to refer to figure 7, 1) the west midlands, 2) London, 3) Cornwall, 4) south Wales, 5) the north (Lancashire and Yorkshire),[1] 6) the north-east and 7) Scotland. It is important to note, however, that these focii vary in size, compactness, and date and rate of growth. This idea, that there is variation in the time and rate at which the regional focii developed. is now examined.

The several focii or clusters of adopters which have previously been identified can be treated as 'units' for the purposes of examining among region variations in the date and rate of adoption of the reciprocating engine. This is achieved by visually assigning all adopters in a particular region to that region. This is easy for the 'well defined' clusters, but more difficult when dealing with regions such as 'The North'. The map in figure 10 shows by means of bar graphs for each of the regional focii the number of adoptions for three-year periods, 1775 to 1800.

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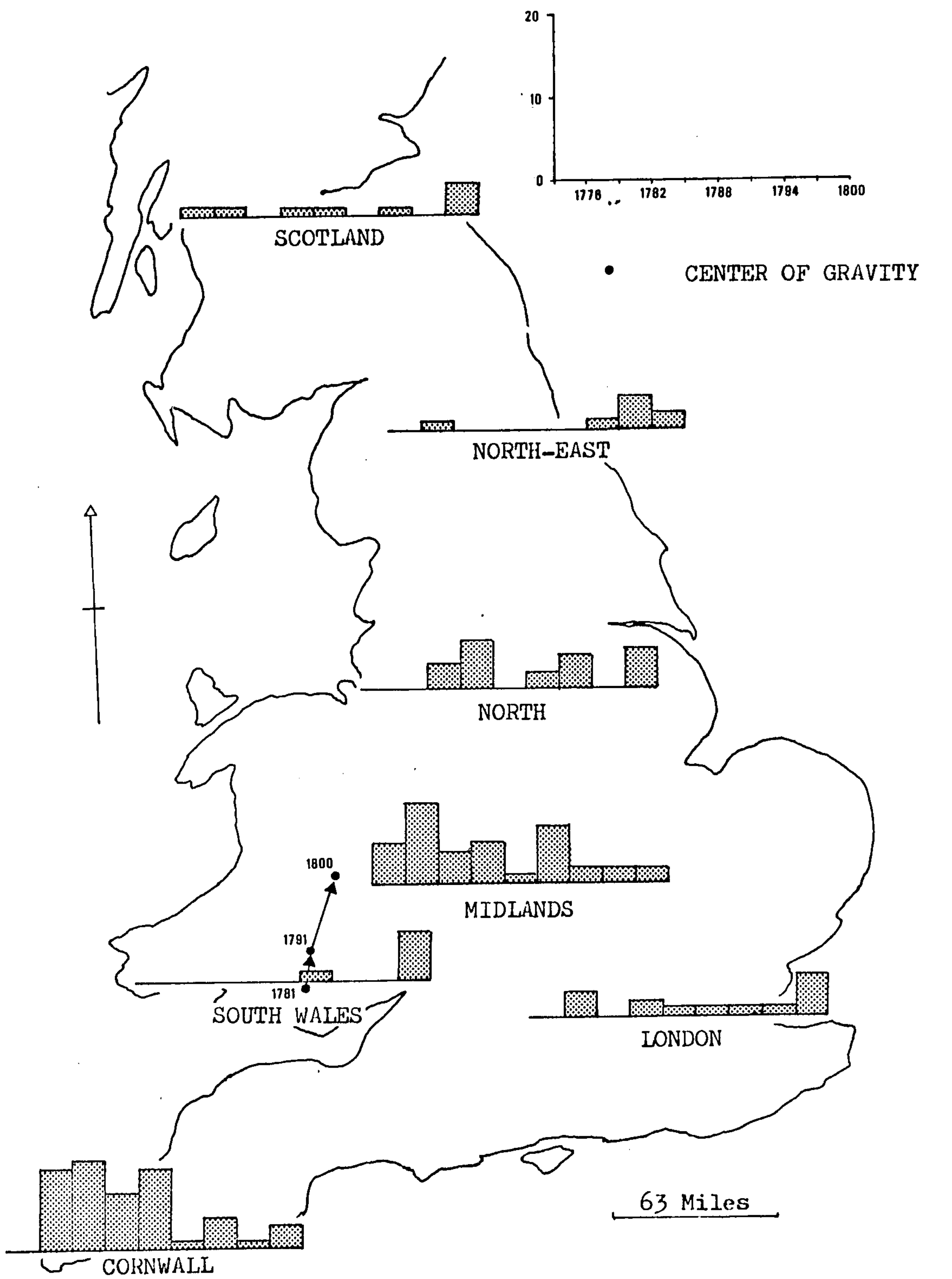
[1]This is probably the least distinct focii.

FIGURE 10. RECIPROCATING ENGINES: ADOPTION BY REGION.



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This shows quite clearly the within-region variations in the tri-annual number of adoptions as well as the among region differences.

The early domination of the pattern of diffusion by the Midlands and Cornwall is particularly striking. These two areas continue to be of major importance for much of the first half of the period. Throughout the years 1775 to 1800, the North is of moderate, but intermittent, importance. London, on the other hand is of a fairly constant, but moderate, importance. The 1790's show the decline in importance of both the Midlands and Cornwall, while other areas become more important, however, not nearly as important as the two former areas in the early period. Towards the end of the period, therefore, there is a general northward shift in the areas of activity, with regard to new adoptions. This trend is reflected in the shifting center of gravity of the total distribution of adopters for three dates, this being shown in figure 10.[1] Although many of the regions only become 'active' towards the end of the period,

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[1]This is also called the arithmetic mean center. For a discussion and method of calculation see, D. S. Neft, Statistical Analysis for Areal Distributions, Monograph Series, Number 2. (Philadelphia: Regional Science Research Institute, 1966), pp. 27-29; 38-47.

it is interesting to note that they become 'latent', that is adopt at least one engine, at a fairly early period.

With the exception of those engines adopted in London, the focii or clusters of adopters do not seem to be oriented to large urban places, and it must be concluded that this type of 'hierarchy effect' is not present to any great degree.

Rotary Motion Engines, 1782-1800

Both the annual number of adoptions of Boulton and Watt rotary engines, and the cumulative growth curve of adoption are shown by means of the graphs in figure 11. The trend of adoptions by year and the smooth slightly concave curve indicate a fairly constant acceleration in the rate of adoption in the period.[1] This indicates a gradual increasing acceptance of the innovation. Not only did the rate of adoption accelerate, but also the average size of engine ordered in the period increased greatly from about 8 horse power in 1784 to approximately 20 horse power in 1800. This is shown by means of the graph in figure 12. In a sense the early use of small engines might be viewed as the 'trial'

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[1]This approximates the lower half of an 'S'-shaped growth curve.

FIGURE 11. ROTARY ENGINES: ANNUAL ADOPTIONS AND GROWTH CURVE.

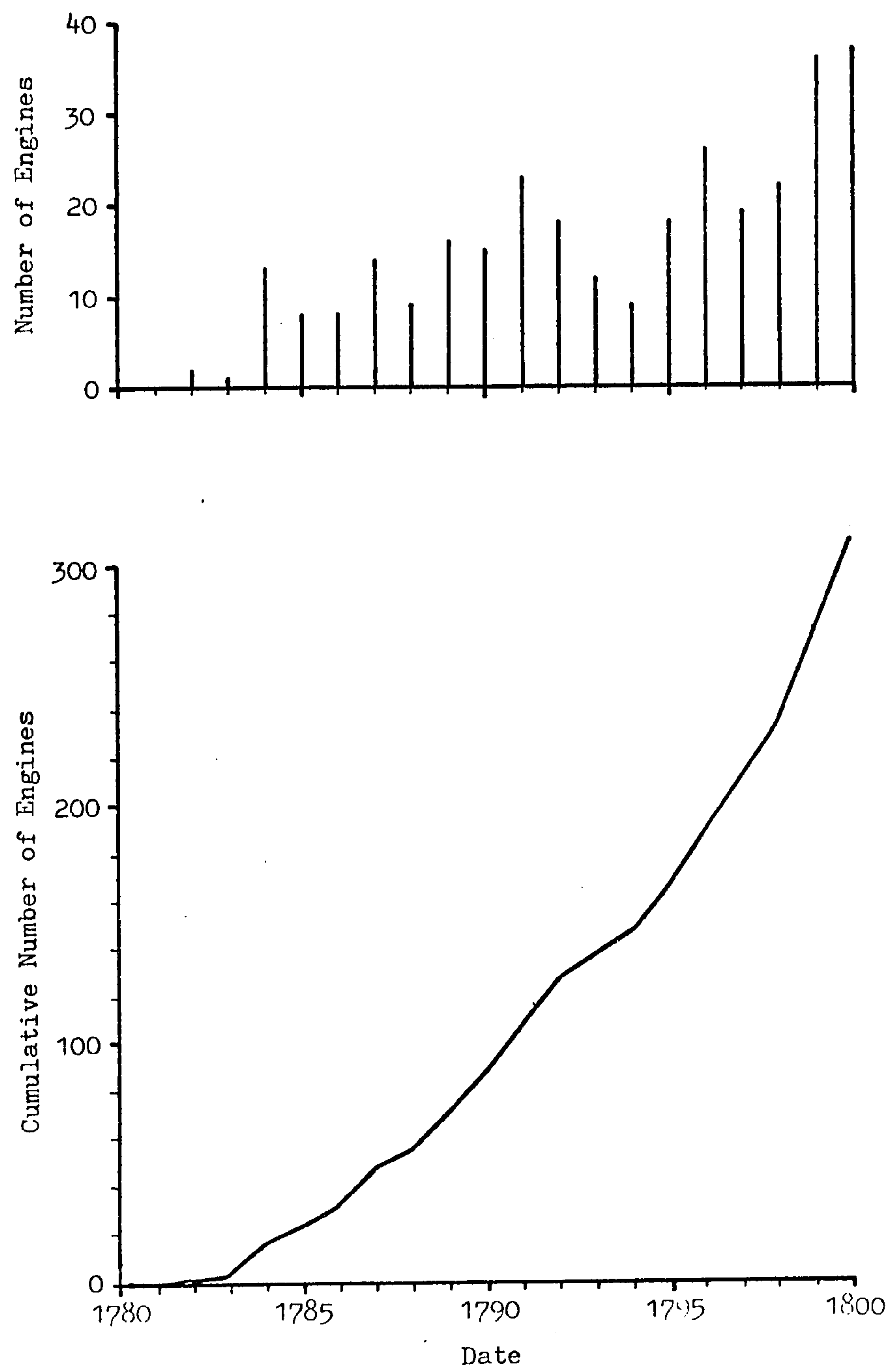

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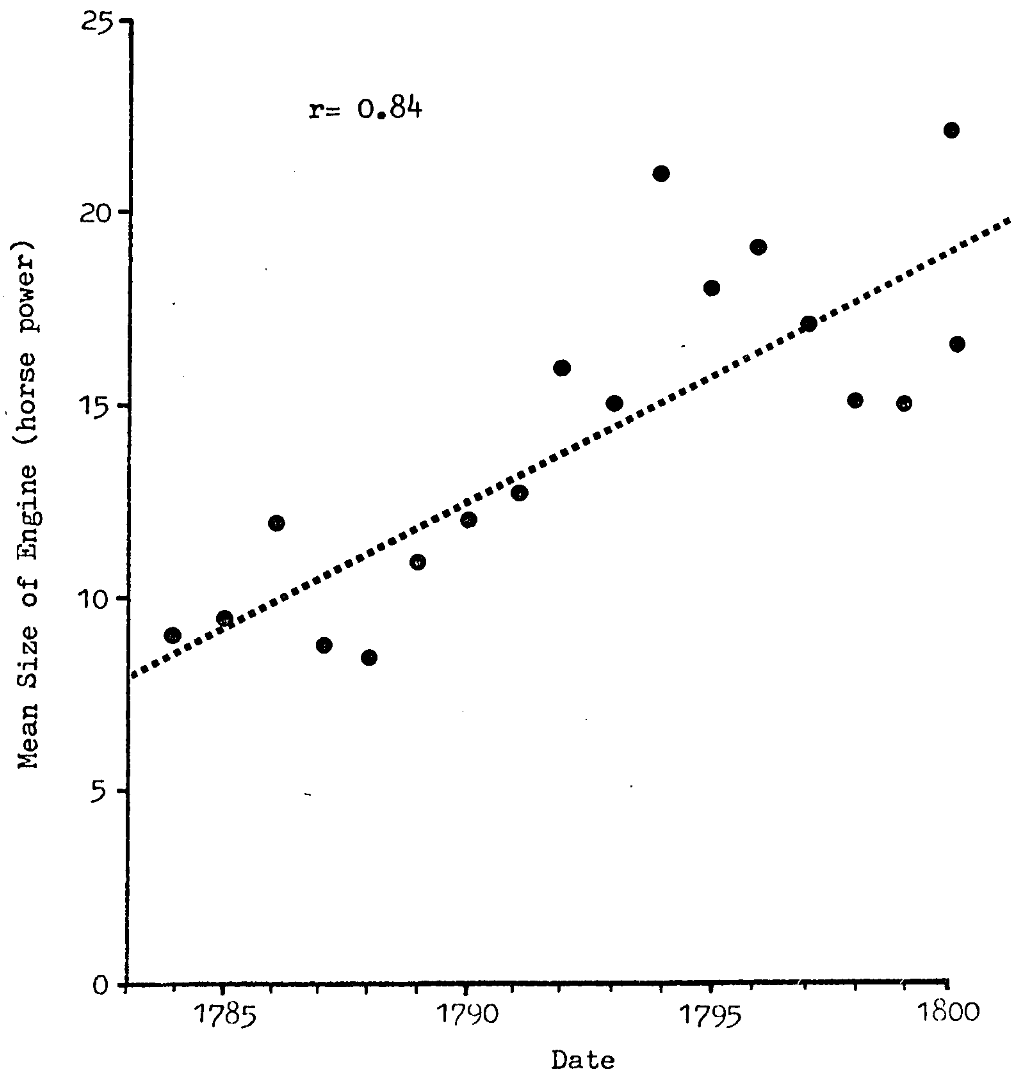
FIGURE 12. RELATIONSHIP BETWEEN AVERAGE SIZE OF ROTARY ENGINE AND DATE OF ADOPTION.



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period for rotary steam power. After the innovation had proved its worth then it was used in much larger units.[1]

The timespatial pattern of diffusion of the engines, in terms of the cumulative pattern of adoptions, is shown by the map sequence in figure 13. The highly aggregated nature of the distribution as it develops over time is reflected, as with the reciprocating engines, by the R-statistics of the nearest neighbour analysis.[2]

As with the reciprocating engine the pattern of diffusion of the rotary engine as it unfolds in timespace shows the emergence of several distinct, and some less distinct, focii. These, however, vary in size, compactness, and the date at which they began to grow. The focii, or clusters, generally become established or 'latent' at an early date, but vary in the rate of growth. This latter observation is

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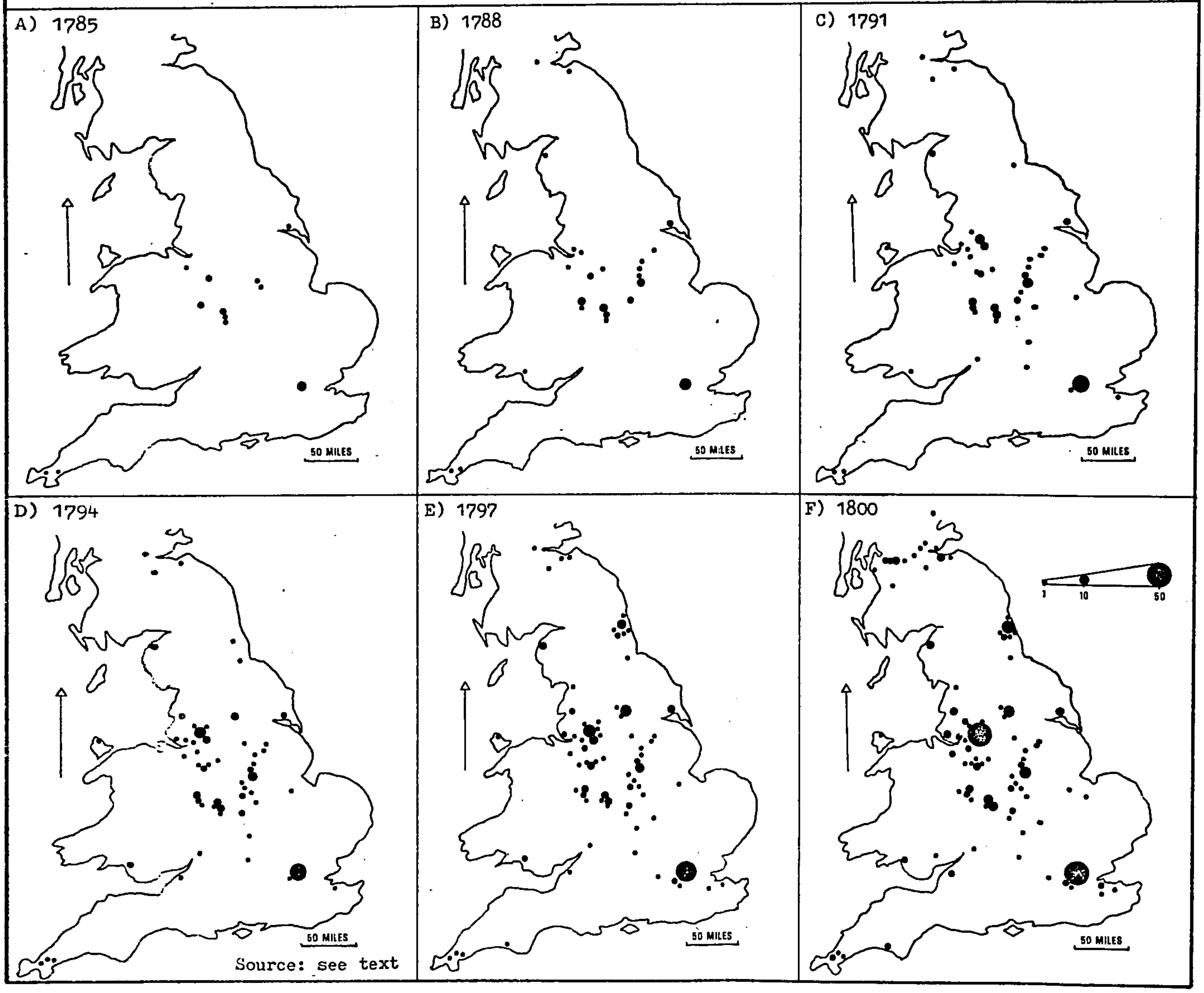
[1]This idea is discussed in more detail in the next chapter where the diffusion of the innovation in the cotton and worsted industries is examined.

[2]The R-statistics for the first eight nearest neighbours for three dates are:

1788				1794		1800	
1st.	R=0.20,	5th.	R=0.25,	R=0.23,	R=0.25,	R=0.20,	R=0.23,
2nd.	R=0.22,	6th.	R=0.26,	R=0.20,	R=0.24,	R=0.22,	R=0.23,
3rd.	R=0.22,	7th.	R=0.27,	R=0.20,	R=0.26,	R=0.20,	R=0.23,
4th.	R=0.25,	8th.	R=0.28.	R=0.20,	R=0.25.	R=0.21,	R=0.23.

FIGURE 13. ROTARY ENGINES: CUMULATIVE PATTERN OF DIFFUSION.



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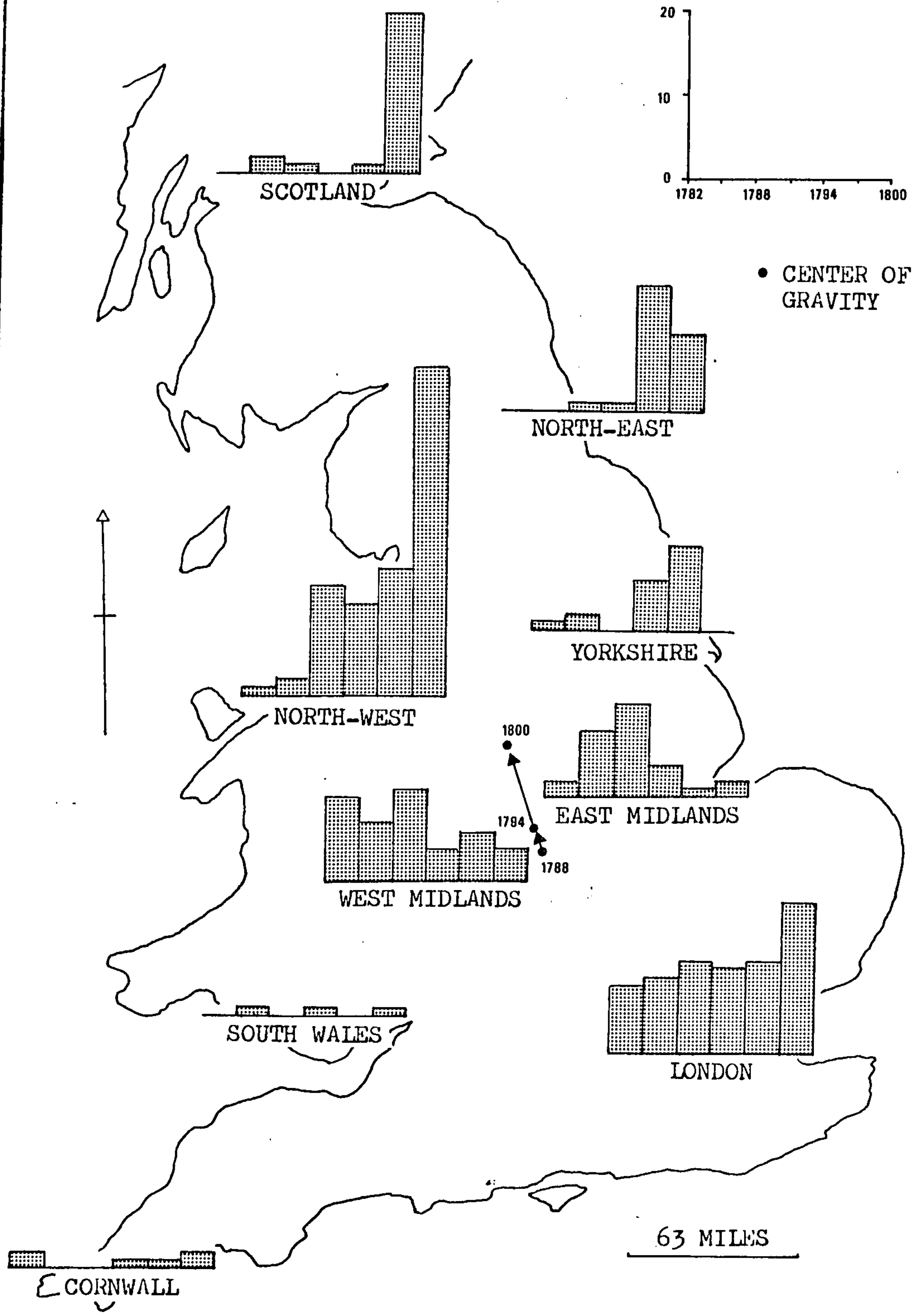
supported by an examination of the map presented in figure 14. This, as with the reciprocating engines, shows within region variations in tri-annual adoption as well as among region variations. The striking feature of this map is the marked variation in the temporal trends of adoption in the different regions. The Midlands (both west and east) and London emerge as the important areas of adoption in the early part of the period. London maintains, and somewhat increases, its importance throughout the period, however, both the east and west Midlands decline in importance. The most impressive increase in adoptions is in the North-West (Lancashire and Cheshire), especially in the late 1790's. In the 1790's other areas, specifically, Yorkshire, the North-East, and Scotland, also become increasingly important areas of adoption.

These developments, in terms of the emergence of focii at different times and their growth at different rates, show the general shift in the areas of activity, or growth in the pattern in timespace. Early adoption in the Midlands and London gives way to the dominance of the northern areas in the 1790's. This trend is monitored by means of the movement in the center of gravity of the overall distribution for the three dates shown on the map in figure 14.

FIGURE 14. ROTARY ENGINES: ADOPTION BY REGION.



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The importance of large cities with regard to the focality of the diffusion pattern can be demonstrated by an analysis of the numbers of rotary engines attracted to such places in the period (see Table 1). London, for example,

Table 1

Orientation of Rotary Engines to Large Cities (within 10 miles)

Date	London		Manchester		All Cities (including Manchester and London)	
	No.	%	No.	%	No.	%
1785	8	33	0	0	9	38
1790	23	27	2	3	27	31
1795	36	22	19	12	69	42
1800	57	19	52	16	138	45

with a population of over 800,000 accounted for a large percentage of the total engines in the early period, as is shown in table 1. This percentage decreases over time, however, while the actual number of engines increases. The opposite trend is evident for Manchester and urban places over 50,000, in general.

Conclusion

The timespatial patterns of diffusion of both innovations are complex. The patterns as they develop exhibit a high degree of clustering, however, multiple focii can be identified. These focii vary in size, intensity, and date and rate of growth. There is no evidence that the innovation spread out from its point of initiation reaching the nearest focii first and the ones farther away later, at least for the reciprocating engine. The evidence in support of this idea for the rotary engine is weak.

In both diffusion sequences the 'limits' of the extent (spatial) of the spread appear to have been set at a relatively early stage in the process. On this 'skeleton' the subsequent developments take place. The two patterns of diffusion exhibit some similarities and some differences. Some of the focii are the same, for example, the west Midlands, the North-East, and Scotland. Others, however, are different. Cornwall was important for reciprocating engines, but not for rotary, whereas, with the east Midlands it was the other way round.

Finally it can be reemphasised that both patterns of diffusion develop multiple focii, which are in part related to the existence of an urban hierarchy, especially in the case of the rotary engine. These focii would appear to act autonomously, growing at different times, rates, and to be different sizes. Nevertheless, the parts are united into a whole -- the timespatial pattern of growth.

The following three chapters will provide insights into the factors influencing the patterns of diffusion described in this chapter. This will be achieved by examining in detail some aspects of the process of diffusion of the innovations.

CHAPTER 4

INDUSTRIAL VARIATION IN THE USES OF STEAM POWER

Introduction

The previous chapter shows the pattern of diffusion of the innovations to be a complex one, and not describable in terms of a simple neighbourhood-type effect. In essence the pattern is one in which distinct regional focii develop. These are of different sizes and densities and grow at different times and rates. How can this type of diffusion pattern be comprehended? The purpose of this chapter is to provide some insights into this question.

In chapter one the 'adoption process' for innovations is discussed and factors are identified which influence both whether a person adopts and the length of time that the adoption process takes. These factors, termed 'resistances', relate to the individual's perception of the potential that the innovation in question has for fulfilling some need. This involves a consideration of the changing relationship between the perceived characteristics of the innovation and certain structural elements of the environment which represent the needs or characteristics of potential adopters.

This chapter demonstrates that many facets of the general pattern of diffusion can be understood in terms of the kinds of relationships outlined above. More specifically, it is argued that variations in resistance (acceptance is the positive side of this concept) are related to differences in the 'potential-for-use' of the innovation, both, 1) among different types of industry, and 2) within particular industries. Involved in testing this hypothesis, therefore, is an examination of the diffusion of the innovations according to the industrial uses to which they were put. First, the among-industry variations in the potential-for-use are discussed, and second, within-industry variations based on a series of case studies.

The Reciprocating Engine

Characteristics

The characteristic push and pull motion of the reciprocating engine made it generally suitable for use as a pumping mechanism. The greatest potential-for-use was in those industries involved in pumping liquids (essentially water), for example, mine drainage, water supply, and water re-cycling.[1] Reciprocating engines could also be used to pump air and as such had a potential use in smelting metals.

Patterns of Use

A graph showing the cumulative curves of adoption of reciprocating engines according to the main uses to which they were put has been constructed, and is shown in figure 15.[2] The changing spatial aspects of the adoption by use is shown also in the series of maps of the cumulative pattern of adopters presented in figure 16.

