COMMISSION
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MONITOR
SPEAR

Proceedings of the Workshop on Quantitative Evaluation of the Impact of R&D Programmes

(23-24 January 1992, Brussels)

Research evaluation

EUR 14.740 EN

Commission of the European Communities

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November 1992

Published by the
COMMISSION OF THE EUROPEAN COMMUNITIES

Directorate-General
Information Technologies and Industries, and Telecommunications

L-2920 LUXEMBOURG

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Cataloguing data can be found at the end of this publication

Luxembourg: Office for Official Publications of the European Communities, 1992

ISBN 92-826-4830-3 Catalogue number: CG-NA-14740 EN-C

Printed in Belgium

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Acknowledgments

This book of proceedings is a compilation of papers and comments presented at an international workshop held in Brussels in January 1992. The workshop was jointly organized by the Department of Applied Economics of the University of Brussels (DULBEA), which assumed the scientific responsibility, and the Directorate-General for Science, Research and Development, MONITOR/SPEAR R & D Programme of the Commission of the European Communities which financed it. Workshop and proceedings are part of a research program on the state-of-the-art of quantitative methods available for the evaluation of the economic impact of R & D programs entrusted to the DULBEA by the MONITOR/SPEAR program.

We are indebted to many people who helped make such a project feasible. First of all, to Luigi Massimo, head of the MONITOR/SPEAR program who, through this project, gave the opportunity to bring together a groups of practicians of economic quantitative methods and some evaluators and policy-makers and to Clara de la Torre, who assumed the operational supervision of the project. Special thanks are also due to the active collaboration of chairmen who arbitrated the debate : Michel Catinat, Pierre Valette, Luke Georghiou and Luigi Massimo. And, last but certainly not least, we are grateful to the active participants who accepted to play the game.

It was a real challenge to prepare the workshop, to set it up and to write the proceedings in the short time of one year. That would not have been possible without the kind cooperation of every contributor.

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Chapter 1 - Measuring the Economic Impact of R & D : An Introduction

Henri Capron

1. Econometrics as an Evaluation Tool

There is an extensive literature reviewing and surveying the strengths and weaknesses of methods available to evaluate R & D activities [1]. These evaluation methods were developed as a science policy tool and their use is necessitated by the increasing need to select research projects and to know the cost-efficiency ratio of public R & D programs. Inside the large spectrum of methods, wanting to pick out one as being the most effective would be presumptuous and vain. Each method has its own strengths and weaknesses and using one rather than another is largely conditioned by the objectives of the evaluation and the availability of information.

When having a look at the literature on the R & D impact assessment methods used by practicians, one notices that econometric methods do not belong to any family and that quantitative approaches as a whole are often considered with a lot of circumspection. So, in a major survey, the US Office of Technology Assessment concludes that, "concerning measuring the returns from publicly-financed R & D, the metaphor of research funding as an investment, while valid conceptually, does not provide a useful practical guide to improving Federal research decision-making. The factors that need to be taken into account in research planning, budgeting, resource allocation, and evaluation are too complex and subjective; the payoffs too diverse and incommensurable; and the institutional barriers too formidable to allow quantitative models to take the place of mature, informed judgment" [Office of Technology Assessment (1986)]. While this report recognizes the usefulness of econometric methods for measuring the economic impact of private R & D investments, it questions their practicability for public decision-making purposes because they fail to give consistent estimates about the effectiveness of public R & D funding. A similar assessment is made by Kerpelman and Fitzsimmons (1985) after a survey of strategic evaluation methods for research programs. They point out that "econometric methods are frequently propounded, but save for cost-benefit analysis,

[1] See, e.g., Gibbons and Georghiou (1987), Luukkonen-Gronow (1987), Danila (1989) and Cordero (1990).

most of these techniques have not received widespread currency for evaluating research programs".

Yet, econometric methods have long been used for evaluation purposes. The impact analysis of economic policy has gained increasing interest since the Second World War and is actively used by policy-makers to measure the effects of alternative policies upon the economic process. Econometric models have been developed because judgmental methods are not suitable for policy analysis, an accurate impact analysis requiring to consider simultaneously the whole mechanism of interactions between numerous key variables and to quantify these interrelations. As such an exercise is not really feasible without the assistance of a model, there is no reliable substitute for econometric models. Although econometric models offer an appropriate framework for impact evaluation, their records must be regarded as an element of information in the decision-making process. Indeed, impact analysis by econometric methods is hampered by methodological drawbacks, conflicting theoretical frameworks and the lack of available data.

These problems gain ground when the evaluation bears on the economic impacts of technological change. The measure of our ignorance concerning the real sources of economic growth was given by, among others, Abramovitz (1956) and led economists to focus their attention on the economic impacts of technological change. Presently, in macroeconometric models, technical change is viewed as an exogenous factor which tampers with production relationships. Its impact is pinned down through a proxy time variable which alternatively assumes that technical change is embodied or disembodied in capital vintages. The embodiment hypothesis stresses the importance of technological improvements in new generations of investments compared to previous ones and, as such, usefully completes the disembodied approach by highlighting the process of creative destruction. A further extension would be resolutely endogenizing technological change by modelling R & D investments. While these investments only represent a part of the contribution of innovative activities to economic growth, adding a knowledge capital variable besides physical capital in macromodels would help improve our understanding of the relationships between technology and economy. According to Klein (1989) in a paper on prospects in macroeconometric modelling, "the origins of technical change need to be built directly into macroeconometric models, and as market conditions evolve, the lasting success of new technologies together with the needs for new lines of development need to be generated by profitability considerations". To do that, he suggests an interdisciplinary collaboration between economists and engineers. Indeed, the latter working at the source of changing technology, they are able to give direct, a priori information about or artificially generated samples of the technological evolution.

While there is a general questioning about the social and economic impact of technology programs, as pointed out by Bob and Viala (1990), the notion of socio-economic effects is a fuzzy concept and must be clarified. As such it should be relinquished in order to focus on specific effects. They also underline that the present evaluation methodologies designed to measure the economic impact of technology programs are insufficient and need further researches. Besides, they remind us that any in-depth analysis of the economic effects of a program is a long and difficult work which implies collecting and processing an impressive quantity of information and must cover several years.

Post-evaluation has generally been focused on technological aspects, leaving out the issue of the economic impact. As science and technology policies have more and more huge financial implications and increasingly overlap economic purposes, the need for intensive studies of the economic impact of such policies is likely to be very strong in the next few years. These considerations frame the rationale of this book.

2. Quantitative Evaluation in Action : an Expert Appraisal

The object of these proceedings is to give an expert overview of the contribution of quantitative methods to the measurement of the economic impacts of technological change. The views which are extensively developed in the following chapters are the rational statements of ground practicians who have been working in this field for several years and who, therefore, are in a position to draw a clear synthesis of the present state-of-the-art of the applied economic analysis of technological change.

These proceedings have been split into three distinctive parts. A first part is devoted to the econometric modelling of technological change with a view to discussing some prominent points in the empirical analysis of the interdependencies between economic performances and R & D investment. The review of issues raised by the econometric modelling of technological change by Bradley and Whelan shows that the endogenisation of technical change in macromodels remains an open field. Yet, they conclude from their analysis that the recent theoretical framework given to the study of growth and technical progress should lead to more empirical studies in the next few years. In their paper, Amable and Boyer show that this process is already in action. Their "walk" in the recent literature on the applied modelling of technological change gives evidence of some first attempts at incorporating technology variables into macroeconomic frameworks. But the measurement of the economic impact of technological change as estimated by R & D investment is not an easy task. Some important problems that such an approach must solve are emphasized by Lichtenberg. Model specification, data aggregation and reliability of productivity measurements are some of the elements which can explain why the econometric estimates of the impact of R & D investment reported in the literature appreciably differ. Similar divergences between the estimates are observed when we focus on studies aimed at measuring the economic impacts of R & D public-funded expenditures. Of course, such a statement raises the question of the usefulness of econometric methods. These issues are discussed by Capron.