The maps demonstrate that the different sets of industrial uses are anything but randomly distributed throughout the total set of adopters. The various industrial groups of adopters are spatially highly localized. From this it is clear that the regional focii of the general pattern of diffusion correspond to particular industrial uses or

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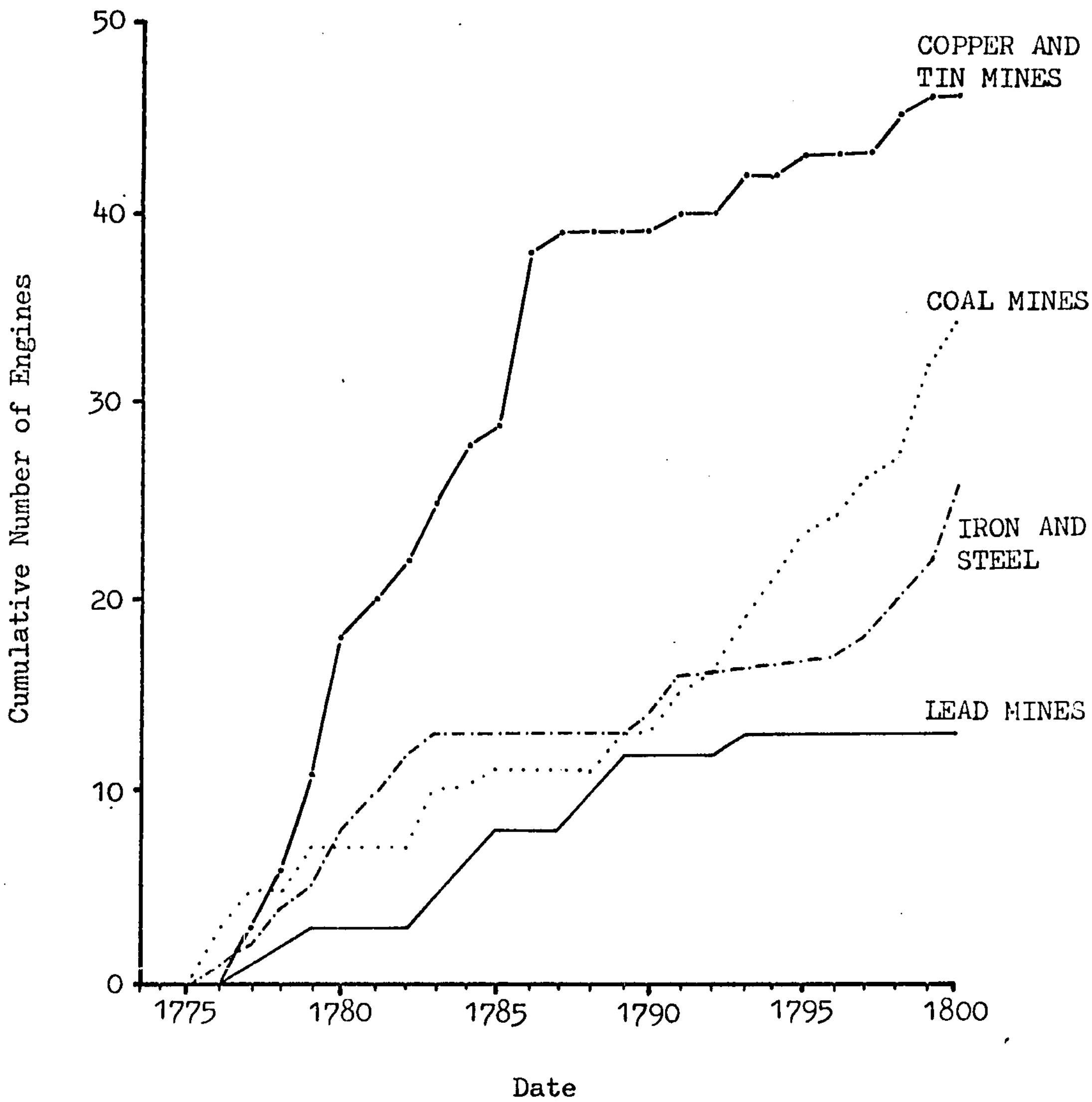
[1]The use of steam power to pump water so it could be reused to drive a water wheel was one way of producing rotary motion. This is an interesting example of the way in which steam power was perceived initially as compared with the changed perception of its role later in the century.

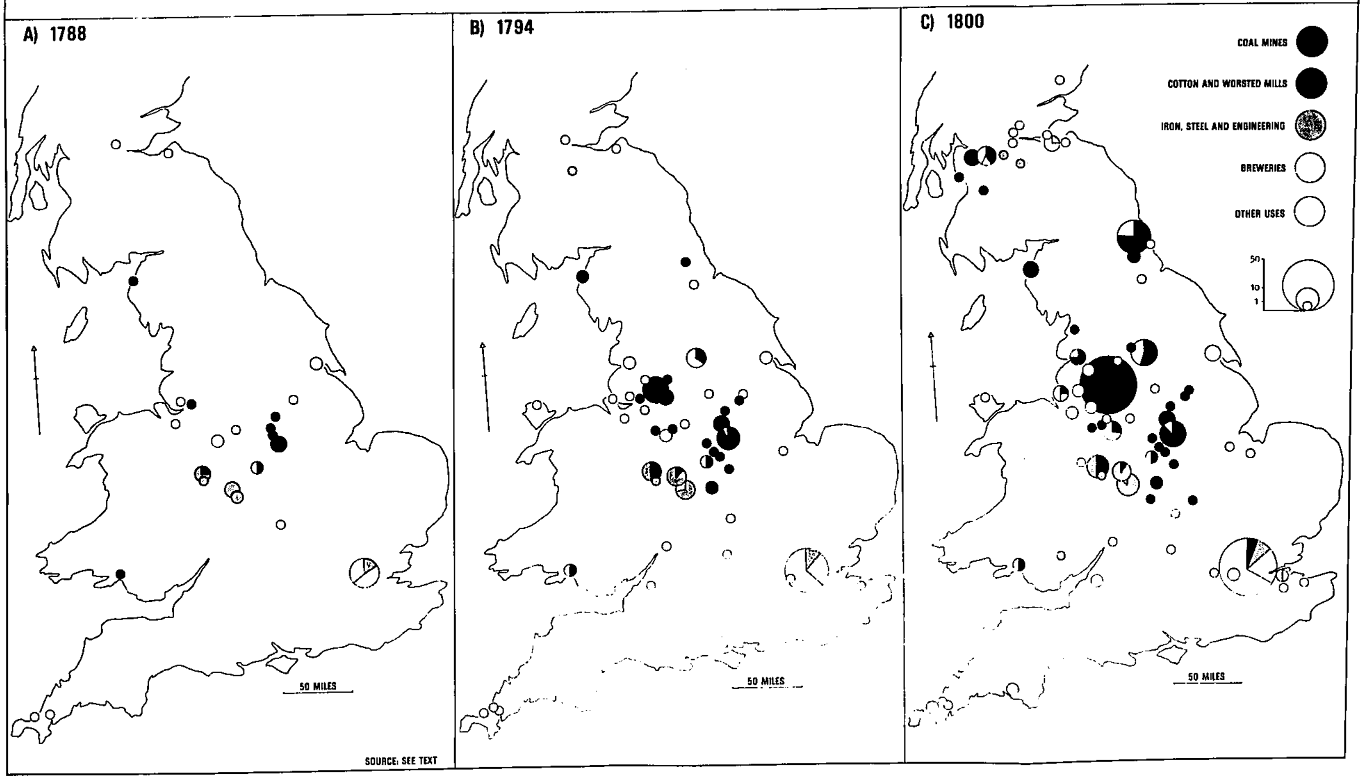
[2]The data is abstracted from Appendix 1.

FIGURE 15. RECIPROCATING ENGINES: ADOPTION BY INDUSTRY.



Source: see text

FIGURE 18. ROTARY ENGINES: CUMULATIVE PATTERN OF DIFFUSION ACCORDING TO USE.



combinations of uses, for example copper and tin mining in Cornwall and coal mining in the north-east. It also follows from this, and the analysis of the graph, that the variations in the date and rate of growth of the regional focii are related to the differential rates of adoption of the innovation within the different industries. A discussion of the major characteristics of some of these industries can shed some light on the reasons for the among-industry variations in the perceived ability to use the innovation.

Copper and Tin Mining

By far the most important industrial use for the reciprocating engine in the study period was in draining the copper and tin mines of Cornwall.[1] This is shown in the graph in figure 15 and in the maps in figure 16. The

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[1]The copper and tin mining industries were largely concentrated with south-west peninsular, however, other isolated copper mines existed. Mona and Parys mines were located in Anglesea and probably had the largest output of any mines in Britain. For details see, J. R. Harris, The Copper King: A Biography of Thomas Williams of Llanidan (Toronto: University of Toronto Press, 1964). Another important mine was at Ecton on the Staffordshire-Derbyshire border see, A. Raistrick, ed., The Hatchett Diary (Truro: D. Bradford Baston Ltd., 1967), pp. 65-66; N. Kirkham, "Ecton Mines," Derbyshire Archaeological and Natural History Society, XX (1947), pp. 55-82. Both this mine and the Parys mine installed Boulton and Watt rotative engines.

period from the mid-1770's to the mid-1880's shows a rate of adoption much in excess of any of the other industries which used the engine. However, the marked change in the rate of adoption in the copper and tin mining after the year 1786 is especially worthy of note. How can this rapid adoption and the subsequent 'virtual stagnation' be accounted for? The answer lies, it is suggested, in the relationship between the characteristics of Watt's innovation and the 'state' of the industry.

In 1778 James Watt wrote, from Redruth, Cornwall, to his friend Dr. Joseph Black: ' . . . we are luckily come among them when they are almost at their witts end how to go deeper with their mines'.[1] In the same letter he also states, 'Several mines formerly abandoned are likely to go to work again through virtue of our engines'. In the Cornish mines most of the ores near the surface had been exhausted by 1770 and pumping water from depths of 60 or 70 fathoms was extremely expensive using Newcomen engines due to the high consumption of coal; all of which had to be imported by sea from South Wales and carried by packhorse

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[1]Letter, J. Watt to Joseph Black, December 12, 1778, in E. Robinson and D. McKie, eds., Partners in Science: Letters of James Watt and Joseph Black (Cambridge, Mass.: Harvard University Press, 1970), p. 41.

to the mines.[1] Also, approximately 90 fathoms (540 feet) represented the maximum depth which could be attained with the aid of Newcomen engines.[2] These factors combined with the low prices of copper after 1770 due to competition from open-cast mining in Anglesea led to the situation, in 1775, where only 18 out of 40 Newcomen engines were at work in Cornwall.[3]

Watt's engine, which used approximately one-quarter of the fuel of the Newcomen engine as well as being more effective, enabled Cornish mines to increase production and '. . . fight back in the bitter price war with Anglesea'.[4] The rapid adoption of Watt's engine in Cornwall is, therefore, explainable in terms of the characteristics of the

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[1]J. Rowe, Cornwall in the Age of the Industrial Revolution (Liverpool: Liverpool University Press, 1953), p. 21.

[2]W. Page, ed., Victoria History of the Counties of England, Cornwall, Vol. I (London: Archibald Constable, 1906), p. 550. A maximum depth of 80 fathoms is given by D. B. Barton, A History of Copper Mining in Cornwall and Devon (Truro: Truro Bookshop, 1961), p. 27. Watt's machine raised the maximum to about 200 fathoms.

[3]J. Rowe, op. cit., p. 72 and E. Roll, An Early Experiment in Industrial Organization (London: Frank Cass, 1968), p. 67, quoting a letter from M. Boulton to J. Watt, 1775.

[4]J. Rowe, op. cit., p. 76.

innovation relative to the 'needs' of the industry. The change in the rate of growth after 1786 is probably due to the fact that the period of initial rapid growth was largely one in which the Newcomen engine was replaced by Watt's (the number adopted to 1786 approximately corresponds to the number of Newcomen engines in Cornwall in 1775 (40). After this, then, the use of Watt's engine would be more or less dependent on new mines being opened up.

Coal Mining

The use of Watt's reciprocating engines to drain coal mines was second in importance. This fact should be viewed, however, in relation to the number of potential adopters in coal mining. Although no precise data on this is available, it is probable that measured by the number of Newcomen engines used in coal mines in 1775, then the potential for the use of the innovation was four or five times as great as in copper and tin mining.[1] Why, then, was the innovation so slowly adopted to this use? First, the number of coal mines which had reached the critical depth (80-90 fathoms)

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[1]See below (chapter six) for information on the number of Newcomen engines and sources.

for Newcomen engines by 1775 was very few.[1] Second, the increased efficiency of the Watt engine was not really a consideration for coal mines, since there was little advantage in saving two-thirds to three-quarters of the fuel consumed when this commodity was virtually free.[2] The only real demand for Watt's engine in coal mining was, therefore, in the few deeper pits scattered throughout the Midlands and other coalfields as shown in maps A and B in figure 16. If this was the situation in 1775, however, it had changed by the 1790's. The North-East coalfield was, by the early 1790's, beginning to exploit coal deposits at depths of 90 fathoms and greater (mining was migrating seawards). This meant that improved drainage facilities were needed

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[1]For details of the general depths of mining on the various coalfields see, R. L. Galloway, Annals of Coal Mining and the Coal Trade (London: The Colliery Guardian Co., 1898), p. 362. Some of the depths given for 1800 are as follows: Staffordshire and Warwickshire, 300 feet; Yorkshire, 420 feet; Shropshire, 462 feet; South Wales, 480 feet; Somerset, 500 feet; Northumberland-Durham, 822 feet; and Cumberland 894-993 feet. See also, pp. 294-5, for a list of the collieries in the north-east with their depths in 1787. For additional information see, T. S. Ashton and J. Sykes, The Coal Industry of the Eighteenth Century (Manchester: Manchester University Press, 1964), pp. 6-12.

[2]The 'small' coal which was difficult to sell could be used.

and Watt's engine was seen to fulfill this need. As a result the reciprocating engine was rapidly adopted in the area, as can be seen from Map C in figure 16. This explains the upturn in the graph in figure 15.

The Iron Industry

The technical processes of the iron industry in the eighteenth century can be divided into those concerned with producing, 1) cast, and 2) malleable iron. In the latter of these, iron produced in a blast furnace was refined in a forge. There were, of course, also finishing processes.

By the start of the period in which Watt's improved engine became available for use, the change-over from charcoal to coke fuel in blast furnaces was well under way and by the end of the century this was virtually complete.[1] This movement involved the development of larger furnaces which could be kept constantly in blast; a situation which required a constant supply of power for blowing the furnaces.[2]

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[1]H. G. Roepke, Movements of the British Iron and Steel Industry, 1720-1951. Illinois Studies in the Social Sciences, Vol. XXXVI (Urbana, Illinois: The University of Illinois Press, 1956), p. 15.

[2]W. K. V. Gale, Iron and Steel (London: Longmans, 1969), pp. 29-30.

Water power for working bellows was in many cases not adequate for this purpose and steam engines (atmospheric) began to be used.[1] There was, therefore, a potential for use of Watt's engine in either blowing furnaces directly or in pumping water for working the bellows. About 20 reciprocating engines, adapted for blowing, were sold during the study period. The majority of Boulton and Watt reciprocating engines used in iron works went to either the west midlands or South Wales as can be seen from the maps in figure 16, however, this will be discussed in detail later in the chapter.

Other Uses

The 'need' for Watt's improved engine in other industries was not so general as in those industries discussed above. To be sure, a considerable number of engines (13) were installed in lead mines (see figures 15 and 16), but this probably reflects adoption of the innovation in fairly

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[1]T. S. Ashton, Iron and Steel in the Industrial Revolution (Manchester: Manchester University Press, 1963), p. 37; C. Wilkin's, The History of the Iron, Steel, Tinplate and Other Trades of Wales (Merthyr Tydfil: Joseph Williams, 1903), p. 30.

isolated mines with drainage problems.[1] In addition, personal influence may have been important in some cases. The most extensive area of lead mining in Britain was in Derbyshire, but the innovation was not, with the exception of one mine, used in this area.

Similar conclusions can be drawn with regard to the use of the improved engine for raising water at canal locks, etc. The only other fairly extensive area of use was for waterworks, however, developments in urban water supply were such that this market was largely London based.[2] This factor combined with the high price of coal in the metropolis and a need for reliability meant that

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[1]For the Bog Mine, Shropshire see, W. Page, ed. Victoria History of the Counties of England, Shropshire, Vol. 1 (London: University of London Institute of Historical Research, 1968), p. 416. For lead mines in Scotland see, A. Clow and N. L. Clow, The Chemical Revolution (London: The Batchworth Press, 1952), pp. 364-377.

[2]J. Radley, "York Waterworks, and Other Waterworks in its North of England Before 1800," Transactions of the Newcomen Society, XXXIX (1966-7), pp. 143-156; H. W. Dickinson, Water Supply of Greater London (London: Newcomen Society, 1954), especially chapter 5; J. Farey, A Treatise on the Steam Engine (London: Longmans, 1827), pp. 253-255.

Watt's engine was adopted.[1]

The Rotary Motion Engine

Characteristics

Watt's invention of the rotary motion engine meant that for the first time steam could be applied effectively to drive machinery involving a circular motion.[2] This made steam potentially useful in all industries involving grinding, winding, and rolling as well as hammering and stamping. Many industries involved grinding at some stage in the process of operation, for example, corn mills, breweries and distilleries, starch making, oil manufacturing, glass and pottery making, etc. Winding was limited essentially to various mining concerns and rolling to certain processes in the manufacture of textiles and metals.

Patterns of Use

The range of uses to which rotary motion steam power could be put was far greater than with the reciprocating

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[1]E. Roll, op. cit., pp. 41-45.

[2]There had been attempts to convert the Newcomen-type engine to rotary motion, but these were not really a success see, E. Roll, op. cit., pp. 107-109.

engine. Cumulative totals of Boulton and Watt rotary engines adopted by various industries are graphed in figure 17. Similarly, the cumulative pattern of adoptions by use is shown in figure 18. Analysis of the graph shows considerable variation in the date, rate and extent of adoption of the innovation by industry. For example, use of engines in the iron and allied industries started early but the rate of adoption was slow and, if anything, declining with time. Adoptions for this use were almost all in the West Midlands area. On the other hand, use of the engine in cotton and worsted mills was late in starting. After a period with a slow rate of adoption (to circa 1790), however, a rapid acceleration took place.[1] By 1800 approximately one-third of all rotary engines erected were in this industry. Spatially, the pattern of adoption in cotton and worsted mills is one of multiple focii.

As with the reciprocating engine the regional focii identified in chapter 3 are related to particular uses or groups of industrial uses. For example, the West Midlands, for iron and coal, London for mixed food processing, etc.,

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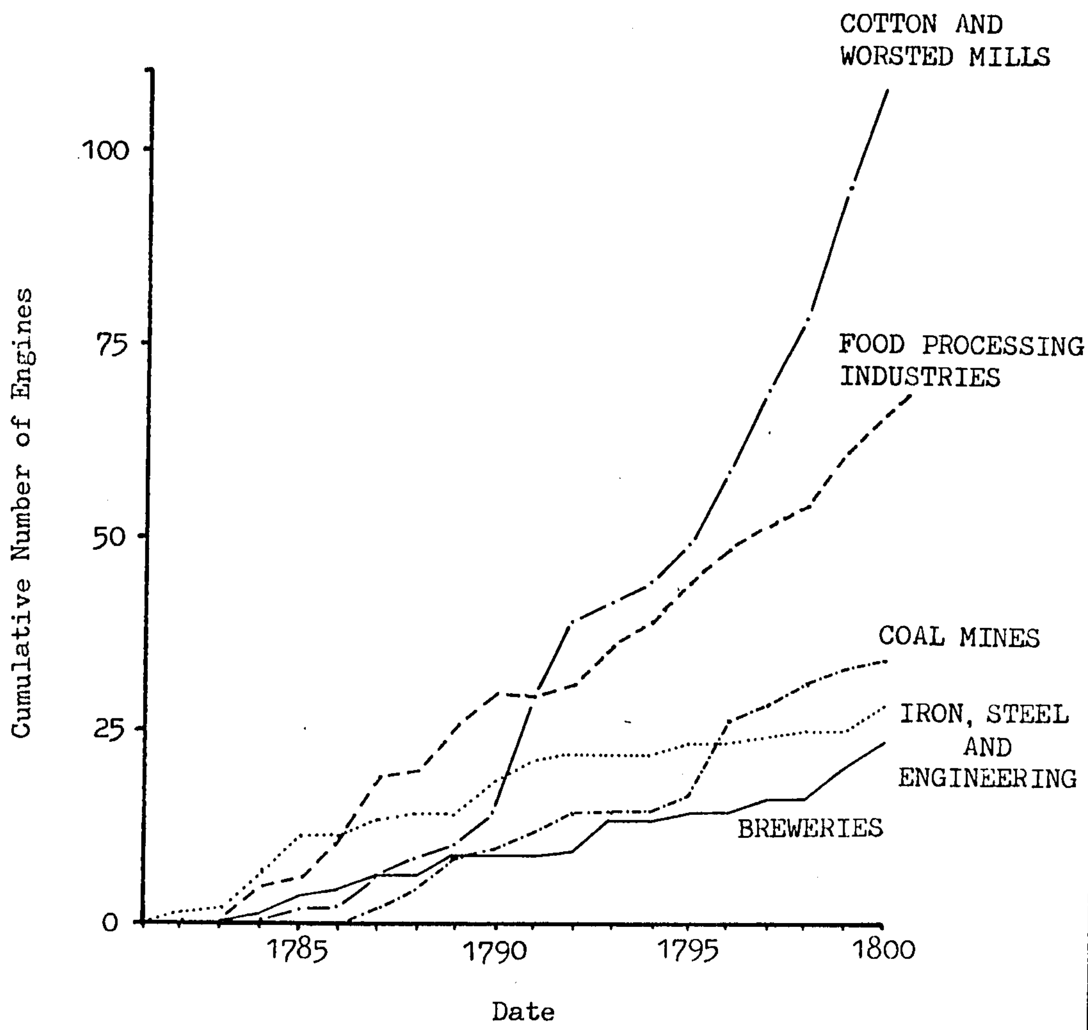
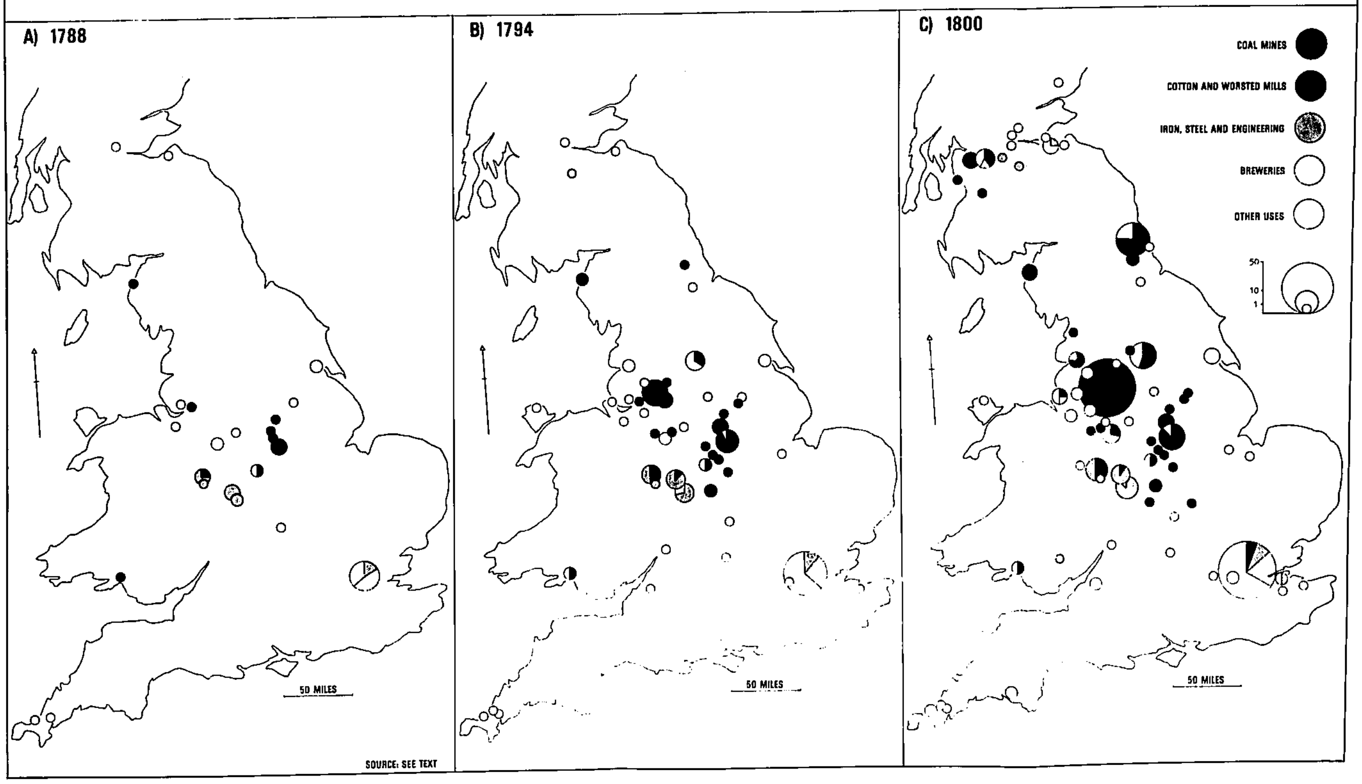
[1]These two industries are treated together due to the fact that they were very similar. In fact many mills were involved in spinning both of these.

FIGURE 17. ROTARY ENGINES: ADOPTION BY INDUSTRY.



Source: see text

FIGURE 18. ROTARY ENGINES: CUMULATIVE PATTERN OF DIFFUSION ACCORDING TO USE.



and the north-east for coal mining. These regional industrial focii adopt the innovation at different times and rates.

The Cotton and Worsted Industries

Why was rotary motion steam power so readily accepted, after an initial period of slow growth, in the cotton-worsted industry? As with the Cornish mines, the answer lies in the perceptual relationship between what the innovation had to offer and what the industry needed. Mechanization of the spinning side of the industry dates from the 1760's and is associated with the innovations of Hargreaves and Arkwright. For spinning fine yarns, however, it was the development of the 'mule' in 1779 which was important.[1] It was mainly a result of these innovations that the cotton and worsted spinning industries became fertile grounds for the adoption of the factory method of production. These early textile factories, or mills as they were known, relied mainly on water power, although horses were also used.[2]

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[1]For details see, M. M. Edwards, The Growth of the British Cotton Trade, 1780-1815 (Manchester: Manchester University Press, 1967), pp. 4-5. R. L. Hills, Power in the Industrial Revolution (New York: A. M. Kelly, 1970), pp. 54-88.

[2]S. D. Chapman, "Fixed Capital Formation in the British Cotton Industry, 1770-1815," Economic History Review, XXIII pp. 238-40; R. L. Hills, op. cit., pp. 89-90.

Thus, by the time rotary steam power became available the spinning side of the industry, including the preparation process, was highly mechanized and concentrated in fairly large units of production (by the standards of the time). In addition, the industry was rapidly expanding as the power-spinning innovation spread,[1] and soon good water power sites near to the main market centres of Manchester, Nottingham and Glasgow were occupied. This led to sites of secondary potential being used, and on such sites water shortages often caused problems.[2] The initial demand for rotary steam power was to supplement the use of water at such sites. As the value of steam power became more apparent, however, mechanized cotton and worsted spinning mills were constructed to use it as the prime motive force (this is discussed below in this chapter).

The reason for the lack, or limited use, of steam power in both the cotton and worsted weaving industry and in other textile industries is related to these different stages of development with regard to mechanization and

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[1]Especially after Arkwright's patent was annulled in 1785.

[4]R. L. Hills, op. cit., p. 134.

factory production.

It was in the late 1780's that Dr. Edmund Cartwright developed his power-loom for weaving cotton and worsted.[1] Although there were some attempts to develop this commercially, for example, by his brother Major John Cartwright in the 'Revolution Mill at Retford', these were generally of limited importance in the study period.

Similarly, in flax spinning, mechanization and the move to factory production were also later than in cotton spinning, dating from the invention of Kendrew, Backhouse and Porthouse in 1787.[2] Nevertheless, a few of the early flax mills did adopt Boulton and Watt rotative engines, for example, the above-named firm at Darlington, John Marshall at Leeds, and Benyon, Marshall and Bage at Shrewsbury.

The woolen spinning and weaving industries were still, during this period, essentially domestic in character. Some developments in the mechanization of the preparatory processes

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[1]For details of these developments see, R. L. Hills, op. cit., pp. 208-229.

[2]W. G. Rimmer, Marshalls of Leeds: Flax Spinners, 1788-1886 (Cambridge: University Press, 1960) gives some information on English developments; see, A. J. Warden, The Linen Trade, Ancient and Modern (London: Longman, Green, 1864), pp. 489-588, for Scottish developments.

had, however, filtered through from the cotton and worsted trades and small mills for this purpose had been developed.[1] Factory production was, however, beginning to be developed in an attempt to integrate all processes under one roof rather than as a result of the mechanization. The first, and largest, such factory was constructed by Benjamin Gott, who was also the first to use steam to drive his preparatory processes.[2]

Coal Winding

The pattern of adoption of rotary engines to wind coal follows very closely the pattern of reciprocal engines used in coal mines. In fact, many of the adopters were the same. The reason for this was essentially that the same factor influencing the use of Watt's pumping engine in this industry, that is depth of mining, was also important for winding coal to the surface. Horse and water gins could be

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[1]Details of technical and other developments in the woolen industry are given in, W. B. Crump, ed., The Leeds Woolen Industry, 1780-1820 (Leeds: The Thoresby Society, 1931), pp. 3-26.

[2]H. Heaton, "Benjamin Gott and the Industrial Revolution in Yorkshire," Economic History Review, III (1931-2), pp. 45-66.

used for shallow mines but not really for deep ones.[1] In addition,

> 'on the expiration of the patent for the application of the crank to the steam engine, in the year 1794, the facility with which Watt's double-acting steam engine could be applied directly to the drive shaft caused it rapidly to supercede all other methods'.[2]

Iron Industry

The main uses of rotary steam power in the iron industry were for driving forge hammers and rolling and slitting mills. The number of engines put to such uses was, however, not great and mainly restricted to the Midlands acquaintance circle of the partners. Another factor of importance in this limited use is that the major innovation which led to the large scale integration of the refining processes in the industry, that of Henry Cort in 1784, did not become widespread in the period.[3] Cort's innovation was combined with

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[1]The use of steam power in winding coal pre-dates Watt's invention of rotary motion. Also 1780 many atmospheric engines were adapted to rotary motion by use of the crank see, D. Anderson, "Blundell's Collieries: Technical Developments, 1776-1966," Transactions of the Lancashire and Cheshire Historical Society, CXIX (1967), pp. 136-137.

[2]R. L. Galloway, A History of Coal Mining in Great Britain. Newton Abbot, Devon: David & Charles, 1969, p. 115.

[3]For details see, T. S. Ashton, Iron and Steel in the Industrial Revolution (Manchester: Manchester University Press, 1963), pp. 87-103; A. Birch, The Economic History of The British Iron and Steel Industry, 1784-1879 (London: Frank Cass, 1967), pp. 34-43.

Watt's by some firms, however, and Folliot, Scott and Co. of Rotherhithe were pioneers (1787) in this respect.[1]

Food Processing Industries, etc.

Corn mills, breweries, distilleries, starch and oil mills, etc., were all potential users of rotary steam power to replace existing power sources. This was especially true of the brewing industry which:

> 'was one of the first to utilize mechanical power to expedite the grinding and mashing of the vast quantities of corn . . .'[2]

and of the large distilleries which developed in London and Scotland in the latter eighteenth century.[3] The use of steam power in this type of industry, however, was not just related to the ease with which the innovation fitted into the existing technical set-up, but also to the scale of operations. Many industries involved in grinding processes, for example, tobacco and snuff manufacturers and sugar grinders were for the most part operated on a small scale which was not conducive to the use of steam.

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[1] T. S. Ashton, "Iron and Steel," p. 97.

[2] Clow and Clow, op. cit., p. 536.

[3] Ibid., p. 553.

Other Uses

There was a wide range of uses to which rotary steam power was applied in the period to 1800, for example, to grind rags in a paper mill and to grind flint, etc., for a pottery. In general it can be stated, however, that the nature of these industries did not make the use of steam power a pressing or obvious need. Paper making was essentially still a hand craft -- not being mechanized until the first decade of the next century.[1] Similarly, the pottery industry, with notable exceptions, was small scale and not heavily mechanized.[2]

To sum up, we can observe that there were specific industries in the last two decades of the eighteenth century which were in a sense 'ripe' for the use of rotary steam power. Which industries were 'ripe' depended largely on the relationship between what the innovation had to offer and the perceived needs of industry, although the adoption of other innovations, for example mechanization, was important.

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[1] D. C. Coleman, The British Paper Industry, 1495-1860 (Oxford: Clarendon Press, 1958), pp. 89-176 and pp. 179-199.

[2] J. Thomas, "The Pottery Industry and the Industrial Revolution," Economic History, III (1934-1937), pp. 399-414.

Within-Industry Variations in Engine Use

Given that specific industries, for example, cotton spinning can be identified as areas of high potential for the use of steam power and that the general pattern of diffusion can be in part 'explained' in terms of this, it is clear that within such a group of potential adopters there are considerable variations in adoption. How can these within-variations be accounted for and what is their influence on the general pattern of diffusion? Detailed case studies of particular industries and areas can provide insight into this question.

The Brewing Industry

Making a decision to adopt an innovation is a difficult process due to the uncertainty concerning the outcome of the adoption. This is the case because the individual or groups concerned will be unsure of the potential value of the innovation, especially where its character makes estimation of the rewards associated with adoption difficult.[1]

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[1]J. S. Metcalfe, "Diffusion of Innovation in the Lancashire Textile Industry," Manchester School of Economic and Social Studies, XXXVIII (1970), pp. 145-160. E. Mansfield, "Technical Change and the Rate of Imitation," Econometrica, XXIX (1961), pp. 741-766.

The uncertainty, or risk, surrounding the decision is largely a result of incomplete information on the nature and potential of the innovation and the consequences of adopting it.

For a given body of potential adopters, therefore, it can be argued that the likelihood of any individual adopting at a given time is related to the risk that the individual associates with trying the item. When dealing with industrial units such as breweries then just as with individuals, there are characteristics which make certain units more likely to adopt than others. The size of industrial unit is one such factor. Not only can larger firms, generally better afford the acquisition of uncertainty-reducing information, but also an innovation of a fixed cost represents, proportionally, much less of a risk investment for a firm with large asset.

In the study period about twenty Boulton and Watt rotative engines were installed in breweries, the majority of these in London. Mathias has pointed out that it was only the largest 'capitalist' breweries that adopted the innovation before the end of the century.[1] Breweries in

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[1]P. Mathias, The Brewing Industry in England, 1700-1830 (Cambridge: Cambridge University Press, 1959), p. 12; pp. 80-81.

general could be classed as either capitalist or publican; the former being manufacturers of porter and located with regard to the large urban markets, especially London; the latter were usually small scale affairs.

The pattern of adoption of rotary engines (see figure 18) for breweries mirrors the pattern of capitalist porter breweries in that it is related to the urban hierarchy. In addition to a marked concentration of adoptions in and around London, engines also went to Glasgow,[1] Liverpool, Plymouth and Nottingham. The production of these breweries (porter) at least in London, was generally over 20,000 barrels per annum, however, round London, a few large ale producers also achieved this figure.

The capitalist breweries were, by the 1780's, already highly mechanized and operating on a large scale. Horse power was the basic motive force used in the grinding processes. Technically, Watt's engine fitted well into the existing organization of these concerns since it could easily be used to replace the horses used for power. In addition, economic factors, such as expanding production, made a more efficient

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[1]One of the early porter breweries outside London was run by the Struthers family in Glasgow. The History of Glasgow (Glasgow: J. Tweed, 1872), p. 859.

power source desirable.[1]

Data on the size of London breweries can be used to provide support for the observations concerning firm characteristics and adoption.[2] This relationship is particularly worth exploring, since it can be argued that all adoptors have essentially the same location (at the national scale) and in all probability there was little variation in the date at which they became aware of the innovation. Thus in a sense this kind of information factor is 'held constant' allowing the size/date relationship to be examined. The graph in figure 19 shows this relationship to be negative and logarithmic (-0.85).[3] This tends to support the notion that date of adoption is related to both uncertainty and that the larger firms are less uncertain, at a given time, than smaller ones, and that larger firms are more likely to be able to afford a fixed outlay of capital for the innovation. The risk associated with this being proportionally

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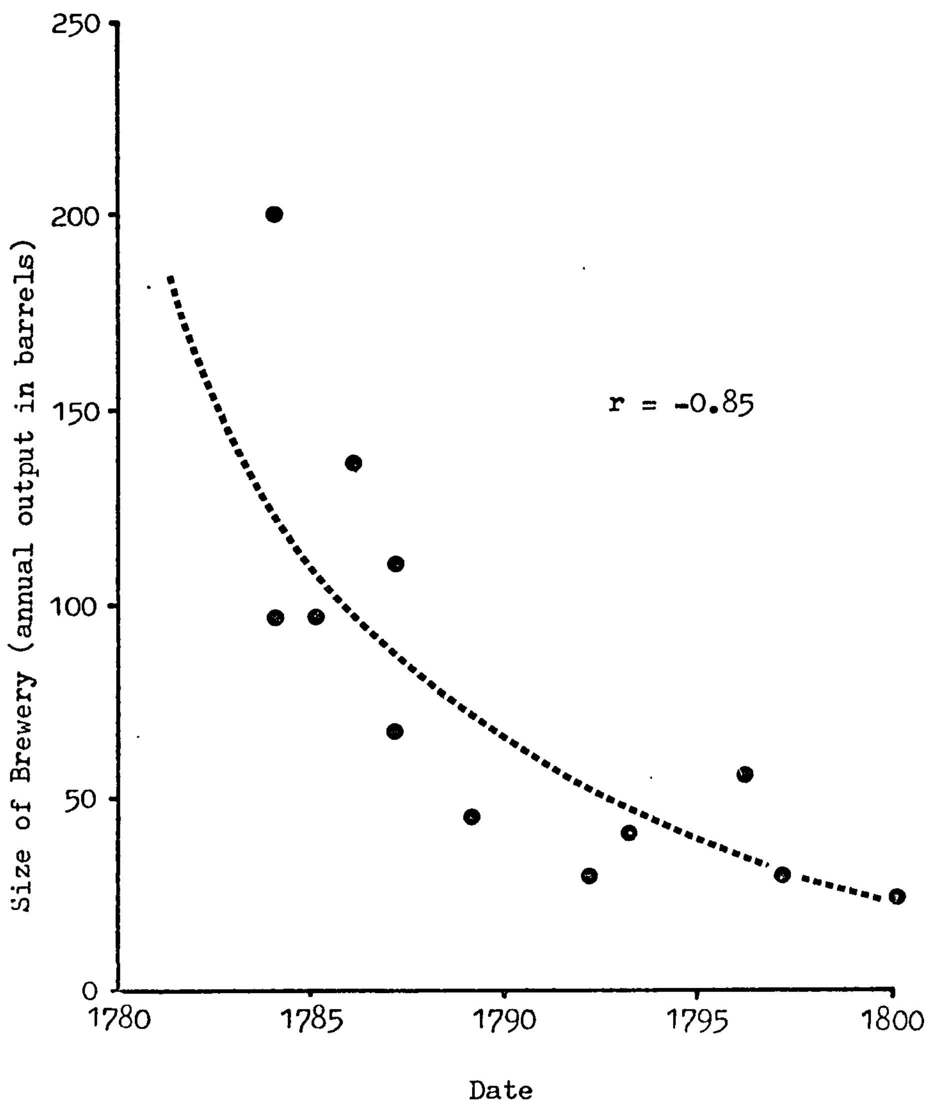
[1]P. Mathias, op. cit., p. 80.

[2]J. Middleton, View of the Agriculture of Middlesex (London: Board of Agriculture, 1807), p. 587. H. A. Monckton, A History of English Ale and Beer (London: The Bodley Head, 1966), pp. 207-218.

[3]Significant at the 0.1% level.

FIGURE 19. RELATIONSHIP BETWEEN SIZE OF LONDON BREWERY AND DATE OF ADOPTION OF BOULTON AND WATT ROTARY ENGINE.



Source: see text

less for a larger rather than a small firm.

Reciprocal Engines in the Iron Industry

The pattern of adoption of reciprocating engines to be used in blowing the coke fired blast furnaces of the iron industry cannot be understood without a brief digression to discuss the origins and development of this industry. Iron was first smelted with coke in 1709 by Abraham Darby of Coalbrookdale; however, it was not until the 1760's that the innovation began to spread. The diffusion was particularly rapid in the 1780's and by 1788 there were some 58 furnaces in blast.[1] The diffusion of coke furnaces is an extremely good example of what has been termed an implementation process in innovation diffusion. Decisions made concerning the adoption of the innovation, for example by persons from the West Midlands, Bristol or London, were implemented in areas like South Wales where conditions were perceived as good.[2] The diffusing pattern of coke furnaces

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[1] T. S. Ashton, Iron and Steel, p. 99.

[2] A. M. John, The Industrial Development of South Wales, 1750-1850 (Cardiff: University of Wales Press, 1950), pp. 23-26. For similar discussion of the industry in Scotland see, M. Hamilton, An Economic History of Scotland in the Eighteenth Century (Oxford: Clarendon Press, 1963), pp. 193-205.

provides a framework within which Watt's blowing engine spread. What factors influenced the intra-industry diffusion? The use of Watt's blowing in blast furnaces shows two distinct timespace clusters, 1) the West Midlands, and 2) South Wales, the former being an early area of adoption, the latter a later one. These two clusters, however, should be seen within the framework of the diffusing coke smelting innovation which is shown in figure 20. This shows that two other major clusters of coke furnaces had practically no adoption of Watt's blowing engine (Yorkshire - Darbyshire and Scotland). Insight into the reasons for this can be provided by analysis of Table 2. This shows rates of adoption for size classes of furnace operations, and clearly demonstrates that larger operations were more likely to adopt.[1]

Table 2

Size (Tons Produced Annually)	Number	Adopters	%
3,000 plus	18	11	61
2,000 - 2,999	9	0	0
1,000 - 1,999	28	2	7
0 - 999	24	2	10

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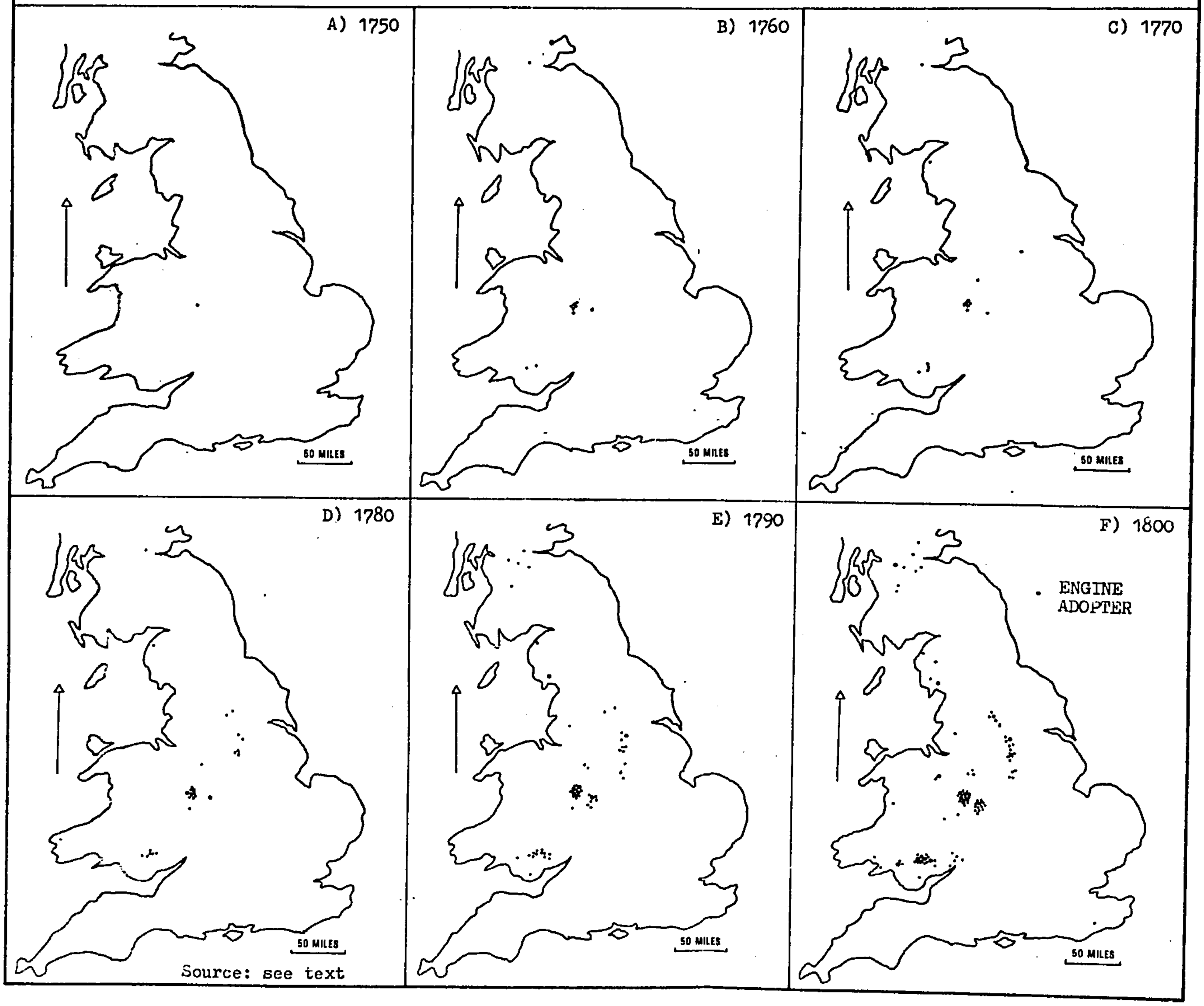
[1]Data mainly from, M. Scrivenor, A Comprehensive History of the Iron Trade (London: Smith, Elder & Co., 1841), pp. 93-96, pp. 359-60.

FIGURE 20. THE DIFFUSION OF THE COKE-FIRED IRON BLAST FURNACES IN BRITAIN.



Source: see text

This can be related to the spatial pattern by the observation that the majority of operations in the size class of over 3,000 tons annual production were either in South Wales or in the West Midlands (Shropshire and South Staffordshire). Even though there seems, as with the breweries, to be a size factor influencing the adoption of the innovation, it remains true that the majority of operations in the Midlands area became adopters in the early period 1770's and 80's, while in South Wales it was the 1790's. It is probable that other factors, such as information flows or influence links are of importance here; this is, however, discussed in some detail in the next chapter.

The Cotton and Worsted Industries

The use of Boulton and Watt rotary-motion engines in the cotton and worsted industries must be viewed within the framework provided by the diffusion of another innovation, mechanized cotton and worsted spinning in factories (mills). The technical developments which led to the factory system in the above industries have already been discussed, however, the actual spread of the innovation has not.

The early growth of this factory system of production is closely associated with the name of Richard Arkwright and with his move from Lancashire to Nottingham in 1769.[1] This move was stimulated by resistance, in Lancashire, to developments in mechanized spinning. Both Arkwright and James Hargreaves (inventor of the spinning jenny) were attracted to Nottingham which was the center of the hosiery industry and a rapidly-expanding market for cotton yarn.[2] Although Nottingham was the 'center of attraction' for cotton spinning in the Midlands, it was not especially suitable for mechanized spinning by water-power, and using horse-power restricted the scale of operation. As a result there was an early expansion of mills into the Derbyshire dales to take-up 'good' water-power sites. This move was led by Arkwright and it was the distribution of his mills that largely determined the locational pattern of the mechanized cotton spinning industry in the area,[3] as can be seen in map A in figure 23.

By the late 1770's and early 1780's, however, the most

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[1]R. L. Hills, Power in the Industrial Revolution (New York: Augustus M. Kelley, 1970), p. 67.

[2]D. M. Smith, The Industrial Archaeology of the East Midlands (Dawlish: David and Charles, 1965), pp. 63-64.

[3]S. D. Chapman, The Early Factory Masters (Newton Abbot: David and Charles, 1967), p. 68.

accessible and attractive water-power sites in the area had been used and Arkwright and others began to turn their attention to alternate areas. The potential for water-power was particularly good in Lancashire, West Yorkshire, and Scotland. The growth of the factory system in these areas was rapid and by 1788 there were some 49 mills in Lancashire and Cheshire, 19 in Scotland, 11 in Yorkshire, and 39 in Nottingham and Derbyshire.[1] The search for suitable water-power sites for erecting cotton and worsted mills is again a particularly good example of an implementation process in diffusion of innovation, the adoption decision (to build a mill) often being made in a different location from that at which the innovation appeared.

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[1] P. Mantoux, The Industrial Revolution in the Eighteenth Century (London: J. Cape, 1961), p. 248. For details of early mills in Scotland see, M. Hamilton, An Economic History of Scotland in the Eighteenth Century (Oxford: Clarendon Press, 1963), pp. 170-184; M. Hamilton, The Industrial Revolution in Scotland (London: Frank Cass, 1966), pp. 122-132. The Midlands developments are dealt with in S. D. Chapman, "The Pioneers of Worsted Spinning by Power," Business History, VII (1965), p. 97-116; S. D. Chapman, "Factory Masters." For some details of early mills in Lancashire and Cheshire see, R. L. Hills, op. cit., and S. D. Chapman, "Fixed Capital Formation in the British Cotton Industry, 1770-1815," Economic History Period, XXIII (1970), pp. 256-258, pp. 260-261. It is worth noting that in 1783 Manchester had only two mills.

The timespatial pattern of adoption of Boulton and Watt rotary engines in cotton and worsted mills has been shown in figure 18. Further insight into this pattern of spread is provided by figure 21, which graphs adoption rates for the four main areas the cotton/worsted spinning industry was located in (Midlands, Lancashire-Cheshire, Yorkshire and Scotland). This clearly demonstrates that each region adopted the use of the innovation at different times, rates, and to different degrees in the study period. Especially worthy of noteis the rapidly accelerating adoption in Lancashire-Cheshire in the 1790's, interrupted only by the crisis in the cotton industry in 1792.[1] It was in the Midlands that the engine was first adopted followed by Lancashire-Cheshire, Yorkshire, and Scotland, in that order. This general northward shift in the overall focus of the distribution is indicated more precisely by the movement of the center of gravity of the pattern, which is monitored in figure 22. It should be noted that this regional sequence of development of steam power in the cotton and worsted industry mirrors the original sequential regional development of the factory system in the industry.

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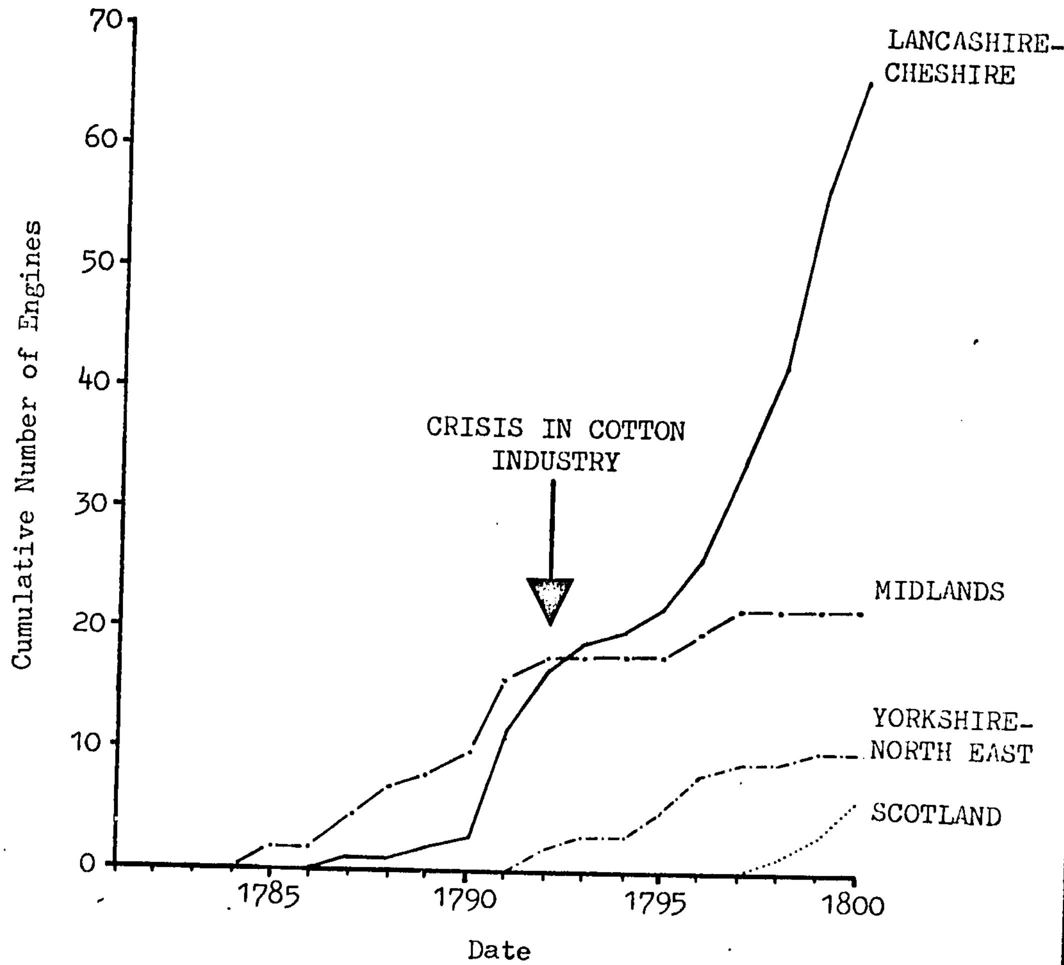
[1]R. Owen, The Life of Robert Owen, Vol. 1 (London: Frank Cass, 1967), p. 38.

FIGURE 21. ROTARY ENGINES: REGIONAL GROWTH CURVES FOR USE IN COTTON AND WORSTED MILLS.



Source: see text

FIGURE 22. SHIFTING CENTER OF GRAVITY: ADOPTION OF ROTARY ENGINES IN COTTON AND WORSTED MILLS.

Source: see text

How can the within-industry spread of steam engines be accounted for? The rapid expansion of the textile spinning mills in the period 1770 to 1790 and their orientation to water-power sites meant that soon many of the best locations were occupied. This led to the utilization of sites of secondary value by entrepreneurs. Similarly, it is possible that in an effort to remain close to the market centers of the cotton industry inadequate water-power sites were used. For many mills, therefore, the supply of water during the summer months was not sufficient. It was as a supplementary power source that steam engines were first used in cotton mills.[1] Pumping engines could of course be used for returning the water to a pond for re-use but rotary motion engines could be used directly to drive the machinery. Some early steam engines (rotary) were also used to replace horse-power.[2] It is due to the above factors that the early spread of Watt rotary engines was within the existing locational framework of mills, which does, of course, change over time. Within this framework individual adoptions were

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[1]Most of the early rotary steam engines were of a small size due to this fact, most being less than 15 h.p. and many being less than 10 h.p.

[2]R. L. Hills, op. cit., p. 89.

determined by a variety of factors, it is suggested. The framework, or infrastructure, of mills as it developed over time in the Midlands has been mapped (see figure 23).[1] Added to this are those units which took Watt's engine. The striking feature of these maps is the concentration of adoptions which developed in and around Nottingham. There are several possible explanations for this phenomenon. It may be due to locally inadequate water-power conditions for those mills which had been induced to locate near and in the town. Chapman suggests, however, that the reason may be one of resistance. He argues that the concentration was of Watt engines rather than steam engines in general, this being due to local opposition to the smoky 'common engines'.[2] It is probable that a combination of the two factors is important, with the first reason providing a framework within which the second operated. It is also a possibility that 'information flow' factors contributed to the pattern of adoptions (see below chapter 5).