The second part of the book deals with some advanced empirical studies which analyze the relationships between technological activities and their economic fallout. They give a flavour of the measurement problems which are facing the practicians who are trying to get inside the black box of technological change. A first wave of papers report results of some experiments using input-output techniques to analyze the sectoral impacts of technological change. Blazejczak and Edler discuss two alternative approaches allowing to evaluate the economic impact of new technologies. The examples reported in their paper illustrate how important expertise is when future sectoral changes due to the diffusion of new technologies are investigated. Innovation-flow matrices are well-suited tools to identify how innovations spread through industrial structures. This approach is developed by Scholz. By combining an innovation survey and input-output tables, he constructs an innovation-flow matrix to measure the direct and indirect effects of process innovation on employment and production in Germany. The results reported in Wyckoff's contribution are a summary of a large-scale study which was realized at the OECD on the structural change in several industrialized countries by making use of input-output tables. The next two contributions are concerned with attempts at assessing the economic consequences of technical progress. O'Sullivan and Röger measure the effects of domestic and foreign knowledge on total factor productivity in the main industrialized countries. The estimation results are then used to carry out a simulation exercise making up the QUEST macroeconomic model to assess the macroeconomic impact of technical progress with particular emphasis on how the labour market reacts to technology shocks. The macromodeller experience reported by Standaert is a good illustration of the irreplaceable character of macromodels for evaluation purposes. While the HERMES model, just like the QUEST model or any other model, was not initially designed for the evaluation of the economic impacts of technical change, the large-scale simulation experiment described in the paper gives unchallenged results. These two simulation exercises show how important it is to improve macroeconometric models in order to grasp the real sources of growth more closely.

The relevance of present macromodels to describe long-term quantitative scenarios is scanned by Zagamé. He highlights the main methodological bottlenecks which slow down the formalization of long-term in macromodels. Yet, he states that enough quantitative evidence now exist about the effects of R & D investments on economic structures to resolutely endogenize them and so improve the analytical capacity of macroeconometric models.

In the last part, which is heterogenous by nature, some prospects about quantitative evaluation methods are discussed. In their paper, Capron and Debande have a look at the economic literature on strategic issues in order to see how their normative conclusions can help implement and target technology policy. The game-theoretical approach appears to be still in an infancy stage of development so that its practical span remains very limited. Besides, they show that the issues related to R & D races and the reaction patterns could be fruitfully studied by resorting to competitive behavior models. The short note-shaped paper by Dryden and Wyckoff describes the central scheme of a research project to be developed at the OECD on the measurement of technology diffusion in the main industrialized countries. Finally, de la Torre and Dumort express the views of policy-makers faced with the real problem of evaluating with the existing tools. They voice out their disappointment regarding the gap between the teachings of economics and the needs of management. Along these lines, one of the conclusive comments of Stanislas Standaert is akin to their idea of dialogue boxes between analysts and decision-makers. Indeed, the feeling of dissatisfaction is mainly the result of a communication gap rather than caused by inappropriate economic tools for policy-making purposes. Although economists must be careful not to claim that their discipline can offer clear-cut prescriptions about the economic guidance of technology policy, they are nevertheless in a position to give some interesting pointers as to how technological change influences economic processes.

What this overview mainly shows is that the empirical economic analysis of technological change has been able to demonstrate that technologies are really at the heart of the economic activity and that, notwithstanding the gap with respect to the theoretical background, the main bottleneck is more the lack of available data than the lack of grounded quantitative methods. This does not mean that we are no longer faced with plenty of problems. To use the quantitative methods more effectively, there is a real need to improve the methodological frameworks which must guide modelling, to adapt econometric tools to the measurement problem considered and to construct a macroeconomic theory of technological change which can give a secure foundation for further empirical works. The issues of methodological benchmarks and of adaptation of econometric techniques are of special interest for an accurate measurement of the economic effects of technology policy.