Throughout the study period water continued to be used

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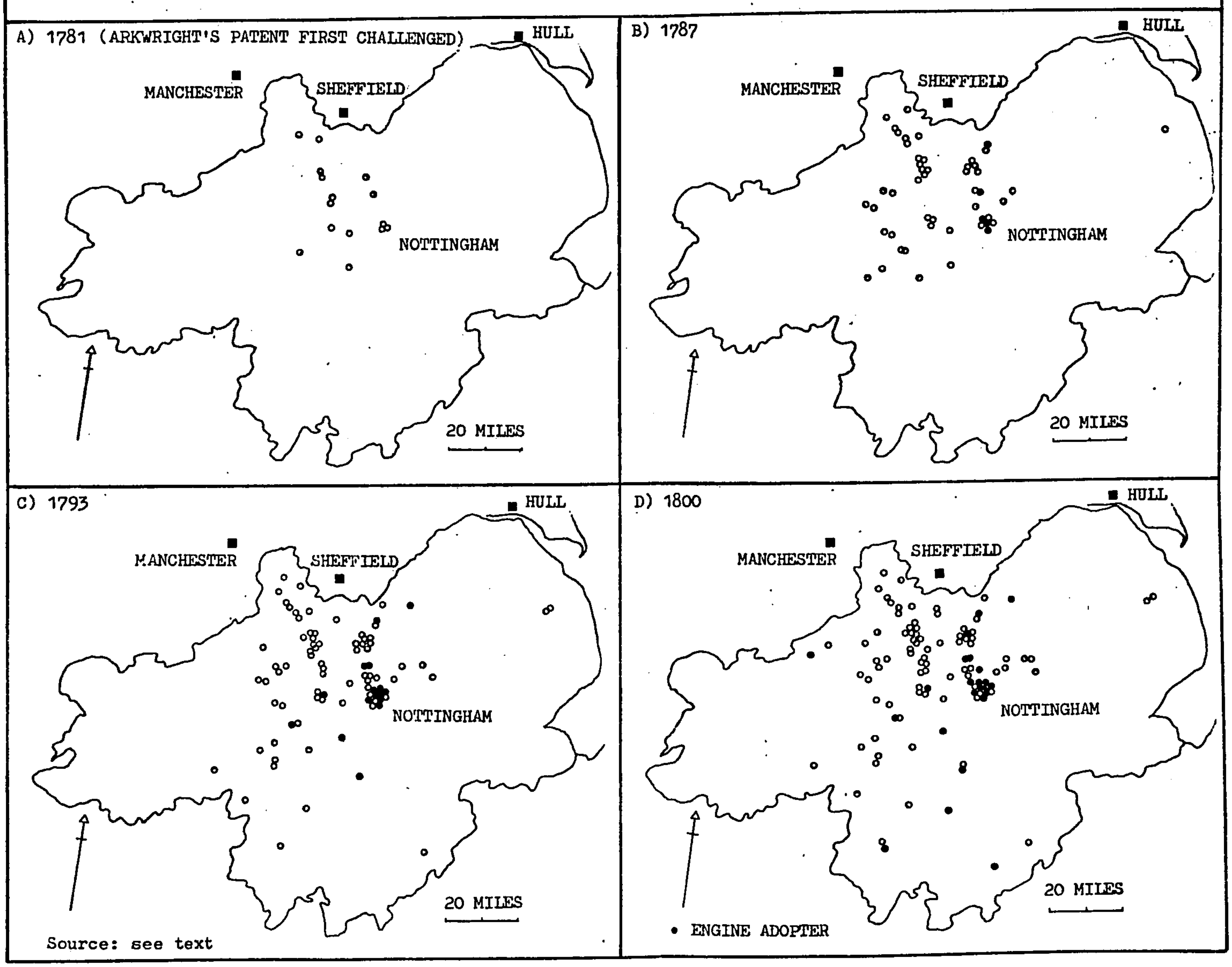
[1]The basic data comes from, S. D. Chapman, Factory Masters, pp. 230-237; S. D. Chapman, "Fixed Capital," pp. 256-266.

[2]S. D. Chapman, Factory Masters, p. 155.

FIGURE 23. THE DIFFUSION OF COTTON AND WORSTED MILLS IN THE MIDLANDS.



as a power source and new sites were developed. A good site was particularly attractive as it could generate as much power as a large steam engine and much more than a small one, in addition, it was virtually free after the initial investment. The failure of steam power to penetrate the water-power stronghold of the Derbyshire Dales is particularly worthy of note.

The early use of rotary steam power to supplement other power sources demonstrated its utility and overcame resistance to its use, in spinning cotton and worsted, based on the belief that it was not smooth enough.[1] As a result entrepreneurs gradually began to realise that steam could be used as a prime mover in their mills. The first textile mill to rely entirely on steam power was the Revolution Mill at Retford in Notts, built by Major Cartwright and he ordered a 30 h.p. Watt engine.[2] By the 1790's the movement for steam mills was growing, for example, in 1791 Grimshaw's were erecting in Manchester a 'very large

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[1]This idea may have been based upon early attempts to use Newcomen engines directly. Watt's double-acting rotative engine was, however, soon to prove it was smooth enough.

[2]S. D. Chapman, Factory Masters, pp. 107-109.

Building and intend to have two or three Fire Engines . . .'[1] The same source provides the following quote: '. . . a great number of Factorys are now erecting in this Town . . .' and 'It is truly astonishing the money that is at this time expending in this place Manchester in erections of that nature . . .'[2] The trend to steam-powered mills continued with the most successful factories being those on the design of Peter Atherton of Warrington, nr. Manchester using 30 h.p. Watt engines.[3] The rapid expansion of the industry throughout the 1790's facilitated the move to steam-powered factories by allowing for the construction of new mills whilst maintaining the existence of the old. What did happen, however, was that the new mills constructed were increasingly located in the large urban places in the cotton areas, for example, Glasgow-Paisley, Leeds, Nottingham, and Manchester-Stockport and the other Lancashire towns. The attraction of these places for

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[1] Letter, B. Lees to Boulton and Watt, January 29, 1791.

[2] Letter, B. Lees to Boulton and Watt, January 17, 1791.

[3] S. D. Chapman, "Fixed Capital," p. 240.

mills, once freed from the restrictions of water power, can be largely explained in terms of orientation to the market and financial centers of the industry. This situation again reveals that implementation decisions are important in the pattern of diffusion. Undoubtedly many persons with capital were attracted to invest in the building of cotton mills to be driven by steam, for example:

> As my intention is, to employ some money to the best advantage. I could wish you to inform me at the same time the same particulars cost etc. respecting an Engine for spinning of cotton as also for slitting and rolling iron to enable me to determine which of them may be purchased to most advantage.[1]

A further example is provided by John Cookson who, having seen an engine at work in London, enquired about one for spinning cotton.[2] The engine was purchased, eventually, and erected in Leeds. The 1790's, therefore, saw the start of steam powered textile spinning factories. The steam engines employed were usually quite large compared with those of the earlier period in the Midlands, often exceeding 30 h.p. The demand for steam engines was very great in

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[1]Letter, J. Foster to Boulton and Watt, February 19, 1792.

[2]Letter, J. Cookson to Boulton and Watt, February 1, 1792.

this period and a demonstration of this is provided by the number of 'pirate' engines which were erected, especially round Manchester.[1] The general shift to larger steam-powered production units in this period must have led to economies of scale in the spinning industry and by the end of the century the industry was highly competitive.[2] Increasing developments along these lines almost certainly led to the gradual eclipse of the more remotely located productive units, as transport costs and reliability of delivery became more important.[3]

Other Industries

Similar kinds of biases to those identified in the brewing and iron industries affected the intra-industry diffusion of steam-power in other industries. In distilling the largest units only adopted the innovation, these being

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[1]A. E. Musson and E. Robinson, Science and Technology in the Industrial Revolution (Toronto: University of Toronto Press, 1969), pp. 393-426.

[2]In the late 1790's many firms in the Nottingham area went bankrupt and sold their engines.

[3]See, D. M. Smith, op. cit., pp. 93-94; S. D. Chapman, Factory Masters, pp. 211-218.

located in London and Scotland.[1] For other industries the use of the innovation was restricted to those one or two units which were either a large size or mechanized or both. The British Plate Glass Co. was one such unit in the glass industry. This firm had a patent for the manufacture of plate glass and this was carried on in a large works at Ravenhead, Lancashire. Founded in 1773 with a capital of £40,000, by 1798 it had been taken over by Pilkington and was valued at £105,000. Steam was used to polish the plate glass.[2] A similar case is that of the firm of Grimshaw, Webster, Hills, and Scarth which in 1794 applied for an engine (rotary) to work their newly invented patent machine

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[1]A. Clow and N. L. Clow, op. cit., p. 553. H. Hamilton, The Economic History of Scotland in the Eighteenth Century (Oxford Clarendon Press, 1967), pp. 106-109, identifies some of the largest Scottish distilleries as being Haigs, James Stein, John Stein, and Aitcheson and Brown of St. Clement Well. All these adopted Boulton and Watt rotary engines. Some of the largest London concerns are identified in J. Middleton, op. cit., p. 578.

[2]A. Clow and N. L. Clow, op. cit., p. 292; J. C. Logan, "The Dumbarton Glass Works Company: A Study in Entrepreneurship," Business History, XIV (1972) p. 64.

for spinning hemp and ropes.[1] In 1795 the firm had still not decided where to locate their new mill, but were considering a site near Sunderland in the North-East and were also contemplating the erection of another mill near London.[2] This provides an interesting example of the importance of an implementation decision.

Although size factors were undoubtedly important, isolated instances of the use of rotary steam power in industries could, of course, be the result of individual acts of insight:

> I yesterday see a peice of machinery at work near Hull which I understand you have a patternt for the constructing of, what I mean is an oile Mill belonging Messrs. Jarratt & Coats worked by a fire Engin, it struck me that a paper mill might be worked in the same manner, . . .[3]

The person in question had, however, at the time not decided where to erect his paper mill, both Hull and Leeds

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[1]Letter, Grimshaw, Webster, Hills and Scarth to Boulton and Watt, August 26, 1794.

[2]Letter, W. Scarth to Boulton and Watt, Feb. 13, 1795.

[3]Letter, T. Houghton to Boulton and Watt, August 30, 1785. The engine was to be used for grinding rags and ropes.

being mentioned as possible sites.

Conclusion

This chapter has demonstrated that the general pattern of diffusion of the two innovations is influenced by factors concerning the perceptual relationship between the 'needs' of industry and the characteristics of the steam engines. This relationship is shown to exist for, 1) among industry variations in the ability-to-use, and 2) within industry variation in use potential. In the first instance it is shown that some industries were, in a sense, 'ripe' for the use of the innovations, however, there might be a whole complex of factors which contributed to this particular state of the industry. Not least of which was the way in which the adoption of other innovations, for example mechanization and the factory system in cotton and worsted spinning, could prepare for the rapid adoption of steam. Within industry diffusion was affected by a number of biases which affected the likelihood of adoption. Of special importance here, for a number of industries, is the size of unit, which is a surrogate for many aspects of behaviour relating to adoption. In the cotton and worsted spinning industries, however, different factors seem to have been important. In this case the intra-industry spread is both through an existing infrastructure of water-power mills where steam was used to supplement the existing power source, and by means of implementation processes. In the latter case, mills were erected which were powered by steam from the start.

Finally, it is clear that many of the regularities observed in the general diffusion pattern in chapter three can be understood in terms of the spread of the innovations through an infrastructure based on the existing and changing needs of industry. It was this that principally channeled the course of the diffusions. That the situation was, however, not as simple as this is demonstrated in the following two chapters.

CHAPTER 5

INFORMATION FLOW PROCESSES

Introduction

In the previous chapter a set of regional industrial biases which apparently were important in channeling the course of the diffusion were identified. The basis for the discussion was, in essence, the changing perceptual relationship between the characteristics of the innovations and the 'needs' of industry. Flows of information are a vital element in the perception process and the purpose of this chapter is to examine such flows and to attempt to relate them, in terms of spatial biases, to the patterns of diffusion.

The flow of information concerning the innovation is a complex timespace event. Ideally, it would be possible to trace both the sources and the information which influenced every individual in his decision to adopt the innovation. This would provide a picture of the timespatial attributes of the information communications infrastructure which was important in the diffusion, and this could then be related to the pattern of diffusion itself. Achieving this goal is not possible, however, both because of the complexity of the 'total event' and due to the lack of adequate data. Available contemporary information on this topic, incomplete and inadequate as it may be, is nevertheless, an important source of insights into the innovation diffusion process. Such data is 'drawn together' in this chapter to create an 'image' in the mind of the reader of the nature of the information flow process.

Initially, scraps of data are used to indicate the significance of information in the adoption decision process and to isolate some of the kinds of biases which affected flows of information in the period. This, essentially aspatial, preliminary discussion provides a basis for an attempt later in the chapter to isolate some of the spatial aspects of these flows and to identify relationships between these and the patterns of diffusion.

Information and the Adoption Process

Once a person is aware of an innovation, the speed of response in terms of the decision to adopt (some never adopt) can be related to 'resistance' factors.[1] Resistance is a term used to describe the uncertainty or risk (attraction is the opposite) that a person associates with trying the new item. Virtually all adoption involves some risk due to uncertainty about the exact nature of the innovation and the consequences (profitability, etc.) of trying it. In this context it is easy to see the importance of information, not only as a source of awareness but also as a means of providing the knowledge which helps reduce uncertainty.

In the discussion in chapter one, several stages in the adoption-decision process are identified. These ranged from awareness to final adoption. What evidence is there for these stages and for the importance of the role of information in the various stages of the process?

Awareness

Persons enter into a 'state' of awareness of an innovation as a result of information receipt. Research has suggested that the so-called 'mass media', as a means of human extensibility, are an important source of awareness of innovation, reaching, as they do, large audiences. It is to

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[1]Some persons may, of course, not be interested in the innovation.

be noted, however, that since they are essentially one-way, that is, involving little feedback, they may not be particularly persuasive.[1] In an historical context even the name 'mass media' may be inappropriate. It is doubtful whether newspapers reached a mass audience in the eighteenth century due to factors such as low literacy and the high cost of the items, and, in addition, they may not have placed much emphasis on including in their contents the kinds of information which would be important in persuading a person to adopt an innovation. It is much more likely that newspapers served an educated and fairly wealthy section of society. Nevertheless, a large number of industrialists, would probably have been in this group and exposed to the news media. It is, therefore, quite likely that many individuals, like Thomas Williams, became aware of the innovation through newspapers:

> Having seen in the newspaper an acct. of a fire engine that was set to work in March at Bloomsfeil Collery and that its Principles are very different from others requiring only one 4th of the fuel of a common engine. Mr. Edward Turner of your place who was in Wales

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[1]This may not be as true for the present day when repetitive advertising, etc., is an important feature of this communications media.

> lately said it was made by you. Which leads me to write desiring to know how much money an engine of yr. sort will cost . . .[1]

Reports about Watt's improved pumping engine had been in the press at least since 1769 when, in connection with the acquisition of a patent, an advertisement describing the engine was inserted in the London Gazette and in the newspapers of greatest circulation in Edinburgh, Glasgow, Dublin, Newcastle and Cornwall, 'being such places where Steam or Fire Engines were most common'.[2] With the erection of the first of Watt's engines at Bloomfield Colliery, in 1776, such accounts became more common, for example, a local newspaper carried an article praising the engine's performance and fuel consumption.[3] The news was also reported in the Cumberland Pacquet.[4]

The firm of Boulton and Watt were well aware of the importance of favourable advertising in spreading knowledge

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[1]Letter, Thomas Williams to Boulton and Fothergill, July 12, 1776, Boulton and Watt Collertion.

[2]Great Britain, Parliament, Parliamentary Papers, 12 June, 1829, "Report from the Select Committee on the Law Relating to Patents for Inventions," Appendix V, p. 254.

[3]Aris's Birmingham Gazette, March 11, 1776.

[4]Cumberland Paquet, March 11, 1776, quoted in E. Hughes, North Country Life in the Eighteen Century. Vol. 2. Cumberland and Westmoreland, 1700-1830 (London: Oxford University Press, 1965), p. 165.

of their innovation.[1] An example of this is the direction given by James Watt to one of their early customers for an announcement in the newspapers:

> If you insert anything about us in the advertisement I would not have more than the following: We hear from Lawton Salt-Works that Mr. S. has now completed his new works on the banks of the Staffordshire canal, which are esteemed to be the most complete in their way of any in the country: the reservoir of brine is situated 100 yards above the brine in the pit and higher than the canal. It is filled with brine by a small fire engine constructed by Boulton and Watt of Birmingham which does its business with great ease and a very small consumption of fuel.[2]

The news media was a means of disseminating information, not only pertaining to the existence of a new kind of steam engine, but also in pointing out its characteristics and the exact nature of its superiority over the old or common engine. This was especially the case where trials between the two types of engines were reported.[3]

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[1]E. Roll, An Early Experiment in Industrial Organization (London: Frank Cass, 1968), pp. 37-8. The firm also used advertising circulars see, Proposal to the Adventurers in . . . circa 1780, Boulton and Watt Collection

[2]Letter, James Watt to Mr. Salmon, April 9, 1778.

[3]Aris's Birmingham Gazette, April 20, 1778; Newcastle Gazette, June 2, 1779.

The impression should not be gained that awareness was only achieved by newspaper accounts, for, although quantitative evidence is lacking, it is highly probable that a great many industrials and others first found out about the engine by interpersonal communication from acquaintances. This will be discussed in greater detail below. Sufficient to mention some examples here. First, at an individual level, interpersonal links could act over long distances to bring about awareness. Robert Barclay the London Brewer and early adopter of the rotary engine, received news of the engine from his Quaker cousins in Birmingham.[1] At another level, the erection of a new kind of engine could have the following effect in stimulating local rumour:

> . . . it has answered one extremely good end: it has made your engines general topics of conversation, and consequently universally known, which they were by no means before in this country.[2]

Awareness of an innovation could give rise to an interest stage in which information about the steam engine

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[1]P. Mathias, The Brewing Industry in England, 1700-1830 (Cambridge: Cambridge University Press, 1959), p. 83.

[2]Letter, James Watt, Jr., to James Watt 1790 from Manchester, quoted in J. P. Muirhead, The Life of James Watt (London: John Murray, 1859), pp. 304-6.

would be sought from a variety of sources. Particularly important in this stage would be information on the performance, cost, ease of use, etc., of the engine. Interpersonal links are, it is suggested, of special importance here.

<u>Interest</u>

That awareness of the innovation could lead to information seeking is shown particularly well from the evidence connected with the Cornish Adventurers, where the 'need' for improved pumping devices was especially great. Rowe points out that even in 1775 when an extension to Watt's patent was being negotiated, the Cornish men contacted Matthew Boulton in London looking for information on the innovation.[1] Richard Mitchell's near contemporary account also sheds some light on the search process:

> About this time 1776 there was a great talk concerning Messrs. B & Watts new fire engine some said they were better others said they were not so good as the old sort: At length some Western Gentlemen agreed to send two Persons to Hawksbury Colliery near Coventry to inspect them, but they brought back different accts. of them.[2]

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[1]J. Rowe, <u>Cornwall in the Age of the Industrial Revolution</u> (Liverpool: Liverpool University Press, 1953), p. 77.

[2]R. Mitchell, "Account of the Introduction of Boulton and Watt's Engine into Cornwall and Opinion of their Merits," July, 1795. Boulton and Watt Collection.

as does Mr. Wilson's statement:

> . . . Thos Dudley an Engineer was at Soho from Cornwall & had examined 2 or more Engines built near that place on Mr. Watts construction, he wrote to his Friends such flattering accts of those Engines superiority over the Engines in common use, that the Managers of Chacewater were induced to apply to B & W to erect a small Engine . . .[1]

These quotations are particularly interesting because they illustrate the importance of the 'demand' for new pumping devices, in Cornwall at the time, as a stimulus to search for innovations.

An examination of the records of letters of inquiry to Boulton and Watt reveals that interpersonal links (acquaintances, etc.) were especially important sources of information and influence. A selection of quotations will serve to illustrate this point:

> I have it some time in contemplation to erect a steam Engine for the purpose of grinding Flint and being recommended to you by my Friend Mr Coates of Hull I write to beg to be inform'd what sort of an Engine will be necessary for that purpose . . .[2]

> Mr Thomas Allingham of Thames Street a gentleman very well known to you, was so kind as to gain our Mr John Cookson permission to see an Engine built by you . . .[3]

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[1]Letter, J. Foster to Boulton and Watt, February 19, 1792.

[2]Letter, J. Cookson to Boulton and Watt, February 7, 1792.

[3]Letter, J. Peckover to Boulton and Watt, December 29, 1791.

> Our Mr B. Gurney had some conversation lately with Mr Wyatt in London about steam engines, who recommended his applying to you for information.[1]
>
> By desire of our mutual friend Mr John Whitchurch I send you some particulars of the efforts of our new invented steam engine.[2]
>
> My friend Mr Geddes manager of the Glass Works at Leith, begs that Mr Watt will consider at his leisure of an answer to the following Question. what might be the prime Cost of a Steam Engine to do the work of ten horses, in grinding kelp and broken Pots and in turning the wheels for cutting and engraving glasses?[3]
>
> I have an intention of erecting a steam Engine and have had your Patent one recommended . . .[4]
>
> By recommendation of Robt Barclay Brewer of Park Street Southwark, we apply to you for information respecting a Steam Engine.[5]

That the latter mentioned Robert Barclay was an important source of information and influence is supported by his own

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[1]Letter, J. Peckover to Boulton and Watt, December 29, 1791.

[2]Letter, J. Watt to Mr. Winchester, October 22, 1775.

[3]Letter, J. Black to Mrs. Watt, December 28, 1787 in E. Robinson and D. McKie, eds. Partners in Science: Letters of James Watt and Joseph Black (Cambridge, Mass.: Harvard University Press, 1970), p. 157.

[4]Letter, R. Kershaw to Boulton and Watt, June 17, 1793.

[5]Letter, R. Coleman & Co. to Boulton and Watt, September 26, 1795.

statement:

> The high opinion I had form'd of your Steam Engine being confirm'd by so many years successful experience of your own, acted upon your improved principle, had induced me to recommend the use of your Engine upon all occasions that require such power.
>
> Being one of the proprietors of the Borough Water Works, work'd upon the old expensive principle, I have lately spoken so much in favour of your improvements . . .[1]

Interpersonal links between potential and previous adopters or other reliable sources of information would provide channels of communication for detailed information concerning the pros and cons of the engine -- information which was vital to decision making. This might sooner or later stimulate the interested party to contact the firm of Boulton and Watt and to ask for details of cost, performance, and acquisition. Although it is not possible to distinguish any stage in the adoption process where the suppliers of the engine are contacted, evidence suggests that when this was done, then, information flows were, in a sense reversed. This is so because prior to entering into an agreement with a potential adopter, the firm of Boulton and Watt would

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[1]Letter, R. Barclay to Boulton and Watt, February 26, 1795.

require information concerning the applicants, that is, whether they were trust-worthy, financially sound, etc. The significance of this would be that potential adopters would have to be recommended by some mutual contact whose opinion was respected by Boulton and Watt. Often this would be a previous adopter or business associate, for example:

> If Boulton and Watt should receive an order from Messrs Wm Seedhouse & Co. of this Town, they may safely trust them.[1]

Similarly, after Edward Shaw of Salford applied to Ewart he wrote to James Watt.

> . . . I have spoke with some people who know him who say you may depend upon his fulfilling any engagements he will undertake - He told me he has got 1,000 in Heywoods Bank.[2]

In addition, McConnel and Kennedy of Manchester, Lawrence Newall of Nr. Rochdale and Robt. Coleman of London were recommended by previous adopters.[3]

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[1]Letter, J. Watt, Sr., to T. Southern, August 11, 1791.

[2]Letter, P. Ewart to J. Watt, May 18, 1791.

[3]Letters, J. Lawson to J. Watt, Jr., May 13, 1797; J. Lawson to M. R. Boulton, December 13, 1797; R. Coleman to Boulton and Watt, September 26, 1795.

Evaluation

Undoubtedly at some stage in the adoption process, reduction of the uncertainty concerning the innovation could be much eased by actual contact with a Boulton and Watt steam engine. This might be considered a 'mental trial' or evaluative stage and contacts which enabled the individual to see an engine at work would be vital. This might be achieved by means of a 'public trial', but more likely through interpersonal contacts. For example, the owner of Bedworth Colliery before deciding to adopt the innovation (1776) visited both Bloomfield Colliery and Willey Forge, Broseley,[1] and as part of the decision making process, Edmund Shaw of Salford '. . . particularly examined into the merits of the other kinds of Engines used about Manchester and is fully persuaded of the superiority of yours . . .'[2]

The effects of seeing the innovation are expressed in the following letter:

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[1] W. H. B. Court, "A Warwickshire Colliery in the Eighteenth Century," Economic History Review, VII (1936-7), p. 221.

[2] Letter, P. Ewart to J. Watt, May 18, 1791.

> I had not the pleasure of seeing any of your Engines till a few Days ago when I was very agreeable surprised to see The Power of Execution of Messrs Goodwyn & Co . . .'[1]

Seeing Goodwyn's engine also stimulated Mr. Whitbread, another brewer to adopt.[2]

Of course, in the early stages of the diffusion when the number of engines erected was few, then, it might be difficult to see one and this would tend to constrain the spread, however, engines at Soho could be examined if the person was willing to travel.[3] Also, the firm in reply to enquiries might list those engines erected or refer the enquirer to a local person who had seen one.[4]

During the decision making process, it is evident that counter information flows developed. They are, in essence, an attempt to resist the innovation by certain parties -- often those with a vested interest in prior ways of doing

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[1]Letter, D. Liptrap to Boulton and Watt, November 23, 1785.

[2]Letter, J. Yallowley to Boulton and Watt, August 26, 1784.

[3]For example, H. Goodwyn, the London brewer, had visited Soho in 1784, before deciding to adopt see, Letter, H. Goodwyn to Boulton and Watt, April 17, 1784.

[4]Letter, Boulton and Watt to W. Chapman, February 22, 1777.

things or from those who perceive the innovation as hazardous. An example of this is the resistance and pressure brought to bear on Peter Drinkwater who erected the first 'Boulton and Watt' in Manchester.

> I should have wrote to you on this subject much sooner had I not been incommoded on all sides by threats of a prosecution for erecting a nuisance - & indeed the prejudice is not yet much - if at all abated - the fact is we have already a great Number of the common old smoaking Engine in & about the town which I confess are far from being agreeable - & the public yet are not all inclined to believe otherwise than that a steam engine of any sort must be highly offensive.[1]

Similar resistance was experienced by George Walker of Chester where 'an envious spirit too much prevails' and 'our Opponant has much influence, and is also stimulated by self interest against our undertaking . . .'[2] In this case, the local resistance was so great that by the mid-1790's the firm was complaining that the old miller and all the bankers in Chester were against them and there was a lack of business.[3]

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[1]Letter, P. Drinkwater to Boulton and Watt, April 3, 1789.

[2]Letter, G. Walker to J. Watt, July 19, 1785.

[3]Letter, G. Walker to Boulton and Watt, November 4, 1796.

Similar resistance is in evidence for other places, for instance, initially from the Cornish Engineers whose livelihood was based on erecting and maintaining the old type of engines, and from the Nottingham area. This shows a concern for the environment and is interesting since this type of concern is probably a consistent factor in technological change. Such resistance as that based on the smoke problem could be easily overcome by the trial of a Watt engine which was designed to be considerably less of a smoke nuisance than the Newcomen.

Trial/Adoption

For most adopters the question of use on a small scale prior to total adoption did not arise, but for some larger firms, and partnership chains, this may have been the practice. Simpson and Barton, cotton spinners of Manchester, for example, first used steam power on a small scale (6 horse-power initially) and later took two larger engines (40 and 30 horse-power). Similarly, with Taylor and Weston Co. and Peter Drinkwater of Manchester.[1] Where individual firms were linked together, for example, by partnership, into

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[1]Catalogue of Old Engines, Boulton and Watt Collection.

chains, then trial adoption was practical. Satisfaction with the initial engine could lead to its use in the other firms.