3. The Way Forward

While we are still far away from a non-controversial understanding of the economic roots and consequences of technological activities, the boundaires of our knowledge are being pushed further out. Technical progress is no longer the residual exogenous factor of economic growth emphasized in the first growth accounting exercises.

Yet, in the next few years, major efforts should be made to throw a bridge between the measurement techniques of intrinsic performances in science and technology and those of the economic impacts of technological performances. Yet, when having a look at the metrics involved, we notice that they are located at different stages of development. What we mean by metrics are bibliometrics, which applies statistical tools to the analysis of the communication media in scientific fields, technometrics which aims at measuring the technical characteristics of inventive and innovative activities, and econometrics which deals with the economic effects of technological change as a major source of growth [1]. Not only do these approaches have a lot to learn from each other but using them simultaneously in order to break through their interactive feedbacks will help give more targetted policy prescriptions.

Another focus point is the distinction between micro- and macromanagement of R & D programs. Both are vital for an efficient management of the research system. While micromanagement deals with each particular evaluation situation in order to ascertain whether the objectives set for well-defined fields of research have been reached, macromanagement refers to the global impact of both the R & D programs and the system of programs. In my view, an appropriate management of R & D programs cannot do without using quantitative methods when the objective is to evaluate the economic impact of the implemented policies, especially, when the macroeconomic effects are being questioned. A major reason for this is that any policy has pervasive effects so that its global impact can only be evaluated by implementing the causal chain of the intricate interrelations between economic aggregates which are directly and indirectly affected by

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[1] Bibliometrics and technometrics may be regarded as the two distinctive components of scientometrics. For an overview of methods and techniques in this field, cf. Van Raan (1988).

the measures. Although models only give a simplified representation of reality, they can offer useful guidelines regarding the design of public policies, emphasize their counterperforming effects and allow us to obtain a structured evaluation of their global incidences.

A facet worth being also looked into are the links between the main components of research. So far, there has only been little evidence of the scope of relationships between fundamental research, applied research and experimental development. Yet, some studies have emphasized the leading role of fundamental research to promote R & D investments and to stimulate productivity growth[1]. These results need further confirmation and call for in-depth analyses. The properties of each of these components are not similar while all these research categories apparently pursue the same objective : improving knowledge. But the incentives are largely different. If knowledge can be assimilated to a public good, experimental development is less of it and basic research is more of it. If knowledge is a same objective, knowledge production from basic research is more generic than the output of experimental development. And so on. Applied research is situated at an intermediate stage between basic research and experimental development and, as such, has intermediate properties. We can speak about the economic impact of R & D expenditures as a whole but so far, we have not been able to draw clear-cut policy prescriptions about the real economic impact of each of its components. When countries restraint public, and in some cases, even private resources to fundamental research in order to meet budgetary constraints, it does make sense to ask questions about the economic impact of fundamental research.

A further important point concerns the usefulness of qualitative assessment results as inputs for quantitative evaluation. The quantitative methods are complementary to, not a substitute for, the qualitative techniques. The latter can helpfully play a central role in the implementation of scenarios, in the identification of priorities for quantitative evaluation and in their calibration. For example, a measurement of the primary economic impacts or of some technological parameters could be evaluated by means of qualitative methods and adequately normalized to be included in a more general economic quantitative model to assess all direct and indirect effects. Such a process has the advantage of focusing the experts attention on some key variables depending on their technical competences and thus reduces arbitrariness and biasness. Since both quantitative and qualitative methods are imperfect, they should be simultaneously used so as to overcome their own limitations. The multidisciplinary character of technology

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[1] Cf. for example, Link (1981), Mansfield (1980,1991), Cunéo (1984), Griliches (1986) and Jaffe (1989).

assessment calls for the creation of real interfaces between the multiple operative fields, each of them contributing an original piece to the evaluation process.