Interpersonal Links and Information Flow

The previous section has provided some insight into the adoption-decision process and it is suggested that interpersonal links were particularly important in channeling flows of uncertainty-reducing information in the innovation diffusion process. The purpose of this section is to explore in a more systematic way the evidence for the existence of a system consequent upon the flows alluded to previously. First, some of the kinds of links are identified and second, the spatial aspects of these are discussed.

Networks

Chapter one has conceptualized communication between individuals (nodes) in terms of the biases which affect the probability of interaction. In examining the diffusion of the improved steam engine, it is evident that there existed a network, or infrastructure, of interpersonal linkages between many individuals (adopters and others) and that this network was important in channeling the flows of information which influenced persons to adopt the innovations. This network can best be viewed, at least in its more static elements, as a structural part of the environment. The fact that it changes over time, however, means that the dynamic (processal) aspects of the net, as a timespatial event, must be recognized.

<u>Biases or Relationships Between Nodes</u>

In this context it is useful to talk briefly about groups. These can be defined as sets of individuals time-spatially united by some form of regular interaction.[1] Merritt has provided a set of criteria for the identification of groups which are based on their perceptual-behavioural patterns. They are as follows:

(1) External Recognition: outsiders recognize the group.

(2) Internal Recognition: insiders recognize the group.

(3) Shared interest and attention patterns.

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[1]This discussion of the concept of group is based largely on R. L. Merritt, <u>Symbols of American Community, 1735-1775</u> (New Haven: Yale University Press, 1966), pp. 15-17). This concept of 'group' is apparently the same as that of 'community' discussed by M. M. Webber, "The Urban Place and the Nonplace Urban Realm," in <u>Explorations into Urban Structure</u>, ed. M. M. Webber (Philadelphia: University of Pennsylvania Press, 1967), pp. 108-110, and p. 141.

(4) Awareness that events, etc., have a collective importance.

(5) Coordination to promote common interests.

(6) The existence of structures/processes functioning in the interest of the group.

Groups defined in terms of the above criteria may of course also be characterized by spatial proximity, but the essence of the 'group' is that nearness is defined in terms of likelihood of interaction. This question will, however, be alluded to later in this chapter.

It is suggested that many of the relationships between the individuals (nodes) in the network are of a group (formally or informally constituted) nature, as defined above, and based on particular biases affecting interaction. This is particularly true because of an individual's total set of acquaintances sub-sets of these tend to be 'role specific', that is, related to the particular role, or function, the individual is fulfilling.[1] The sub-sets are, however, not mutually exclusive.

Three categories of contacts, or types of relationships, can be identified as important in defining the acquaintance network of adopters of the innovations examined in this

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[1]M. M. Webber, Ibid., p. 114.

study. These are, 1) kinship, 2) business, and 3) social linkages. The latter of these includes religious, friendship, and society membership relations. A brief discussion of the nature and importance of these links will be followed by an examination of some of their timespatial aspects.

Kinship Connections

Many individual adopters of the innovations were introduced to them through a satisfied relative. For example, the Green family of Nottingham in addition to using rotary steam power in their local cotton and brewing concerns also introduced it in the Rotherham brewery run by one of the sons.[1] Similarly, the Stein brothers in Scotland adopted rotary engines for use in their distilleries at Edinburgh and Kennet Pans.[2]

Kinship relations with non-adopting 'influentials' were also important. The early use (1785) of Watt rotary steam power in the iron rolling mills of Mr. Dobbs of Kingsnorton, Nr. Birmingham, was almost certainly due to his being

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[1]Letter, H. Green to Boulton and Watt, October 29, 1792; H. Green to Boulton and Watt, August 25, 1793; A. Green and Co. to Boulton and Watt, September 26, 1793.

[2]Letter, J. Stein to Boulton and Watt, October 7, 1786.

the brother-in-law of Thomas Southern, an important Soho employee.[1] A final example of such contacts is worth quoting in some detail, incidentally, it provides another instance of the significance of implementation decisions in diffusion.

> I feel myself strongly recommended to yr kind services - in being the son in law of your late friend Mr. Smeaton. Being in the oil crushing business & having found a connection at Hull, it is my design to erect a steam engine there . . .[2]

Business Contacts

These were an important element in the acquaintance network through which information could pass. A number of entrepreneurs linked by business ties of various kinds, for example, partnerships, financial agreements, producer-user relationships, etc., can be considered as a group in many respects. An example of the way in which certain industrial figures acted as a group to protect mutual interests is the organization of the 'United Chamber of Manufacturers of Great Britain' in 1785. Formed for protectionist purposes, its members included such persons as Boulton, Watt, Reynolds

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[1]Letter, J. Atkinson to T. Southern, May 11, 1794.

[2]Letter, J. Brooke to Boulton and Watt, July 6, 1795.

and Wedgewood.[1]

That this type of link was important in the diffusion of the innovations, can be demonstrated by reference to some examples. John Wilkinson was a powerful ironmaster with extensive interests in England and Wales.[2] From an early period he had been linked with Boulton and he became their principal manufacturer of engine parts, especially cylinders, in the period to 1795.[3] Wilkinson was one of the first customers for the reciprocating engine and by 1777 he had taken four of them. Similarly, he was an early and extensive user of the rotary engine. Other enterprises with which he had associations also became users of the engines. The Stockdale Cotton firm of Cark-in-Cartmell, Lancashire, which was closely linked with Wilkinson, and also with Watt since at least 1768, was the first cotton mill to use a Watt

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[1]A. Raistrick, Dynasty of Ironfounders (London: Longmans Green Co., 1953), p. 98.

[2]A. H. Dodd, The Industrial Revolution in North Wales (Cardiff: University of Wales Press, 1951), pp. 132-143.

[3]E. Roll, An Early Experiment in Industrial Organization (London: Longmans Green Co., 1935), p. 25.

reciprocating engine (ordered 1786).[1] Both Stockdale and Wilkinson were connected with lead mines in North Wales which also used the engines and with the Paris Waterworks, which provides an early example of the use of the engines in France.[2] Wilkinson's business interests extended to the Welsh copper industry and he was a partner in the enterprise of Thomas Williams in Anglesea, where Watt's rotary engine was also used.[3]

Boulton and Watt and Wilkinson had strong business connections with the Darby's and Reynold's complex of iron founding industries at Coalbrookdale, Shropshire which also used Watt engines extensively from an early date.[4] Other business complexes (many firms linked by partnership or other close ties) existed in this period. A particularly notable

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[1]W. H. Chaloner, "The Stockdale Family, the Wilkinson Brothers and the Cotton Mills at Cark-in-Cartmell, C. 1782-1800," Transactions of the Cumberland and Westmorland Antiquarian and Archaeological Society, LXIV, n.s. (1964), pp. 356-372.

[2]For details of J. C. Perrier and the Paris Waterworks see, E. Roll, op. cit., pp. 48-55.

[3]J. R. Harris, The Copper King (Toronto: University of Toronto Press, 1964), pp. 61-62.

[4]A. Raistrick, op. cit., Cpt. 9.

one being that focused on the Walkers iron and steel concerns near Rotherham, Yorkshire.[1]

Social Contacts

Although social contacts can be made through kinship, business and other links, two types of contacts were especially important in late eighteenth century industrial society. The first of these was the system of religious connections which existed especially among Nonconformist religious groups, such as Quakers and Unitarians.[2] Persons of similar religious persuasion are more likely to communicate with each other and evidence suggests that such groups as those mentioned above had well-established networks of social contacts strengthened by kinship and business ties which were used for disseminating information on various topics of mutual interest. The establishment of these especially strong links can be partly explained by the fact

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[1]E. H. John, ed., The Walker Family: Iron Founders and Lead Manufacturers, 1741-1893 (London: Council for the Preservation of Business Archives, 1951), pp. i-vii.

[2]For an excellent brief review of some of the main features of Dissent in Britain see, N. J. Smelser, Social Change in the Industrial Revolution (Chicago: University of Chicago Press, 1959), pp. 66-77.

that dissenters had established and attended their own schools and academies as substitutes for the traditional universities from which, by law, they were excluded.[1] These Quaker schools and dissenting academies not only provided a more liberal and scientifically and commercially biased education than was generally available, but also brought into contact many potential scientists, industrialists, and business persons.[2] The very nature of the dissenting churches, which emphasized the virtues of thrift and hard work as well as the attitudes to child-rearing mentioned earlier, meant that a disproportionately large number of business persons came from such origins (including Quakers). These persons, with their interest in science and technology resulting from their more liberal education, would undoubtedly have been more open to accepting innovations than other persons.[3]

The importance of Nonconformist connections with regard

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[1]R. E. Schofield, The Lunar Society of Birmingham (Oxford: Clarendon Press, 1963), pp. 10-11.

[2]For details of Quaker Schools and Meetings see: A. Raistrick, Quakers in Science and Industry (Newton Abbot: David and Charles, 1968), pp. 32-34.

[3]See previous statements on this in chapter one.

to the pioneers of worsted spinning by power (some of whom adopted Watt engines) has previously been noted by Chapman who states:

> The Presbyterian-Unitarian group - which found its ultimate focus in Dr. Priestley at Birmingham - was celebrated not only for its democratic political and humanitarian social views, but also for its intellectual leadership in 'natural philosophy'.[1]

The links of the above group with Priestley are particularly important since he was very closely connected with Boulton and Watt. Evidence that other adopters of Watt engines had similar religious affiliations and connections with Dr. Priestley is available for the Leeds area. Both Thomas Fenton and John Marshall, early users of reciprocating and rotary engines, were Unitarians, the focus of this group being Mill Hill Chapel where Dr. Priestley had resided before his move to Birmingham.[2] A similar group of Nonconformist adopters of the innovation also existed at Manchester.

The social and business network of the Quakers was particularly impressive, especially in the iron industry.

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[1]S. D. Chapman, "The Pioneers of Worsted Spinning by Power," Business History, VII (1965), p. 115.

[2]W. G. Rimmer, Marshalls of Leeds: Flax Spinners, 1788-1886 (Cambridge: University Press, 1960), p. 11; 26.

Raistrick states that:

> . . . the linkage in the case of the iron works is so close that at first sight it would appear as though it were the normal policy to marry daughters to eligible small ironworks . . .[1]

The Darby's, Reynolds' and Dearman were all Quakers with extensive connections as far afield as the quaker Fox family in Falmouth.[2] The complex of connections also extended to other industries, especially the London-based brewing trade. For example, news of the rotative steam engine was passed to Robert Barclay by his Quaker cousins in Birmingham who were also influential in getting him to adopt the innovation.[3] It is highly probable that Quaker connections were responsible for the adoption of Watt rotary power in the oil mill of J. Peckover at Wisbeth. He was in partnership with B. Gurney who was linked by marriage to the Barclay and Perkins families.[4]

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[1]A. Raistrick, Dynasty, p. 45.

[2]The Fox family were bankers and adventurers in Cornish mines, including North Downes. They were related to the Barclay's in London and the Lloyds see, A. Raistrick, Quakers, pp. 330-331.

[3]P. Mathias, The Brewing Industry in England, 1700-1830 (Cambridge: Cambridge University Press, 1959), p. 83.

[4]Letter, J. Peckover to Boulton and Watt, December 29, 1791; A. Raistrick, Quakers, p. 329.

The second type of social connection that was of importance is that related to membership of a literary and philosophical society. These societies were formed in many of the larger towns in Great Britain in the latter part of the eighteenth century and consisted of groups of local industrialists, scientists and others who met to discuss matters of mutual interest.[1] The meetings provided forums for exchange of information, and discussion of new scientific and technological developments. In addition the members undertook their own research and were no doubt stimulated in this respect by the many travelling lecturers who demonstrated current trends in science and technology, including Watt's patent steam engine. These groups, which often had connections with each other by means of corresponding members, can be characterized as being actively engaged in a search for new ideas and discoveries. They also provided an "information field" which was favourable to the discussion of technological and other innovations. Many influential industrialists and scientists were members of these local societies, and often honorary members of others. Persons like Boulton, Watt,

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[1]For details see, A. E. Musson and E. Robinson, Science and Technology in the Industrial Revolution (Toronto: University of Toronto Press, 1969), pp. 87-199; Schofield, The Lunar Society.

Priestley and Samual Galton were members of the Birmingham based Lunar Society, the latter person being a business associate of Matthew Boulton and one of the proprietors of the Birmingham Canal Navigation Co., which used Watt's engine to raise water.[1] Others, like Wedgewood and Roebuck whilst not actual members of the society were closely associated with it.

Leeds also provides evidence of the importance of the local society in diffusing scientific and technological information. Some of the local members were early apprecia-tors of the possibilities of the use of Watt steam power. For example, John Smeaton, the respected and influential engineer, was a member.

In Manchester a formally organized society was started in 1781,[2] again this was heavily impregnated with religious dissenters. Although the society had a mixed membership in terms of occupations, there appear to have been several tradesmen and manufacturers including some who were early to

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[1] B. M. D. Smith, "The Galtons of Birmingham: Quaker Gun Merchants and Bankers, 1702-1831," Business History, IX (1967), pp. 132-150.

[2] For details of this society see, Musson & Robinson, op. cit., pp. 153-159.

recognize the potential of rotary motion for use in cotton spinning mills. The latter of these included the Drinkwater brothers, the Philips, George Lee, Robert Owen, Thomas Yates, etc. It is probable that the use of Watt steam power by many of the literary and philosophical circle was stimulated by the fact that in 1788 James Watt Jr., first attended meetings and by the following year he had become Joint Secretary. He was in close association with other members especially T. Maxwell and Charles Taylor, to whom he was apprenticed and Thomas Henry, the chemist who was a friend of James Watt Sr. These persons formed a clique interested in chemistry and as a group they were influential in the introduction of chlorine bleaching to Lancashire. It was certainly the close connection of, 1) Thomas Ridgeway of Wallsuches, Horwich, and 2) the firm of Joseph Baker & Co. with Thomas Henry, and the Watts which led to those two enterprises being the pioneers of the use of rotary steam power in bleachworks, both in the Bolton area.[1]

To sum this up it can be said that there developed in the latter part of the eighteenth century local and regional

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[1]For details of connections see, Musson and Robinson, op. cit., pp. 251-337 especially pages 285-291, 303-305, 315. J. Taylor, Watt Jrs., employer was involved in the Baker concern.

focii for the rapidly increasing number of persons interested in science and its applications. Most of the important industrialists and scientists of the period belonged to such societies. In addition these 'interest groups' were integrated at a national level by the strong connections between them and with the Royal Society in London.[1] These groups of 'innovators' appear to have been a significant factor in diffusing information on science and technology generally and on the improved steam engine in particular. This finding would appear to fit with the notion that there are hierarchies of contacts which operate at different scales. Information might be gained by means of national or inter-regional contacts then spread intra-regionally or locally.[2]

In concluding this section it should be emphasized that variously defined groups can be identified which were highly

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[1]W. H. G. Armytage, "Education and Innovative Ferment in England, 1588-1805," in _Education and Economic Development_, ed. C. A. Anderson and M. J. Bowman (Chicago: Aldine, 1965), p. 386.

[2]An example of this is Josiah Wedgewood whose national and regional contacts probably led to his early adoption of steam power. He then used his influence locally, see, J. Thomas, "Josiah Wedgewood as a Pioneer of Steam Power in the Pottery Industry," _Transactions of the Newcomen Society_, XVIII (1936-7), p. 19.

inter-connected in terms of a network. The main biases which affected the likelihood of a relationship existing between individuals have been identified. These biases, for example religion, tended to be reinforced by others such as kinship and business ties, and as a result a well defined network of associations between various adopters of the innovations existed. Such a network is, however, difficult to map in terms of the actual flows of information in the adoption process. A surrogate for these flows is provided by the infrastructure of industrial contacts in late eighteenth century Britain; a phenomena which is itself difficult to reconstruct in detail. Nevertheless, certain aspects of this infrasturcture can be identified and mapped.

Describing the Network

The following section constitutes an attempt to establish and map some of the links, in the network which has been postulated to exist, between adopters and others in the diffusion of the innovations. It is probably true to say that all individuals in society can be linked together by means of indirect connections, however, the stronger, or more direct, a relationship then the greater its significance for passing information and for mutual influence between the nodes.

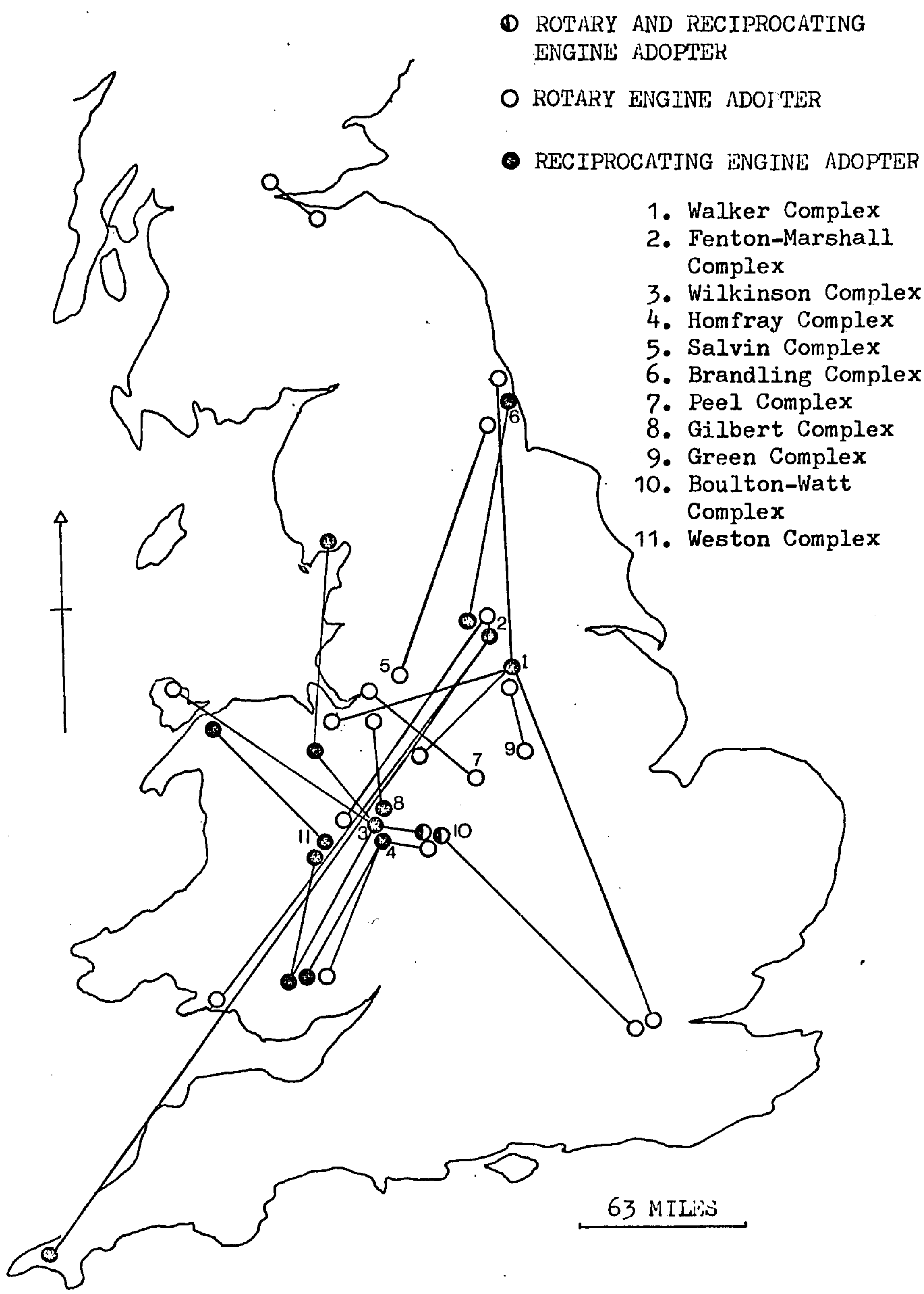
There will, therefore, be a concentration here on what are considered to be 'important' connections. It should be noted also that those links established represent an unknown proportion of the actual ties which existed.

Business Partnership Links

The timespatial locations of engine adoptions by units (firms) cannot in all cases be viewed as relatively independent decision making units. In many cases relationships between them existed by means of partnerships or other strong business ties, for example father and son. In such cases nodes (firms) which are widely separated, geographically, are, when distance is measured in terms of the likelihood of interaction between them, for all intents and purposes the same place. Geographically separate entities which were linked to other units in the ways described above are shown on the map in figure 24. In general, connections over short distances, for example, within towns, have been excluded from the map as the main intent is to show the inter-regional linkages which existed in the study period (1775-1800). It is evident, from the map, that the following conclusions are justified:

(1) Linkages extended, in many cases, over considerable geographical distances.

FIGURE 24. BUSINESS PARTNERSHIP LINKS BETWEEN ENGINE ADOPTERS.



Source: Bibliography and Boulton and Watt Papers of steam for many industrial uses. To emphasize the point once again, such a network would indicate groups of individuals linked over considerable distances and this would to some extent limit the development of a strong neighbourhood effect.

These links only represent what can be called 'first order' business ties. Other connections existed, some more important than others. An example of a 'weaker' link not incorporated in the previous discussion is the business relationship between Josiah Wedgewood and the firm of Boulton and Watt, which was in part based on a financial loan.[1] Another type of still weaker connection is exemplified by the contact between James Spedding of Whitehaven and Boulton and Watt. He supplied engine parts to the Soho firm and adopted their reciprocating engine for use in his iron mine.[2] It can be seen from this that business partnerships and other connections provide a complex structuring of timespace and that it is this type of structure that the diffusion of the innovation is related to.

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[1]J. Thomas, "The Pottery Industry and the Industrial Revolution," Economic History, III (1934-37), p. 407.

[2]E. Roll, op. cit., p. 56.

(2) Many entities were linked together in some business complexes.

(3) Adoptions of both innovations (types of engines) occurred in some complexes.

Although not shown it is also clear that such business connections provided links between different types of industry. For example, the Walker complex was involved in iron and steel as well as the lead industries, and Thomas Fenton of Leeds had links with coal mining, copper mining and smelting, and flax spinning.

What is the significance of such a network in terms of the timespatial pattern of diffusion of the innovations? First, it provides evidence of the existence of a national scale network of inter-regional business links. Such a network would undoubtedly facilitate the rapid spread of the innovations from the point of initiation. This can be illustrated by the fact that if the appearance of the innovation at region z is dependent on a chance contact with a region x or y where the innovation is already then the spread would be expected to be slow, however, such channels as those above would mean that if the innovation is adopted at one unit in a business complex then adoption at other units is likely to follow rapidly. The contacts between different types of industry would also aid the rapid adoption

Influentials

Certain individuals in a network of social contacts can be termed influentials.[1] These persons, for a variety of reasons, use their influence to persuade other individuals to adopt an innovation, or to pass on information. The evidence suggests that in the diffusion of the innovations studied here the role of such persons was especially significant. This section will identify some of these persons and the role played by them. 'Influentials' can vary in importance from those who are instrumental in getting a single person to adopt to those who persuade a great many. This importance will largely depend on three factors, 1) how active, or well motivated they are, 2) their range of contacts and how well respected their opinion is among those contacts, and 3) their period of activity. By the latter is meant the date at which they start influencing others to adopt a specific innovation. This date may correspond with when they themselves become adopters or, due to the fact that influentials do not have to be actual adopters of innovations, it may be determined by some other event.

A good place to start in the study of influentials in

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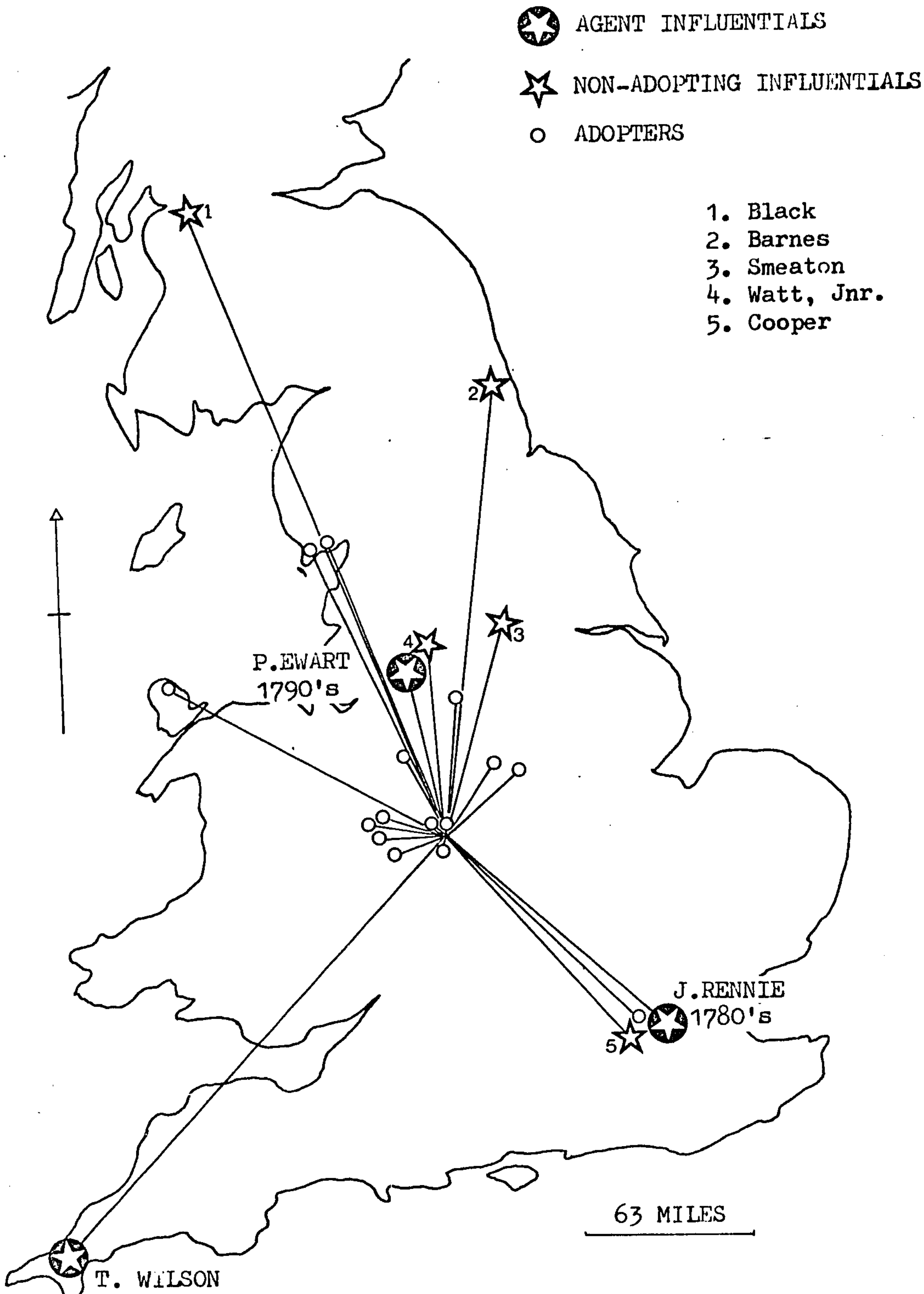
[1]See chapter one for a discussion of these individuals.

the spread of Watt's reciprocating and rotary engines is with Matthew Boulton and James Watt. As self interested propagators of the innovations they obviously would be influential amongst their own acquaintance circles. Some of the adopters of the innovations who had acquaintance links with the partners have been traced and these are mapped in figure 25. Links have only been included which are positively known to pre-date adoption. This map shows that, although some of the links of the firm with adopters were over considerable distances, the majority were concentrated in the Midlands area. The preponderance of 'local' links indicates that the firm had a degree of influence in the Midlands, which was, no doubt, responsible for the extensive early use of the innovations in that area. In particular, this would help to account for the use of reciprocating engines in an area where the advantage to be gained, in terms of saving coal, was not very great (see below chapter 6). The map in figure 25 also shows the links of the firm with influentials who were not adopters -- of course the adopters identified on the map could also be influential. As expected the locations and the dates at which these persons became active in a locality correlates well with the emergence of the major regional focii identified in chapter three. It is not

FIGURE 25. BOULTON AND WATT'S FIELD OF INFLUENCE.



Source: Bibliography and Boulton and Watt Papers possible to say, however, that the focii emerge because of the influentials or on the other hand that the influentials emerge because of the local 'demand'. This will, however, be discussed in a little more detail below.

Who were these influentials and what role did they play in the diffusion of the innovations? Individuals used their influence to promote the sale of engines for a number of reasons. It might be that they recognized the merits of the innovation and this reason combined with either friendship for Boulton and Watt or the fact that they were employed or otherwise connected in business to the firm led them to actively promote the improved steam engine. In the first category fall such individuals as John Smeaton, the engineer. Although he made his living, in part, from erecting engines of his own design he recognized that in certain circumstances Boulton and Watt's engines were better. He became convinced of the value of the engine after its early trial against one of his on the Birmingham Canal.[1] In the period following he was responsible for several adoptions in the Yorkshire area,

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[1]This was the trial at Smethwick Locks in 1778.

including the Hull Waterworks.[1] James Watt wrote of this man:

> Mr Smeaton has behaved with the utmost candour and friendship and has even recommended a customer to us more than once.[2]

John Rennie and Peter Ewart, like Smeaton were engineers. Both of them came from the same part of Scotland, Ewart being originally Rennie's assistant. John Rennie was a mill wright, however, he had attended university and was acquainted with Drs. Black and Robinson.[3] It was through the latter that he was introduced to Boulton and Watt with whom he was offered a job in 1784, working on the Albion Mill project.[4] This was the start of a mutual agreement between Rennie and the firm in which he introduced many orders to them, and they in turn

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[1]In 1784, Smeaton visited the Craven Cross Lead Mine, in Yorkshire, and recommended a Watt engine be erected. See, Letter, J. Smeaton to J. Watt, October 5, 1784. He was probably influential in getting Thomas Fenton, of Leeds to use the reciprocating engine in his coal mine. He was also responsible for the early use of a rotary engine in the oil-cake mill of Coates and Jarratt of Hull. This was used to replace a Smeaton waterwheel see, L. T. C. Rolt, Thomas Newcomen: The Prehistory of the Steam Engine (London: Macdonald, 1963), pp. 134-135

[2]Letter, J. Watt, to J. Black, December 12, 1778 in Robinson and McKie, op. cit., p. 41.

[3]C. T. G. Boucher, John Rennie, 1761-1821 (Manchester: Manchester University Press, 1963), pp. 1-9.

[4]For details of this, see below chapter six.

recommended him as millwright.[1] He already had a wide range of contacts in his professional capacity and, after the Albion Mill established his reputation, he became a very influential 'consulting engineer' both in Britain and on the Continent being 'firmly established as the leading engineer of his day'. In this role he could recommend the use of Watt steam power where he thought it was needed, and this he did on a number of occasions. The pattern of adoptions in which he was probably influential is shown on the map in figure 26. This shows a concentration in the London area where he lived and was most active.[2] Other contacts are, however, widely scattered, for example, the Crinan and Lancaster Canals.

Although the direct evidence is not strong it was probably Rennie's contacts with the Edinburgh area of Scotland which led to early adoptions of rotary engines in the industries, especially distilling, of the area.[3]

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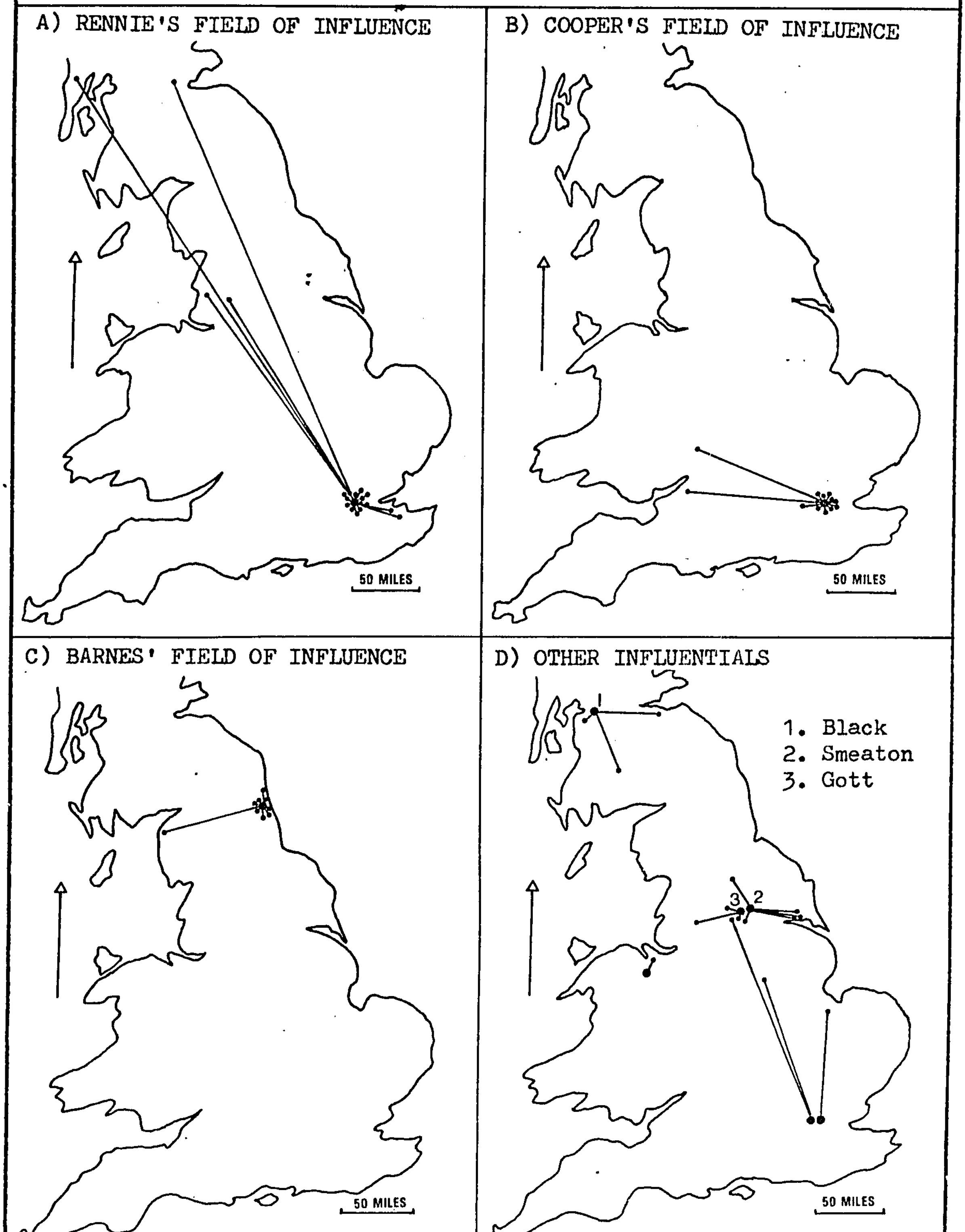
[1] C. T. G. Boucher, op. cit., p. 10.

[2] He was also a member of the London-based Society of Civil Engineers and a founding member of the London Literary and Philosophical Institute.

[3] Letter, J. Rennie to J. Watt, January 11, 1785.

FIGURE 26. FIELDS OF INFLUENCE OF SELECTED INDIVIDUALS.



Source: Boulton and Watt Papers

Ewart, having worked with Rennie in London, became an employee of Watt in 1788 and was sent to erect their engines in Manchester in the early 1790's.[1] In his dual capacity as engineer and employee of Watt he was probably responsible for several adoptions of the rotary engine in mills in the Manchester area, including those of Mr. Douglas, Lawrence and Yates & Co., and Salvin.[2] Another influential employed by the firm was Thomas Wilson who was active in Cornwall (see below chapter 6).

Many persons acted out of both friendship for Watt and a conviction that the innovation was worthwhile. Dr. Black, Watt's old contact, was one such person and he appears to have been influential in several adoptions in Scotland (including Leith Glass Works, Wanlockhead Lead Mine and Quarrelton Coal Mine).

James Watt Junior was in a similar position. He was apprenticed to a Manchester firm in 1788 and rapidly became accepted into local scientific and industrial circles. Watt

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[1]W. C. Henry, "A Biographical Notice of the Late Peter Ewart," Memoirs of the Literary and Philosophical Society of Manchester, VII (1846), 2nd Series, pp. 113-135.

[2]Letter, P. Ewart to T. Southern, January 6, 1792. Letter, P. Ewart to T. Southern, December 7, 1791.

Junior's move to Manchester coincided with the first orders for rotary engines from that area and Peter Drinkwater, one of the early users mentions being a near neighbour of his (a possible source of influence?)[1] That young Watt was actively promoting the innovation in the area is evident from his correspondence.[2] He was, however, at various times in the 1790's active in Scotland, where he contacted Mr. George Baxter of Dundee and Messrs. Haig and Co., distillers, and in the Newcastle area.[3]

Other influentials were important in other areas. Thomas Barnes was manager of Walker and Benwell collieries in Tyneside and he acted as a consultant for others.[4] He had contacted B & W in 1793 as a result of the 'high reputation your improved steam engine has acquired' and in 1794 he requested permission to visit Cumberland and inspect the Watt

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[1]Letter, P. Drinkwater to Boulton and Watt, April 3, 1789.

[2]See, for example, Letter, J. Watt, Junior, to Mr. Southern, August 17, 1789.

[3]Letter, J. Watt, Junior, to Mr. Lawson, July 26, 1799. Letter, J. Watt, Junior, to M. R. Boulton, February 3, 1796.

[4]H. W. Dickinson and R. Jenkins, James Watt and the Steam Engine (Oxford: Clarendon Press, 1927), p. 253.

rotative engines at work 'drawing coals' there.[1] He soon became convinced on the grounds of theory and experience that Watt's engine was superior.[2] In the years that followed a great many orders for rotative engines to be used in local coal mines, as well as other enterprises came to Boulton and Watt via this man (see, figure 26).

In the Manchester area Benjamin Lees appears to have performed a similar function, although of less importance. He contacted local persons and also took it upon himself to advise the firm:

> I take the liberty of mentioning for your government, whether it would not be proper for you to advertise them rotative engines in the Manchester papers, mentioning some particulars, and if you was to refer the publick to look at that of Mr Drinkwaters (if this would be agreeable to him) it might bring them to be generally used in the Cotton & Woolen branches.[3]

Similarly, in London J. Cooper, millwright was influential:

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[1]Letter, T. Barnes to Boulton and Watt, September 16, 1793. Letter, T. Barnes to Boulton and Watt, April 24, 1794.

[2]Letter, T. Southern to J. Watt, Junior, September 8, 1795 quoted in Dickinson and Jenkins, op. cit., p. 253.

[3]Letter, B. Lees to Boulton and Watt, January 17, 1791.

> Some time ago, I recommended Messrs Pryor & Co of Limehouse, Colour Manufacturers, to apply your Fire Engine to their works, there, I now find they have come to a determination of doing it . . .[1]

> I have at last persuaded Messrs Clowes & Co to adopt your Engine . . .[2]

In the period from 1789 he was probably instrumental in getting about a dozen persons to adopt the rotative engine, as can be seen in figure 26 and this figure only includes those for which a record exists.

Many other persons were influential to a greater or lesser degree. Wilkinson, Darby and Reynolds, Wedgewood, and many others, having themselves had early and favourable experience with Watt steam power and being closely associated with the partners were without doubt influential in getting others to adopt.

It is interesting to note that different influentials operated at different scales, both spatially and numerically. Although, there is probably a scale-continuum from Local to Inter-national, for purposes of clarity if three such scales can be identified; local, regional, and national/international.

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[1]Letter, J. Cooper to Boulton and Watt, November 8, 1798.

[2]Letter, J. Cooper to Boulton and Watt, March 28, 1796.

Some influentials were active, according to the evidence, at a local scale only, others at all three scales.[1]

It is difficult to evaluate the precise effect of influentials on the pattern of diffusion of the innovations. Their activities were, for the most part centered on the major areas of adoption, such as Cornwall, London, Manchester, and the North-East. As noted earlier, however, it is not possible to state that these were areas of extensive adoption due to their effect. It is probably more realistic to state that there is a complex circular relationship between the 'demand' for the innovation in an area, the emergence of local influentials in that area, and the rapid spread of the innovation in that locality. Since the patterns of contacts, or fields of influence of most of these persons were highly focal in nature this would tend to reinforce any neighbourhood effect. The wide range (spatially) of some contacts would also aid the spread of the innovation to other areas and cause what has been termed a 'short-circuit' effect.

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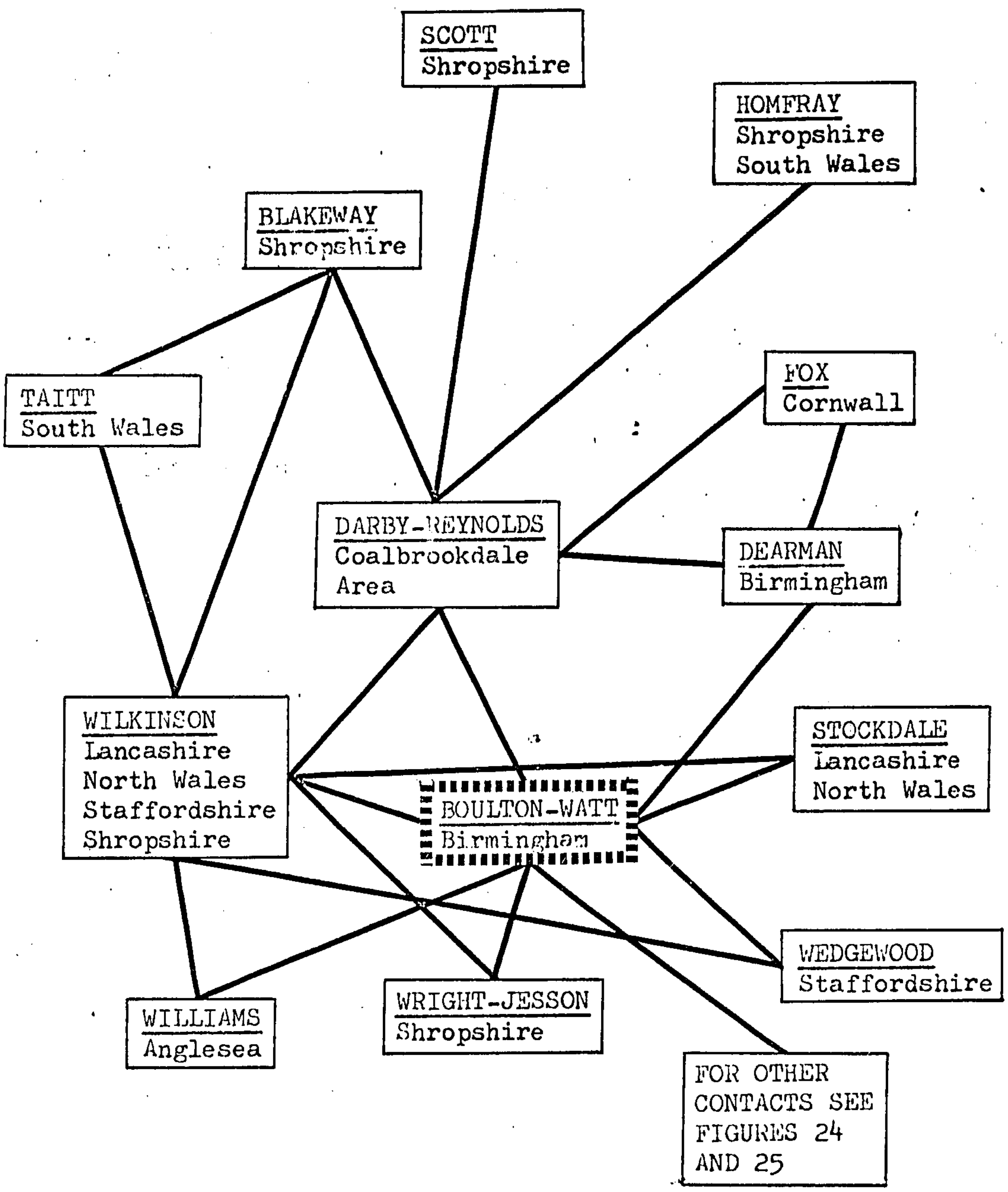
[1]For similar comments see, T. Hägerstrand, "On the Monte Carlo Simulation of Diffusion," in Quantitative Geography, Part 1: Economic and Cultural Topics, ed. by W. L. Garrison and D. F. Marble, Northwestern University, Department of Geography, Studies in Geography No. 13 (1967), p. 8.

Complex Connections

Thus far two fairly simple aspects of the acquaintance infrastructure or network which was important in the diffusion of the steam engine have been discussed, business partnerships and influentials. In the latter case the situation is basically one where person A passes on information (influences) persons B_1, B_2, B_3 . . . B_n. However, in some instances the information is not available to establish this kind or relationship and also influence may come from many directions (persons) at once. This is particularly true when a group of adopters are complexly interconnected. In such a case the 'system' or group may be defined in terms of its highly connected core, and the boundary occurs where connections become weak or non-existant. In such a system the individuals are by no means independent but behave as a group (see previous discussion), and adoption of an innovation is in many ways as much a group decision as an individual one.

Two examples will serve to show the importance of this type of linkage. One complex system of interconnections existed between many of the Midlands industrialists who were early adopters of both the reciprocating and rotary engines. This pattern of connections is shown diagramatically in figure 27. The nature of the relationships between many of

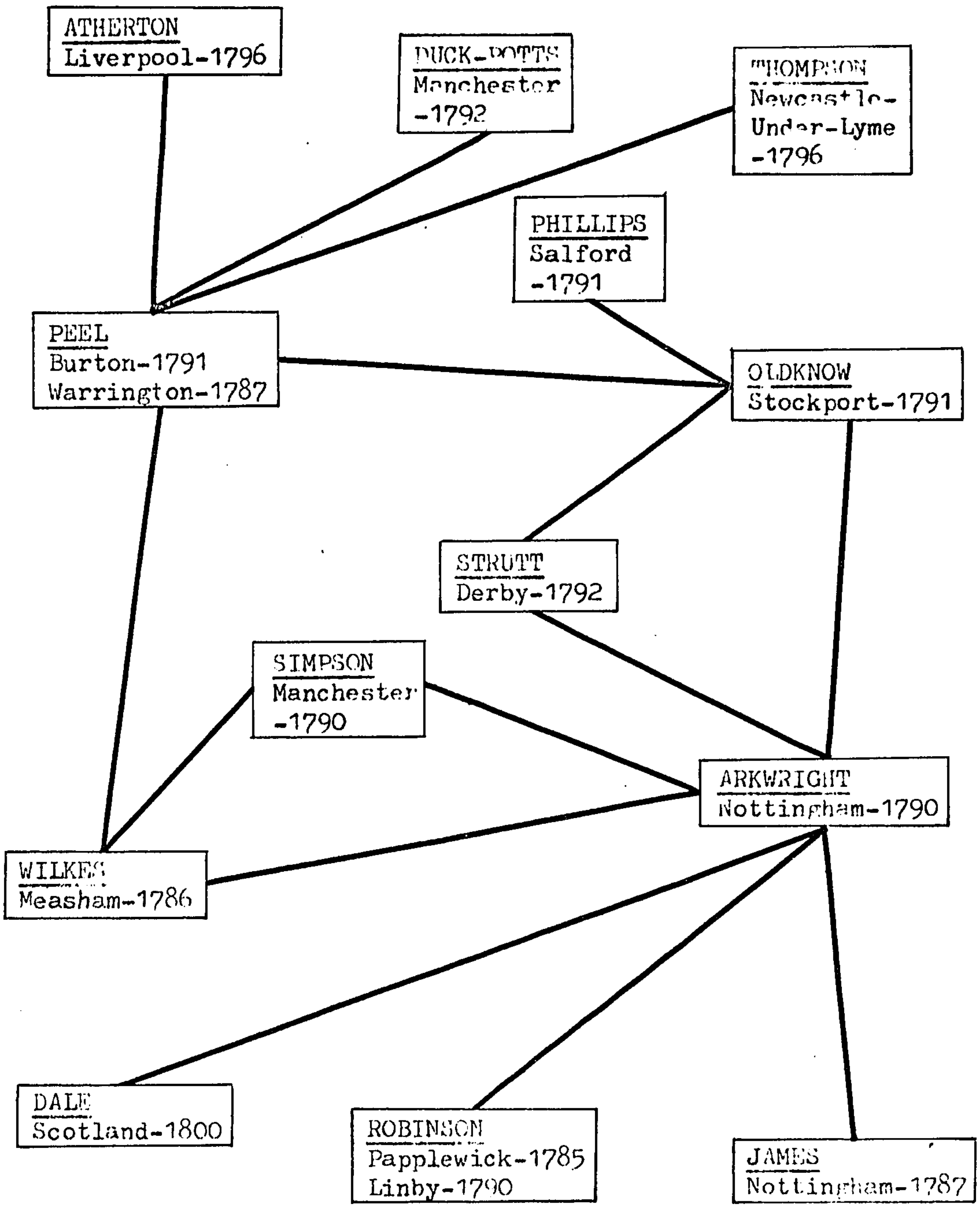
FIGURE 27. LINKS BETWEEN MIDLANDS' ENGINE ADOPTERS.



Source: data collected by author (bibliography) these persons have already been alluded to. Sufficient to say, therefore, that it was this circle with Boulton and Watt, the Darby's and Reynolds' of Coalbrookdale, and John Wilkinson with his interests in Staffordshire, Shropshire, and North Wales at its core, that very much influenced the pattern of diffusion, both spatially and by industry, in the Midlands and to a lesser extent in other areas.

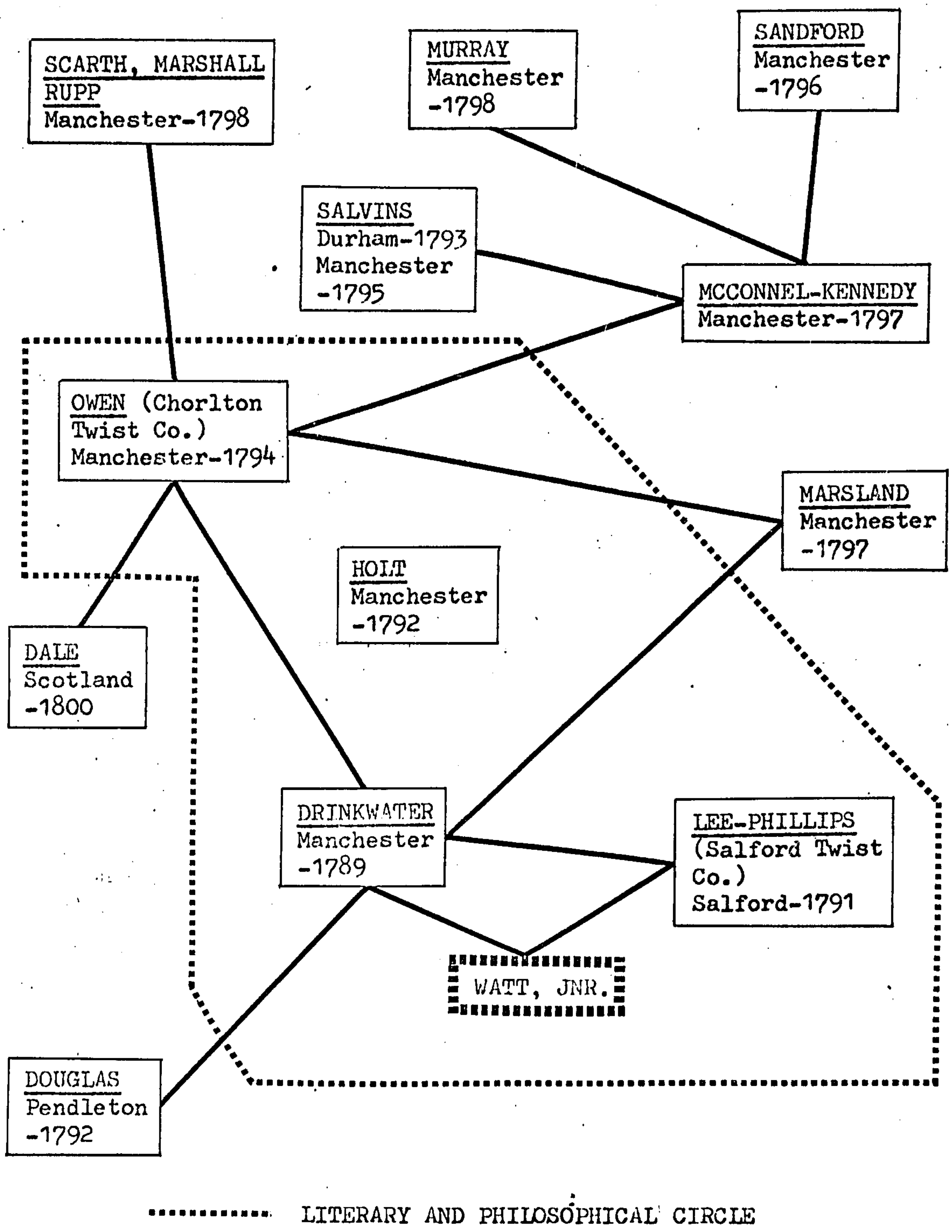
A similar set of complex interrelationships is evident among the adopters of rotary motion in the cotton and worsted industries. In this case the links are based on partnerships, ex-partnerships, financial and other business arrangements. One of the interesting points that can be made about the links in this case is that there appear to be two distinct groups of individuals who are highly connected. These two groups are shown, again diagramatically, in figures 28 and 29. The network shown in the first 'map' is focused on some of the older established pioneers of mechanized cotton and worsted spinning. Many of these persons were active in the Midlands, although they also had connections in Lancashire and as far afield as Scotland. It is interesting to note, however, that this group is not composed of the earliest users of Boulton and Watt rotary steam power -- few connections have been established for the earliest users in

FIGURE 28. LINKS BETWEEN ENGINE ADOPTERS – ESTABLISHED COTTON AND WORSTED MILLS.



Source: Boulton and Watt Papers and Bibliography

FIGURE 29. LINKS BETWEEN ENGINE ADOPTERS – NEW COTTON AND WORSTED MILLS.



Source: Boulton and Watt Papers and Bibliography the Nottingham area. It was this well defined group, nevertheless, which was probably influential in introducing the rotary engine into Lancashire (Peel and Yates, Warrington). As has already been noted in chapter four, the Midlands spinners basically used rotary steam power to supplement water power, and the really significant development of the use of steam was later in the 1790's in the Manchester area. In this context it is clear that the second complex of individuals, those shown in figure 29, were important. This network, essentially limited to Manchester itself, was in part focused on the Literary and Philosophical Society and had an important contact in James Watt Junior. It is apparent that many of the persons in this circle were not established spinners, but persons with scientific and entrepreneurial interests, for example machine makers, who were 'drawn' to steam-powered spinning in the 1790's. Often ex-employees of persons engaged in steam-powered spinning, these individuals would start out on their own, and they were responsible for early large-scale use of the innovation. For example, the Chorlton Twist Company, which included Robert Owen as a partner, ordered a thirty horse-power engine in 1794. Similarly, the Salford Twist Company run by George Lee, Peter Drinkwater's ex-employee, took a thirty horse-power engine in 1791 and another in 1799. This group in Manchester was, therefore, focused on a newly emerging body of entrepreneurs who were abreast of the scientific and technological developments of the time.

Conclusion

This chapter has dealt with three aspects of the information flow process associated with the diffusion of the Boulton and Watt reciprocating and rotary motion engines. First, the adoption-decision process is examined and the role of information, from a variety of sources, in this process is discussed. Interpersonal contacts are identified as being especially important sources of information and influence in this context. Second, some of the major biases affecting the likelihood of interaction between adopters of the innovations are investigated. It is suggested that the ties between industrialists in the period were based on many interrelated biases such as religion, business contacts, kinship, and membership of a scientific 'interest group'. These two sections are preliminary to the third which examines some timespatial aspects of the network of contacts which was important in spreading information concerning the innovation. This shows that national level inter-regional partnership ties existed between many adopters of the innovations and suggests that this network could channel the spread of the innovations rapidly to many parts of the country. On the other hand, with some exceptions, the pattern of influentials and their contacts tended to be fairly localized. As a consequence this would likely create or reinforce a neighbourhood-type effect. Finally, some insights into the kinds of complex interconnections which existed between groups of adopters in some regions are provided. These type of links would, it is argued, tend to aid rapid spread of an innovation.

The importance of attempting to examine the spatial attributes of information flows, however limited this might be, is that this can be related to the general diffusion patterns dicussed in chapter three, and insight into the reasons for the regularities observed in the patterns are provided.

One particularly important conclusion to be drawn from this chapter is that the flows of information, or patterns of contacts, seem to have been anything but random. In fact, it is clear that many such contacts are in many cases a result of purposive behaviour on the part of the firm of Boulton and Watt. The organization formed extensions of itself by means of 'influentials', and, therefore, widened its range of influence. This was in addition to the influence which it wielded among its own acquaintance circle. This point will, however, be followed up in much greater detail in the next chapter.

CHAPTER 6

THE ORGANIZATION AND THE DIFFUSION

Introduction

Where an organization exists which is concerned with an innovation then part of the role of such a body is actively to try to modify the probabilities of individuals adopting the innovation, either positively or negatively. Depending on the success of its efforts in this and other ways the agency can have a greater or lesser effect on the pattern of spread of the innovation.

Chapter one presents two models which relate to the role of the organization in diffusion of innovations. The first of these, shown in figure 2, shows the relationship between the organization and the sub-processes of innovation diffusion in general terms. The second model (figure 4) conceptualizes the role of the organization as a goal-seeking adoptive unit in more detail. This latter model points out that an agency has both general goals (aspirations) and more specific criteria for evaluating the environmental potentials for the acceptance of the new item. This evaluation is based on information that the organization has, or collects, concerning the environment, and the quality and quantity of this information will affect the accuracy of the 'image'. Action taken by the organization to affect the spread of the innovation is based in part on this image of potentials' risks, etc. The model is dynamic in that the organizational system adapts its behaviour to perceived changes in the external environment.

The purpose of this chapter is to demonstrate the general applicability of the model by examining it in the light of information concerning the role of the firm of Boulton and Watt as an organization in the diffusion of the reciprocating and rotary engines.

General Goals

The general aim of Matthew Boulton in becoming associated with Watt's improved steam engine (the reciprocating engine initially) was that the firm should become engine makers to the whole world.[1] That such broad horizons were

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[1]See chapter two.

set initially is indicated by Boulton's early rejection of Roebuck's offer to let him make engines for the midland counties. For Boulton's plan to come to fruition, however, it was essential that the interests of the firm be protected by a patent and this was the reason for the extension of the original 1769 patent, in 1775, for the period of 25 years. This provided the security within which the firm could be built up, being based initially on the reciprocating and later on the rotary engine as well. It is evident that such plans were in Boulton's mind as early as 1776 for in his correspondence he gives a precise statement of intent, that is, to produce between 12 and 15 reciprocating and 50 rotative engines annually.[1]

What was needed to allow these general aims to be achieved in the long term was an initial market for engines which was both extensive and stable. This would allow them to build up the business on a sound base.[2] Such desires must have provided criteria for evaluation of the environment

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[1]Letter, M. Boulton to J. Watt, February 24, 1776, quoted in H. W. Dickinson, Matthew Boulton (Cambridge: Cambridge University Press, 1937), p. 90. These figures were not achieved.

[2]E. Roll, An Early Experiment in Industrial Organization (London: Frank Cass, 1968), p. 67.

in terms of a search for such a market.

Environmental Evaluation

Even before the firm of Boulton and Watt was formally organized in 1775, the partners must have had potential markets in mind. Effort in developing and perfecting the innovation was not spent without a fair degree of certainty that there would be rewards associated with it. As widely travelled persons with extensive industrial and other contacts the partners must have had access to a good deal of information concerning various areas (both spatial and industrial) where the innovation would be potentially useful. Information, like that passed from Dr. Small to Watt, as early as 1771, must have had a great effect on the firm's perception of potential markets:

> A friend of Boulton and me in Cornwall sent us word four days ago that four or five copper mines are just going to be abandoned, because of the high price of coals, and beg me to apply to them instantly. The York Building Company delay rebuilding their engine, with great inconvenience to themselves, waiting for yours. Yesterday application was made to me, by a mining company in Darbyshire . . . because they must quit their mine if you cannot relieve them.[1]

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[1]Letter, Dr. Small to J. Watt, February 14, 1771, quoted in J. P. Muirhead, The Life of James Watt (London: John Murray, 1859), p. 250.

What is really interesting about this statement is that the reference to Cornwall, according to Rowe, does not give an accurate picture of the situation there at the time it was written. He argues that there was in fact a boom at the time and if any mines were forced to close it was due to rash speculation.[1] This emphasizes the important point that quality and quantity of information is a vital element in the study of organizational behaviour. The actions of the agency will generally be affected by the information available, and this may not always be an accurate or complete picture of the realities of the environment.

It has already been mentioned that the firm was initially interested in an extensive market on which to build up its business. It is evident that this factor was one of the two explicit criteria used by the firm in evaluating market potential. Desire for an extensive market can be interpreted as a need for a relatively large spatial concentration (high density) of potential adopters. The second criterion was based on variations in the pattern of demand (resistance) for the innovation. Since Watt's engine was

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[1]J. Rowe, Cornwall in the Age of the Industrial Revolution (Liverpool: Liverpool University Press, 1953), pp. 75-76.

more efficient, in terms of fuel consumption, than the common ones it was intended to supplant, it was expected that demand for it would be greatest in areas where the price of coal was high. It follows that such areas would be viewed as the most favourable potential market for the innovation, however, the actual criterion used in evaluation was more complex than this. It was decided that the engines would not be sold outright, but that the firm would draw a premium for their use for the period of the patent.[1] Further, the premium would be based on the actual fuel saving capacity of the machine compared with one of the previous types. The actual premium worked out was two-thirds of the saving, and this meant that where the price of coal was high then the firm would make more profit than where it was low. Since, using this method, it was not really worthwhile erecting engines where coal was cheap a minimum limit of five shillings per ton was set for coal used in the engines, and persons willing to pay this could have an engine even if the actual price of coal was below this figure.

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[1]A similar system of renting had been used with Newcomen engines see, E. Roll, _op. cit._, p. 27.

The other criterion, although not stated explicitly was related to certain aspects of the technical superiority of Watt's engine. It has previously been noted that the innovation enabled pumping to be carried on in deeper mines.[1] This meant that demand for the engine was particularly great in areas of deep mining.

The Early Prospective Utility

The discussion of the characteristics of the surface for potential use of the reciprocating engine can be clarified by the use of set theory terminology. Figure 30 shows three overlapping sets. Set A represents those areas of concentrated demand (high density), set B areas with a high price of coal, and set C those with deep mining. The regions defined by these sets can be cumulated as shown by the diagram to give regions with different combinations of the three attributes defined by the sets. It is therefore possible to have a region which represents the coincidence of all three sets and such an area would be a peak of potential according to the criteria chosen. This theoretical situation has its actual counterpart and this is now

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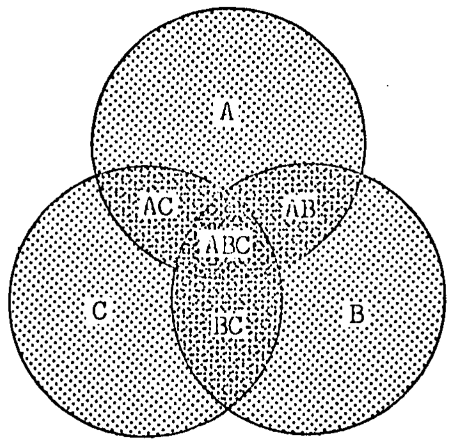
[1]See above chapter 4.

FIGURE 30. SET THEORY INTERPRETATION OF REGIONS OF SALES POTENTIAL FOR RECIPROCATING ENGINES.



A B C	LOW POTENTIAL
AB AC BC	MEDIUM POTENTIAL
ABC	HIGH POTENTIAL

A = AREAS WITH CONCENTRATED DEMAND

B = AREAS WITH HIGH PRICE OF COAL

C = AREAS OF DEEP MINING

Source: author

presented.

Areas of High Density

The most accurate measure available of the total set of potential users for the reciprocating engine is that relating to the use of engines the innovation was intended to supplant (Newcomen). Data on the location of such engines is not complete and probably not very accurate, however, it is sufficiently so for our purposes. The approximate pattern of use of Newcomen Engines in the early 1770's is shown in figure 31A.[1] This shows a discontinuous region of use with especially high concentrations in the north-east coalfield and in the copper and tin mines of Cornwall. Other secondary concentrations are evident in London (waterworks), Derbyshire (lead mines), the Midlands (coal, iron, etc.) and in South

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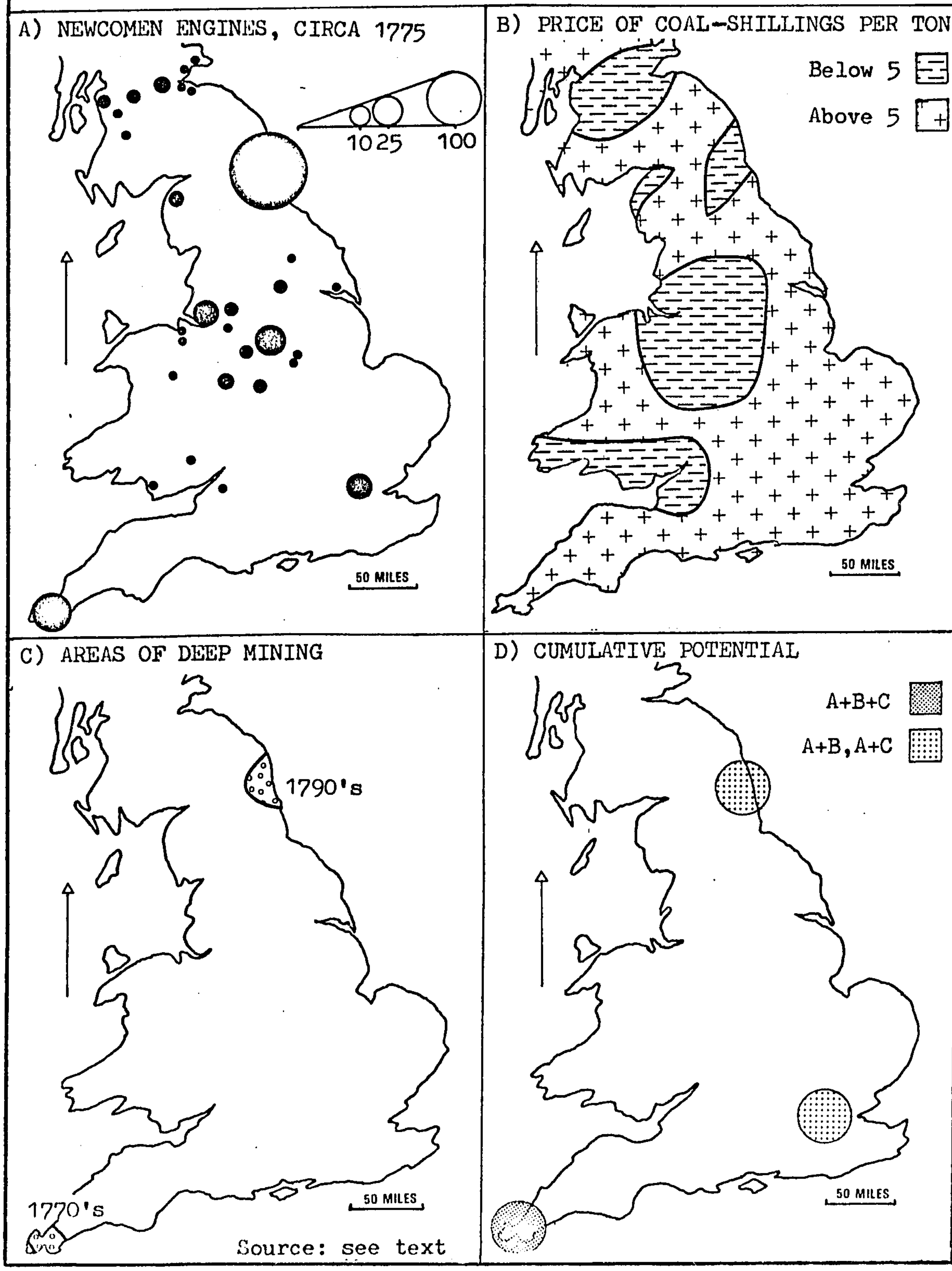
[1]The main sources used in constructing this map were: J. R. Harris, "The Employment of Steam Power in the Eighteenth Century," History, LII (1967), pp. 133-148; R. L. Galloway, Annals of Coal Mining and the Coal Trade (London: The Colliery Guardian, 1898), p. 262; B. F. Duckham, A History of the Scottish Coal Industry. Vol. 1 (Newton Abbot: David and Charles, 1970), p. 84, pp. 363-365; W. Rees, Industry Before the Industrial Revolution, Vol. 1. (Cardiff: University of Wales Press, 1968), p. 348; A. Raistrick, "The Steam Engine on Tyneside, 1715-1778," Transactions of the Newcomen Society, XVII (1936-7), pp. 131-163; F. Nixon, "The Early Steam Engine in Derbyshire," Transactions of the Newcomen Society, XXXI (1957-9), pp. 1-28.

FIGURE 31. SALES POTENTIAL REGIONS FOR THE RECIPROCATING ENGINE.



Lancashire (coal). This pattern represents a surrogate for the overall pattern of demand as it existed, however, new enterprises would be added to this in the study period.

Price of Coal

Data from which an accurate map of the spatial variation (for 1775) in the price of coal can be constructed are not available. In addition such data as are available are difficult to use due to lack of compatibility between both the units of measure used and the quality of different coals. However, such data as are available have been used to construct a highly generalized map of this phenomena as can be seen in figure 31B. It is generally evident that the only areas where the price of coal was below the minimum acceptable price (5 shillings) were those on, or very near to, the coalfields. This was so because, although the price of coal at the pit head might be very low (one shilling and six pence per ton for low quality coal, for example), the cost of transport over land was prohibitive, being as much as one

[1] Some of the main sources used include: T. S. Ashton and J. Sykes, The Coal Industry of the Eighteenth Century (Manchester: Manchester University Press, 1964), pp. 235-236; "Agreements," Boulton and Watt Collection.

shilling per ton mile.[1] Water transport was cheaper, but even so the price of coal in London and Cornwall, for example was well over 10 shillings per ton. Based on this, the map in figure 31 shows two regions; one where the price of coal is assumed to be below 5 shillings and the other where it is above.

Deep Mining

In 1775 the only extensive (in number) area of deep mining was in Cornwall. By the 1790's, however, another area had developed in the north-east coalfield.[2] These areas are mapped in figure 31C.

Cumulative Regions of Potential

Super-imposition of the three maps (see figure 31D) to indicate the areas of high and low potential results in the following observation; in 1775 there was only one area of peak potential -- Cornwall. This area had high concentration of Newcomen Engines, high price of coal, and deep mining. London was an area of secondary potential. In the 1790's

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[1]B. F. Duckham, op. cit., p. 209.

[2]For a discussion see chapter 4.

the north-east also developed as an area of secondary potential. An examination of the activities of the firm in the early period shows the way in which their behaviour was orientated to this potential surface.

Organizational Activities

It is one thing to recognize potential markets, but quite another to get them to accept an innovation. Even though the 'adventurers' of Cornwall were actively searching for improved devices with which to drain their mines and had heard of Watt's improved engine, it remained for the utility of this to be demonstrated.

Orders from the Cornish mines were slow in coming and in 1776 T. Ennis wrote to Boulton:

> I find the people here too much bigoted to their old plan; nevertheless I still hope to see your Engine work in this Country.[1]

There had, of course, been enquiries, for example, from Thomas Dudley a Cornish engineer, but these had not yet resulted in an order. As a result of the impasse Boulton and Watt made a special offer;

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[1]Letter, T. Ennis to M. Boulton, July 6, 1776.

> We will erect at our own expence those parts of a Fire Engine which are peculiar to our Inventions and if that engine is not better than any Engine in Cornwall in respect to the Quantity of water raised by the fuel consumed we will remove it without any charge . . .

they were convinced that:

> If we erect one engine at our own Expence that will be a sufficient example to enable the Cornish Gentlemen to judge for themselves . . .[1]

The persuasion process was slow, but persons like Dudley were assisting. He wrote to John Wilkinson in September 1776 reporting that he had 'exerted every effort in our power to open Gentlemens Eyes and get the Invention Introduced' and some success was being made.[2] The effort was rewarded, and the first order obtained in November 1776. Also an order was received from Thomas Wilson who represented Thomas Fenton & Co. of Yorkshire at Wheal Busy, Chacewater. This man was to become the firm's agent in Cornwall. This latter engine was the first set to work in the fall of 1777.[3]

The situation was changing, but slowly:

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[1]Letter, Boulton and Watt to Mr. Wilkinson, October 3, 1776.

[2]Letter, T. Dudley to J. Wilkinson, September 18, 1776.

[3]E. Roll, op. cit., p. 72.

> By what I see & hear among our Cornish Gentlemen they are chiefly against the Invention except a few with who it gives me pleasure to think dwells the greatest capacity ... Virgin is settled for further proceeding in the common method with putting in 2 large new Engines, I endeavoured by every method to turn them from their wrong way but it proved Quite in vain . . .[1]

However, the incentive, the success of the local Watt engines, and the influence of persons such as Wilson and Dudley were paying off. By 1778 Dudley could report:

> Mr. Watts invention appears to get ground fast in Cornwall and from what has been already shown all former unbelievers is made converts . . . the Spirit Engine at this place answers every expectation and have been very instrumental in removing doubts,[2]

and later the same year James Watt wrote:

> The universal confidence of the whole County in the abilities of the engine is now fully established.[3]

However, not everyone adopted the innovation at once as is shown by the following quote:

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[1]Letter, T. Dudley to J. Watt, August 2, 1777.

[2]Letter, T. Dudley to M. Boulton, January 31, 1778.

[3]Letter, J. Watt to J. Black, December 12, 1778, in E. Robinson and D. McKie, eds., Partners in Science: Letters of James Watt and Joseph Black (Cambridge, Mass.: Harvard University Press, 1970), p. 41.

> You will remember Trevaskus proprietors applyd for an estimate some time since but after agreed to put in Mr. Harris' Water Engine which cost them between 5 & 600 Pounds and obliged to give it up as they could not do anything with it.[1]

It is apparent that the firm of Boulton and Watt from an early date saw the potential of the Cornish market and that initially their main activity in aiding the spread of the innovation was in this area. Attempts were made to provide the potential adopters in that locality with information on the merits of the innovation. This was done in many ways. Thomas Wilson a local 'influential' was made the firm's agent and every attempt was made to get an engine erected in the mining area so that personal contact with the machine would demonstrate to the adventurers its superiority. For the same reason much was made of trials between the old and the new types of engine. A measure of the commitment of the firm to this area is shown by the fact that they even rented a house there and took shares in some of the mines.[2] This again emphasizes the purposive behaviour of the firm in trying to direct its influence and extend its contacts to

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[1]Letter, T. Dudley to Boulton and Watt, January 26, 1779.

[2]E. Roll, op. cit., pp. 84-94.

particular industries and areas. Not only Cornwall was the scene of effort on the part of the firm to spread its innovation. A special interest was taken in the London waterworks, especially by James Watt. The potential market there must have been recognized early as Watt was visiting the waterworks in 1775 and making notes.[1] It is probable that, although this market was fairly small, the great publicity value attached to it was an attractive feature.[2] The firm already had an established agent in London in connection with Boulton's previous interests.

One method of promoting the spread of the reciprocating, and later the rotary, engine was by means of demonstrating its superiority over common engines. Every engine set to work was, in a sense, on trial, but in some instances this was more important than others. Such cases would be where the engine was introduced to a new use or locality, and success could raise the credibility of the innovation. When the first engine was built at Soho persons like John Smeaton

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[1] Ibid., pp. 41-44; H. W. Dickinson, Water Supply of Greater London (London: Newcomen Society, 1954), pp. 67-70.

[2] E. Roll, op. cit., p. 45. This again points to the firm's efforts to direct the flow of advantageous information.

had been invited to attend the engine and assess its performance.[1] In the initial stages of the diffusion trials were of special importance and could be reported in areas of 'interest' by the press:

> We hear from Coventry, that a few days ago a trial was made between two fire-engines, at Hawsbury Colliery, near that town, viz. one of the old construction, and one of the new improved engines.

Following an account of the results it was stated:

> The superiority of the new engine, erected by Messrs. Boulton and Watt, must therefore greatly promote the mining interests of this kingdom, since the proprietors of mines may save by the new improvements, a sum equal to two thirds of that usually expended in fuel: and likewise may have such engines erected in the terms of the old construction.
>
> The ingenuity and utility of the contrivances of Messrs. Boulton and Watt respecting the fire-engine, in certain situations, stand confessed by all able and experienced mechanizations; but how they will apply as highly advantageous to the coal-mining interests in the circle of Newcastle may deserve examination.[2]

Similarly, evidence from Cornwall suggests that trials and demonstrations were important in the adoption decision

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[1] J. Muirhead, op. cit., p. 249.

[2] Newcastle Gazette, June 2, 1779.

process:

> We have got a preference from Mr. Cole before any other & is to wait till Wh Buzy is tryed on whose suckcess it depends . . .[1]
>
> I have no Material news from Cornwall to Communicate as every one appears to wait the trial of Ting Tang & Whl Busy Engines.[2]
>
> There is a mine or mines called Poloory & Ale & Cakes just new setting out but defers the Beginning of the Engines until ours is at work as Mr. Beauchamp the Principle Proprietor tells me that if it appears that any savings occurs from the Invention he will immediately adopt it in their mines.[3]

and when the rotary-motion engine was introduced trials were also important:

> Mess. Hatch & Smith the greatest distillers in England I am informed wait only the trial of M. Liptraps to order one - Mr. Booth in Turnill Street in same style.[4]

and,

> Our trial last monday Benwell was accompanied by a very rainy day, which prevented the Pit Gear from doing so well as it should

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[1]Letter, T. Wilson to J. Watt, November 23, 1777.

[2]Letter, T. Dudley to J. Watt, June 14, 1777.

[3]Letter, T. Dudley to J. Watt, August 2, 1777.

[4]Letter, J. Rennie to J. Watt, October 10, 1786.

> have done. The engine however acted the part perfectly and gave great satisfaction to a large Company who attended with great patience. The proof is that I have since received six orders for 20 horse Engines, only one of which is wanted in a hurry . . .[1]

In aiding the spread of the reciprocating engine the firm undertook various kinds of activity in the areas of high perceived potential. Where the firm found the erection of engines less desirable it is evident that they refused orders:

> The Coal Mines in Yorkshire will not pay us for our attention on that business and therefore we have in general declined Engine orders where coals are of less value than four or five Shillings per Ton, particularly as we have hitherto been overloaded with Business where Coals are at a high price . . .[2]

This quotation also serves to introduce another factor already alluded to in chapter 3, which probably had quite an effect on the speed of the diffusion, that is, the difficulty of supplying all engines requested. Although the firm did

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[1]Letter, J. Watt Jr. to M. R. Boulton, February 11, 1796.

[2]Letter, Boulton and Watt to Samuel Walker & Co., May 22, 1781 in, E. H. John, ed., The Walker Family: Iron Founders and Lead Manufacturers, 1741-1893 (London: Council for the Preservation of Business Archives, 1951), p. 58. In some cases where the coal was very cheap the engine was so desirable that the adopters were willing to expend large sums of money see, for example, Letter J. Lees to Boulton and Watt, April 16, 1791.

not actually make the engines, at least in the early period, there were other limitations on the annual production. For example, accurate plans had to be draughted, and engine erectors had to be available. An instance of this inability to meet all requests is provided in the following quotation:

> Our Mr. Longridge wrote you in Jany 1785 to treat with you for one of your small rotative Engines - you were then so full of orders that you were not at liberty to treat with us - we beg leave now to repeat our application. . .[1]

Such factors as these, as well as the difficulties associated with delivery of engine parts from their producers, provides an example of how important the capitalization of the diffusion agency can be. If this is not adequate then the rate of production, and diffusion, may be inhibited, especially when one firm has a monopoly.

Changing Perception and the Introduction of Rotary Motion

It is clear that by the early 1780's the firm of Boulton and Watt were beginning to realize that if the engine business was to increase then new markets would have to be

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[1]Letter, W. Hawkes to Boulton and Watt, July 30, 1794. For another example see, W. H. Chaloner, "The Cheshire Activities of Matthew Boulton and James Watt, of Soho, Birmingham, 1776-1817," Transactions of the Lancashire and Cheshire Antiquarian Society, LXI (1949), p. 125.

found.[1] This was so, because they could see that their main market for reciprocating engines, Cornwall, would soon be exhausted and there were few waterworks (another, but smaller market) outside London. Boulton was aware that there was no other 'Cornwall' to be found, at least for reciprocating engines and it was seen as vital to develop rotary motion.[2] This is clearly an instance of the effects of 'feedback' from the environment, in terms of information on changing conditions, leading to the organization adapting its behaviour. Modification of the innovation, in terms of its conversion to rotary power, would allow its application to mills. It was Matthew Boulton who recognized the acute need for rotary motion to work mills 'which is certainly an extensive field'.[3] In particular, he thought that the engines would be applicable to corn and flour mills and possibly in winding ores and coals.[4] These potential markets

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[1] E. Roll, op. cit., p. 111.

[2] H. W. Dickinson, Matthew Boulton, p. 113, quoting M. Boulton.

[3] Ibid., p. 113.

[4] E. Roll, op. cit., p. 111.

were more attractive than 'these transient mines'.[1]

A patent was obtained for rotary motion in 1781 and it was decided that the profits from this would not be based on the coal saved but on an annual premium or an outright sale.[2] This meant that perceived potential-use surface was related to the locations of what the firm viewed as potential adopters, and as such it was, in part, directly related to the urban hierarchy.

Promotional Activity

Boulton and Watt saw the main market for the rotary engine as being the corn mills. In order to tap this market it first had to be demonstrated that the steam engine could be used in such a way. To do this, initially, a small corn mill was erected at Soho. Since the industry was market orientated, however, the main area of potential was London. In order to prove the usefulness of steam power in grinding corn, both to the London area and the country in general, the Albion Mill project was instigated. This was the first

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[1]Letter, M. Boulton to J. Watt, December 7, 1782, quoted in J. Lord, Capital and Steam Power (London: Frank Cass, 1966), p. 162.

[2]This varied with the size, in horse power, of engine being used.

mill to be designed and built to use rotary steam power.[1] The mill idea was probably initiated by Matthew Boulton, but it was built by Samuel Wyatt, a friend of the partners. The partners did, however, provide financial support. The corn mill, built as a commercial venture, but also a show-piece, was opened in 1786, and John Rennie, who had been employed on the project as well as being the firm's agent in Southwark, London, wrote to Watt as follows:

> There was present an innumerable crowd of spectators, which as it was her first trial gave one a good deal of uneasiness. All went away satisfied.[2]

Although the mill was never really a commercial success, and it was burnt down in 1791, its value was considerable as James Watt noted:

> What raised their reputation the most was their splendid exhibition at the Albion Mill . . .[3]

The enterprise clearly demonstrated the value of rotary steam power in grinding corn and must have had a great effect both locally and nationally. Few engines were erected to drive

[1]J. Mosse, "The Albion Mills, 1784-1791," Transactions of the Newcomen Society, XL (1967-8), pp. 47-60.

[2]Letter, J. Rennie to J. Watt, March 9, 1786.

[3]Memoir of Boulton by Watt, in H. W. Dickinson, Matthew Boulton, p. 204.

corn mills, however, but other industries involving the grinding of grain were extensive users of the innovation. The decision to implement the project in London shows how acute was the perception of the partners with regard to promoting their rotary engine. Many provincial industries had some contact with London due to the fact that their owners travelled there regularly. It was probably contact with the Albion Mill, for example, which stimulated John Stein, a Scottish distiller, to adopt the innovation.[1] Similarly, the strong connections between the Nottingham-based hosiery-oriented cotton and worsted spinning industries and London, which was a source of both raw cotton and capital, probably were influential in the early use of steam power in the textile mills of the Nottingham area. In particular, Timothy Harris, the second person in the area to adopt a Boulton and Watt rotary engine, had very likely been to Albion Mill and the favourable impression gained there led to his enquiry.[2] It has been shown in chapter three that

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[1]Letter, J. Stein to Boulton and Watt, August 7, 1786.

[2]R. L. Hills, Power in the Industrial Revolution (New York: Augustus Kelly, 1970), pp. 156-157.

the London market was of prime importance for rotary engines. Undoubtedly many local industrialists were impressed by the Albion Mill, which, in addition to demonstrating the utility of rotary steam power, had the important influential engineer, John Rennie, associated with it. Some details of his activity in the area have been given in chapter five. It is interesting to note that, as shown in the graph in figure five in chapter four, that the early use of rotary steam power was especially evident in industries which employed similar techniques of production to the Albion Mill. Breweries, distilleries, starch manufacturers, etc., all included the grinding of grain as one of their production processes, and it was generally this process to which steam was applied. This would again emphasize the importance the favourable information field created by successful application of the innovation to a process in reducing the uncertainty associated with adoption in similar industries.

Once the attention of the firm had been drawn to a particular area (spatial or industrial) of demand or potential, it followed that some activity was undertaken to promote sales. This might be in the form of the incentives used in Cornwall or the Albion Mill project in London. Such an undertaking as the latter one, however, would be costly. For the most extensive areas of perceived potential for sales a local agent was established, these were not solely engaged in the work of the firm, however. It has already been mentioned that Thomas Wilson became an agent in Cornwall in the 1770's. Rennie was established in London with the introduction of rotary motion in the 1780's. The firm's increasing awareness of the potential for the sale of rotary engines in the Manchester area led to Peter Ewart, Rennie's ex-employee, being sent there in the early 1790's. This awareness of the potential of the Manchester area was probably, in part, a result of information passed to the partners by James Watt junior, who moved to that area in 1788. In such ways the firm endeavoured to extend its field of contact in areas of perceived high potential.

The firm's promotional activities were not restricted to agents, demonstrations, and trials. Less formal means could be used. The first order for an engine in Scotland, from Peter Colvile of Torryburn, resulted from Watt's visit to the country in 1776 to get married.[1] This fact which again emphasizes the mobility of the persons connected with promoting the engines spread. Also, due to the fact that the firm

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[1]L. T. C. Rolt, James Watt (London: B. T. Batsford, 1962), p. 67.

of Boulton and Watt acted, essentially, as consulting engineers in preparing the plans for engines and in assisting in their erection, many employees were constantly visiting areas where the firm had some interest. In the course of these movements it was easy for the employees, engine erectors and others, to visit local persons who were known to be potential customers. It was probably such a contact which stimulated John James of Nottingham to enquire about an engine to replace the horses used in his cotton mill.[1] Similarly, George Houstoun, in Scotland, was contacted by James Watt Junior:

> I did not know till I had the pleasure of seeing your son here, that you undertook the erection of Fire Engines at such a distance as this.[2]

This quote provides, in addition, an interesting example of the individual perception of 'availability' of the innovation. The evidence for the importance of such 'travelling salesmen' is particularly clear in the case of James Lawson, one of Soho's more important employees. He often visited areas on the firm's business, to see that the engines were

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[1]Letter, J. James to J. Watt, February 27, 1786.

[2]Letter, W. Fergus to J. Lawson, August 17, 1799.

working correctly or to answer enquiries, and in the course of these visits he made many contacts. The period when he was most active was the late 1790's and to give some idea of his range of activity his journey for one year, 1798, has been mapped and is shown in figure 32. This demonstrates the high mobility of the firm's agent, even at a time when transport was not easy. That such contacts as those made by Lawson could be important is shown by the following quote:

> In consequence of what passed between you & some of our partners when you was at this place, we are now come to a resolution of having a patent Steam Engine erected to work our mill which lies next to the sea.[1]

Of course these activities also provided valuable information for the firm on the state of the environment:

> I expect orders for one or two 10 Horse Engines here & I should think a few more of that size will be wanted soon as all the hand mule spinning must be given up as it will no longer pay.[2]

In other areas where an agent was not located the efforts of local influentials, like those mentioned in the previous chapter, could be counted on. In special circum-

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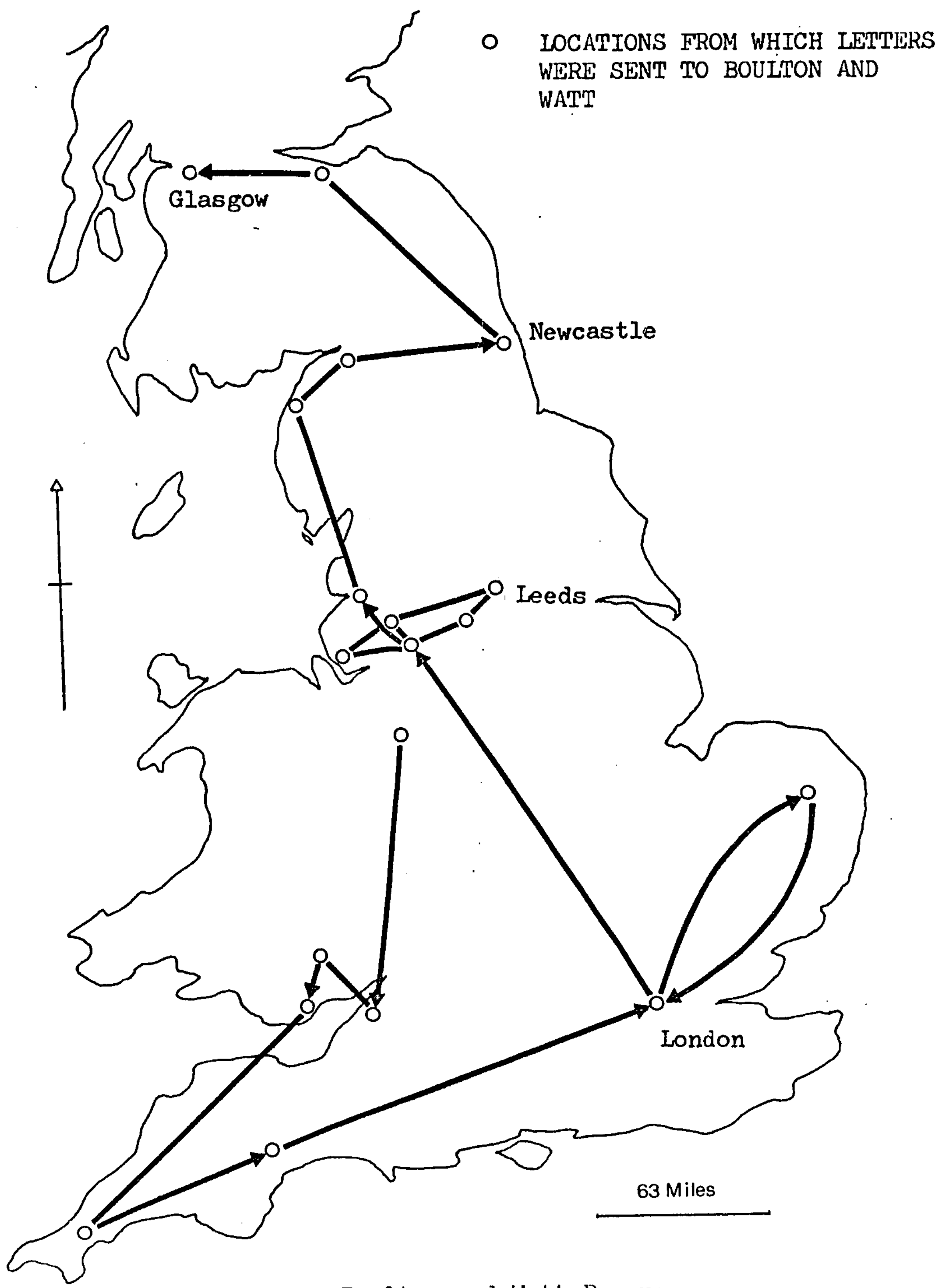
[1]Letter, W. Fergus to J. Lawson, August 17, 1799.

[2]Letter, J. Lawson to Boulton and Watt, August 19, 1798.

FIGURE 32. LAWSON'S PEREGRINATION, 1798.



Source: Boulton and Watt Papers

stances someone could be sent to the area, for example, in 1796 Watt Jr., was at Newcastle. The area was just developing as a market for rotary engines and the importance of the visit can be seen from the record of it:

> I am now employed looking about me here, and getting acquainted with our customers, as well as endeavouring to form new connections, in all which Mr. Barnes obligingly takes upon him the office of being my chaperone [?]. Under his auspices I am engaged for every day this week, and I fear, for the great part of the ensuing one; anxious as I am to return home, I will not lose the opportunity that now occurs of establishing useful connections. There is every reason to presume that we shall soon monopolize the business of this place and it shall not be lost I assure you for want of due civility and attention upon my part to the different Colliery Agents. I adopt with them, John Wilkinsons' Maxim that the best way to secure their friendship is to eat and drink heartily with them.[1]

One other function of the firm's employees is worth mentioning at this point. As the period for which the patent was in force came to an end the firm was increasingly troubled by 'pirate' engines. These were usually constructed in violation of the patent and were generally cheaper to buy than Watt's rotary engine. Such engines were especially important in the Manchester area and reflect the 'demand'

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[1]Letter, J. Watt, Jr., to M. R. Boulton, February 3, 1796.

for rotary power which in all probability the Soho firm could not meet adequately.[1] The employees of the firm played an important part in 'seeking out' and reporting in these pirate engines and thus aided in the protection of the patent.

The efforts were, however, not equal to halting the establishment and operation of firms producing engines and these were already viable production units by the time the patent expired in 1800.

Conclusion

This chapter has examined the efforts of the firm of Boulton and Watt, as an organization, to manipulate the patterns of spread of both reciprocating and rotary engines. It is clearly demonstrated that the organization is a purposive (teleological) system engaged in attempting to achieve some goals. It is in terms of these goals, or aspirations, that the environment is viewed and we have seen how the firm's activities, in terms of its attempts to aid or retard the spread of the innovation, were orientated to

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[1]See, A. E. Musson, and E. Robinson, op. cit., pp. 393-426.

an 'image' of the potentials of this environment. Further, it has been shown that the firm's actions were adjusted timespatially to reflect changes in the perceived environment. All these factors demonstrate the general utility of the model, discussed earlier, as a device for conceptualizing the role of the organization in diffusion.

The findings of this chapter unite with those of the previous chapters by showing the way in which the general patterns of diffusion of the innovations (chapter 3) are related to the firm's conscious efforts to selectively influence the spread of those innovations both in particular localities and industrial sectors (chapter 4). These purposive actions, involving trials, incentives, and the activities of agents and influentials, on the part of the perceptive business men at the head of the organization were in essence attempts to influence the flows of information concerning the innovation (chapter 5). In this way the firm extended its influence in particular areas by making information, and in a sense the very existence of an engine is information, available. Such activity in areas of high perceived potential was matched by negative action in areas thought to have low potential for sales or profits. In this way the firm modified the probabilities of adoption of the innovation in a spatially selective manner.

CONCLUSIONS

Summary

The general aim of this research is to provide insights into the innovation diffusion process. This goal is achieved in two ways, first, a conceptual framework for the process is developed, and this provides a basis for the empirical investigation of the diffusion of James Watt's steam engine innovations, which constitutes the second part of the study.

Innovation and diffusion is an extremely complex time-spatial event and the purpose of the conceptual framework is to clarify the process. In order to do this the findings, statements, and generalizations of many researchers in several fields are drawn together and integrated into an orderly system. The concepts used vary in their degree of generality, but all have in common the fact that they apply to many empirical examples. In this way the process is simplified without losing touch with reality.

The framework, more specifically, breaks down the innovation and diffusion process into a series of sub-processes. After a brief discussion of the innovation process, then, the diffusion of innovation is examined in terms of an information flow process, an adoption-decision process, an acquisition process, and an implementation process. Special attention is given to conceptualizing the role of the organization, or agency, in diffusion of innovation.

The analysis of the diffusion of the steam engine innovations starts with an examination of the general patterns of spread. This shows that there is little evidence of a simple neighbourhood-type diffusion pattern. The growth pattern as it develops in timespace is one of multiple regional focii which differ in size, compactness, and date and rate of growth. In this respect the pattern is clearly different from many of the empirical regularities identified by previous researchers. In order to provide some insights into the peculiar nature of this pattern of diffusion, three lines of investigation are followed. First, variations in the industrial use of the engine are examined. Second, information flow processes are discussed, and third, the role of the organization in the diffusion is assessed (chapters 4, 5 and 6).

It is found that one of the main factors influencing the pattern of spread of the innovations is the nature of the environment in which the diffusion takes place. One of the main features of this is the potential-for-use of the innovation in industry, and this of course changes over time. This potential can be defined in terms of the relationship between the needs of industry and the individuals' perceptions of what the innovations had to offer relative to these needs. Variations in potential-for-use are examined both among industries and within particular industries. These factors, combined with the high degree of localization of some types of industries, channeled the course of the diffusion.

A person's ability, or potential to use an innovation, as defined above, is not a static thing. Like all perceptual phenomena it can change, and information plays a fundamental part in bringing about these changes. Chapter five examines information flows in relation to the changing perception of the innovation which occurs during the adoption-decision process. Biases are also identified which affect the likelihood of interaction between persons and, therefore, define a network of links between industrialists. Some of the timespatial attributes of the network of interpersonal contacts between adopters of the innovations are also examined in chapter five. In particular, inter-regional partnership ties, the emergence and fields of activity of some 'influentials', and certain acquaintance circles are investigated, and their significance for understanding the general pattern of diffusion is pointed out. It is suggested that long distance contacts would aid the rapid spread of the innovation, while the strong local fields of contacts which were characteristic of many influentials would tend to reinforce the neighbourhood effect in the diffusion pattern. This is probably the case in the Midlands where the local influences of the firm led to extensive early adoption of the reciprocating engine, even though the area was not one of 'great need' in terms of the price of coal.

Uniting both the flows of information and the needs of industry was the activity of the organization, the firm of Boulton and Watt (chapter 6). This agency selectively, in terms of both location and type of industry, influenced the course of the diffusion. In fact, it is the purposive action of the firm, undertaken in the light of the partners' perception of the potentials for use of the innovations in the changing environment, which, in a sense, guided the whole event called the diffusion.

The general patterns of diffusion of the innovations are, therefore, understandable in terms of the kinds of industrial, informational, and organizational biases which channeled the spread. These acted together in a complexly interrelated way to produce that manifestation of the innovation diffusion process represented by the timespatial pattern of locations of adopters of the innovation.

The two sections of the study, the conceptual and the empirical, therefore, act together to provide insights into the innovation and diffusion process. The first provides a basis for examining the second, and this, in turn, gives a greater understanding of the processes outlined in the conceptual framework.

Conclusions

General Comments

In the introduction to this dissertation it is pointed out that generally a particular approach to the study of the process of innovation and diffusion has been favoured by geographers. This approach involves the development of operational models in which certain behavioural assumptions[1]

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[1]For example, those relating to the nature of general spatial regularities in human interaction (information flow).

are, by means of Monte Carlo simulation techniques, used to produce hypothetical patterns of diffusion for certain innovations. The simulated pattern is then compared with an actual pattern of diffusion in order to 'test' the validity of the model and the initial assumptions.

One of the weaknesses of this approach is that simplistic assumptions concerning human behaviour are made in order to facilitate the development of the model. Also, the means of testing the value of the assumptions is inadequate since similarity of pattern does not necessarily mean similarity of process. In addition, emphasis on this type of approach has tended to lead to a neglect of detailed empirical investigation of innovation diffusion processes.

If it is accepted that one of the objects of research on innovation diffusion is to develop testable generalizations concerning the process, then it can be argued that such a goal is best achieved by empirical investigation of particular diffusion phenomena. Such investigation should, however, proceed in the light of existing concepts and generalizations relating to the process being studied. In this study such a body of generalizations is organized to form a conceptual framework for the innovation and diffusion process. This clarifies the process and is a source of hypotheses and questions which serve to guide the empirical investigation. The conceptualization is, however, partially a product of the empirical findings of the study. This fact suggests that in future research an attempt should be made to maintain a constant interplay between the general and the particular aspects of innovation diffusion.

Other Conclusions

At this point the conceptual framework presented in chapter 1 will be used as a basis for discussing some of the conclusions drawn from the study regarding the nature of the innovation diffusion process.

Information Flow

The aspect of innovation diffusion which has received most attention from geographers is that relating to the mechanisms by which information concerning innovations is spread. The findings of this study suggest that information flow processes are very much more complex than generally has been recognized and that the simplistic assumptions about the nature of these processes which are employed in simulation models are totally unrealistic. Particularly important are the observations made concerning 1) influentials and partnership links, 2) potential adopters searching for information, 3) the importance of different kinds of information and information sources in the adoption process, and 4) the activities of the firm of Boulton and Watt in spreading information about the innovations.

The Adoption Decision

Whether or not an individual adopts an innovation and the speed with which adoption takes place will depend in large measure of the changing perceptual relationship between what the innovation has to offer relative to some need. This study shows that many factors may affect an individual's (industries) potential-for-use of the innovation. The importance of such considerations for the pattern of spread of the innovations becomes clear when it is pointed out that such factors can provide several alternative explanations for both the neighbourhood and hierarchical diffusion effects observed by geographers and usually accounted for by information flow processes. This study shows that the locational pattern of industrial units which are potential adopters of the innovation (whether clustered or otherwise) provides a 'structure' within which the pattern of adoptions evolves. The fact that certain industries with high potential-for-use are localized in one or more areas may produce a neighbourhood-type pattern of adoptions. A similar kind of situation in which the industry is urban-oriented might, however, produce a hierarchical diffusion pattern.

Even if a particular industry is identified as an area of high potential, within that industry individual units may vary in their ability-to-use based on characteristics such as size. Where this is the case, and variations in size are not randomly distributed throughout the population of potential-adopters units, then the fact may be reflected in the pattern of diffusion. For example, the rotary motion engine was only adopted by the largest breweries and the fact that these were located in London led to a cluster of adopters in that city.

Finally, in trying to provide insight into the pattern of spread of innovations which were used in a variety of industries, it should be emphasized that the overall diffusion pattern is an aggregation of the spread of the innovations within many industrial sectors. Clustered patterns of adoption in some industries, hierarchical patterns of adoption in others, and still other kinds of adoption patterns for some industries, all combine to form the general pattern of spread.

Acquisition

Some conclusions can be drawn regarding the way in which problems of acquiring the innovations may have affected the course of the diffusion. First, it is likely that the supply of engines could not always meet the demand. This was due to the fact that even though Boulton and Watt did not actually make engines for most of the study period they still had to draft plans and supply workmen for erecting the engines. Therefore, such factors as the difficulty in obtaining skilled workmen and limitations in the firm's available capital might be obvious factors affecting the production of engines. Second, there is evidence that for the reciprocating engine the firm was not anxious to encourage adoption where the price of coal was low and the fact that they had a negative attitude to such areas may have affected the pattern of spread. Third, some persons situated at great distances from Birmingham may have failed to adopt the innovations even after knowing about them due to the mistaken notion that the firm would not supply its product in such areas.

Such factors as those outlined above, and more general problems of acquisition, can have significance for the pattern of diffusion of an innovation. The number and location of 'sales outlets' for an innovation is, for example, a factor worth considering. If such units supplying an innovation are located in urban areas then this might help account for hierarchical diffusion patterns. On the other hand a sales outlet in an area might produce a local cluster of adoptions.

Implementation

Limited evidence is provided in the study for the importance of what has been termed an implementation process in the diffusion of the innovations. In some cases the decision to adopt the innovation was made at a different location to that at which the decision was implemented and the steam-powered factory constructed. This means that any pattern of diffusion may to a greater or lesser degree represent a pattern of implementation rather than adoption. Where the adoption of an innovation has implications for changing the locational requirements of the industry or activity which adopts it then the implementation process may be particularly important and the shift of the cotton spinning industry to urban centers with the advent of mills relying solely on steam power is a good example of this.

Where this kind of process is in operation then the location of the innovation represents the result of a locational decision based on some kind of assessment of the environment in which that decision is to be acted out. Such a process might produce a clustered pattern of innovation locations, for example, when the activity is oriented to a particular resource which is localized in its occurrence. On the other hand the same kind of process could produce a variety of different kinds of pattern.

The Organization

One of the most significant aspects of the diffusion of the innovations studied in this dissertation relates to the part played by the firm of Boulton and Watt in the diffusion process. It is clearly demonstrated that the firm's image of the environment in terms of the rewards associated with the use of the innovations in different areas (both regions and uses) formed a framework within which their actions, with regard to aiding or limiting the use of the innovations, were set.

It has already been mentioned that the activities of an organization can be important in the acquisition process. In addition, it should be emphasized that the firm's efforts to aid the spread of the innovation by using trials, incentives, agents, etc., are an important element in the information flow and adoption-decision processes.

Where such an organization exists its significance for the diffusion of innovations is that it can act as a link between the changing state of the environment, the mechanisms of spread, and the innovation itself. The pattern of spread may be seen as the outcome of the complex changing relationship between these three elements.

Linking Pattern and Process

Usually in geographical investigation of innovation diffusion the timespatial pattern of locations of adopters of the innovation is taken as the basic point of reference and this constitutes the phenomenon to be 'explained'. The insight gained into the nature of the diffusion process by simply examining the pattern of spread is, as shown in chapter 3 of this dissertation, strictly limited.

The patterns of adoption of the innovations exhibit some degree of clustering and orientation to urban places and these patterns might be interpreted in terms of the neighbourhood and hierarchical effects identified by Hagerstrand and others and, therefore, explained in terms of spatial biases in information flow. More detailed investigation, however, reveals that a wide range of alternative explanations for both neighbourhood and hierarchical effects are possible. This suggests that a willingness to accept particular process explanations for patterns, without considering alternate explanations, should be guarded against.

A final comment is directed to the problem of identifying specific processes and assessing their influence on the pattern of diffusion. In many instances it is apparent that the pattern of spread of an innovation is the outcome of several processes acting together in a complexly interrelated way. In addition, the individual processes may vary in their importance over time. It follows that if, for example, a clustered pattern of adoption is observed then this effect may be due to the combined effect of several processes and factors. Further study can, of this problem, hopefully, provide insights into the way in which diffusion processes operate.

Suggestions for Further Research

Often the outcome of any research project is not only that insight is provided into a particular problem, or set of problems, but, and this is just as important, that this insight provides a fuller appreciation of the limited extent of our knowledge concerning the phenomena being studied. Questions arising out of this situation can, however, serve to guide further investigation, and so lead to additional insights. Some topics which it is felt warrant further study are outlined here.

Although only briefly discussed in this work, the process of innovation and its timespatial pattern of occurrence would seem to be a rewarding area for future research. Little work has been done in this area, especially from a geographical point of view, and yet the topic is one of such importance that it should not be neglected. The main difficulty associated with such work would seem to be related to lack of access to suitable data. A start could be made, however, with patent records, which exist for considerable periods of time for many countries. It is clear that such research must be involved not with aggregate patent statistics but with those relating to particular kinds of activity, if any meaningful conclusions are to be reached. The conceptualization of this process presented in chapter one might serve as a starting point for such a study.

Making decisions to adopt an innovation or to do anything else often involves collecting information pertinent to the decision making process. Little is known, however, about the waysin which persons search the environment for information. Making locational decisions usually involves searching the environment, and often the pattern of search may decide the outcome, where this is the location of some item. Investigation into patterns of search in relation to the above kinds of problems might prove very rewarding in terms of extending our understanding of both the adoption-decision process for innovations and the locational decision process in general.

In many cases the decision to adopt an innovation can be viewed as distinct from the decision as to where to implement it. In many cases the appearance of an innovation in the landscape is the result of implementation decisions, and this would appear to be especially true of more important industrial, commercial, and administrative innovations. Cases where the diffusion of an innovation is purely by means of an implementation process can be found. For example, an innovative government policy requiring the establishment of new administrative units may be implemented by a commission specially established for the purpose. Little is known about the kinds of mechanisms involved in such diffusion processes. The topic is thought, however, to have potential importance for a number of areas of geographical interest. The links between this topic and industrial and commercial location theory, and the development of a system of urban central places are clear and as yet have been virtually ignored.

Investigation of the role of organizations, or agencies, in innovation diffusion is another pressing need. Extensive empirical research is required to improve our understanding of this topic. What are the best measures to aid or inhibit the spread of an innovation? How do such factors as financial resources affect the performance of an agency? How does the organization evaluate the environment in which its decisions are going to be acted out? All these questions, and many others, might prove to be profitable avenues to follow in terms of increasing our understanding of innovation diffusion processes. Such study would seam to be best conducted at the level of the individual organization and would almost certainly involve more detailed study of the decision making process.

Finally, it should be emphasized that there are obviously close connections between all the research suggestions outlined above. Also, the problems are clearly not just related to the innovation and diffusion process but to many of the 'areas' in which geographers, in particular, and social scientists in general are interested at the present time.

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APPENDIX I

RECIPROCATING ENGINES: ADOPTIONS BY DATE AND USE

Use / Date	Cotton Mills	Coal Mines	Salt Mines	Copper/Tin Mines	Iron Mines	Lead Mines	Iron Works	Copper Works	Lead Works	Engineering	Breweries	Canals	Private Water	Tunnels	Docks	Water Works
1774										1						
1775																
1776		3					1			1	1					
1777		2	1	3		1	1					1				
1778				3		1	2					1				3
1779		2		5		1	1									1
1780				7			3									
1781				2			2									
1782				2			2									
1783		3		3		1	1									
1784				3		2						1				1
1785	1	1		1	1	2										1
1786				9												2
1787				1												
1788						2										
1789		2				2										
1790							1		1			1				
1791		2		1			2					1				
1792		1														
1793	1	3		2		1						1				
1794		2										2				1
1795		2		1												
1796		1					1									1
1797		2					1									
1798		1		2			2									
1799		5		1			2									
1800		2					4	1				2	1	1	3	
Total	2	34	1	46	1	13	26	1	1	2	1	10	1	1	3	10

Source: Boulton and Watt Paper.

APPENDIX II

ROTARY ENGINES: ADOPTIONS BY YEAR AND USE

Date Use		1782	1783	1784	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800	Total
	Cot. Mills				2		4	2	1	4	15	10	3	2	5	9	11	9	17	14	108
	Wors. Mills								1										1		2
	Flax Mills									1		1		1	1				1	1	6
Tex-	Wool Mills											1	1		1	2			1	1	7
tile	Silk Mills																			1	1
and	Dyehouse					1					1								1	1	4
Allied	Bleachery									1								1		1	3
Trades	Colour Mfg.											1		2				3			6
	Print. Wks.														1				1		2
	Ropery														1				1	1	3
	Coal						2	2	4	1	3	2			3	9	2	3	1	2	34
Mining	Salt								1							1					2
	Cop./Tin			2				1		1				1						1	6
Metals,	Iron Wks.	1	1	5	3		2			4	2	1					1	1		3	24
Engi-	Cop. Wks.												1								1
neer-	Lead Wks.								1		1				1			2	2	1	8
ing,	Gun Mfg.										1										1
and	Pat.Shot Mfg.																		1		1
Allied	Mint				1			1													2
Trades	Ironmongers														1						1
	Flour Mill			1	1	1	1	2	2							1				2	11
Agri-	Breweries			2	1	1	2		2			1	3		1	1	3		3	3	23
cul-	Distilleries					3	1						1	1	2	1			2		11
tural	Oil/Mast.Mill			1			1		2	1					1	1			2	1	10
Pro-	Starch Mfg.			1						1				1							3
ces-	Sugar Mfg.													1		1		1	1		4
sing	Tob./Snuff					1															1
	Drug Mfg.						1			1							1				3
	Tannery											1									1
	Paper Mfg.					1															1
	Glass Mfg.							1									1		1	1	4
	Pottery	1		1									1							1	4
Misc.	Portable (mortar)												1							2	3
	Water Wks																	2			2
	Canal Pump.								2				1								3

Source: Boulton and Watt Papers.