A final issue concerns the spatial impacts of technological change. The impact of R & D programs is not spatially neutral. In the hypothesis that they really promote technological ability at the European level, there is a risk that they only benefit the technologically more advanced regions. In this case, it could be concluded that public funds are optimally used and, hence, satisfy the criterium of effectiveness. Yet, if less favored regions are crowded out of the allocation process, the policy will generate perverse effects by increasing regional disparities and, hence, will undermine both stability and equity objectives. As pointed out by Mowery (1990), the long-predicted decline of the West has failed to materialize. The real challenge for Europe is perhaps to ensure convergence in diversity in order not to slip into Cardwell's Law. Indeed, the European political fragmentation is at the source of its technological creativity, since according to Cardwell's Law, no nation has been technologically very creative for more than a historically short period. In other words, the historical European technological advantage has something to do with the spatial dynamic, the European technological center of gravity moved over time. So, the impact assessment of European programs cannot disregard what the main objective for the participation of a country must really be depending on its own technological constraints. Hence, any evaluation of the economic impact of R & D programs will give asymmetric results between the technologically more advanced countries and the technologically less advanced countries. In the lagging regions, implementing policies aimed at developing innovative products may not be very effective. In most cases, these regions do not enjoy a comparative advantage in R & D activities, and the stress should therefore be put on the transfer of technology and the acquisition of knowledge in the fields of technology and management. Besides, the impact assessment should be designed in such a way as to highlight the spatial spillover and spinoff effects of R & D policies. The measurement of spillover and spinoff effects is a major factor in impact evaluation. Such effects are three-dimensional : they materialize across sectors, they are distributed over time and they diffuse throughout space. If a technology policy is successful in regionally fostering technological capabilities, the programs may serve to increase the overall international competitiveness of lagging regions or to give them the knowledge infrastructure required to reduce regional imbalances. So, spatial effects are a main component of the efficiency degree of a technology policy and, as such, cannot be disregarded when the evaluation objectives are set.

These general issues show that a thorough understanding of the economic intricacies of science and technology is still a long way off. There are more open questions than answers and there are large unexplored horizons for future researches.

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Part One

Econometric Modelling of Technological Change

Chapter 2 - Econometric Modelling and Technological Change : A Review of Issues

John Bradley and Karl Whelan

1. Introduction

One embarks on a review of the economics and econometrics of technical change with a certain amount of trepidation. Even a cursory examination of the vast literature that has grown up around this area makes it clear that not only is it an "unfinished" subject in a process of constant renewal and extension, but in addition there are major differences in the basic approaches, attitudes and paradigms that researchers bring to bear on the subject. No short review of issues can attempt to be both comprehensive and impartial, but rather must be selective and biased, the point of view of the reviewer being heavily conditioned by his or her previous research orientation. For the record, we approach this subject from a background of research and policy applications using conventional large-scale macroeconometric models of a neoclassical/Keynesian kind where, whatever about the many other problems with such models, the manner in which they handle technical progress certainly leaves very much to be desired. This may appear to be the more abstract end of the market, but it is the theoretical and empirical context from which much practical evaluation of the effectiveness of R&D draws its roots. Hence, we are not too apologetic if we appear to be straying far from practical matters.

An insight into "high theory" difficulties in this area is conveyed by the article on technical change in the New Palgrave Dictionary of Economics (Metcalfe (1987)) where it is claimed that within the development of economic thought, the study of technical change has never played a major role. More specifically, Metcalfe, writing in the mid-1980s, summarised the position as follows:

> 'By the time Robbins came to write his methodological characterization of the neoclassical scheme in 1932, not only had technical progress been handed over to the psychologists and engineers, but the very nature of the questions posed by economists had changed fundamentally. Gone was the emphasis on accumulation and progress and in its place stood the analysis of the allocation of given resources under given technical conditions and, moreover, subject to a definition of competition as a state of equilibrium quite incompatible with the increasing returns implications of the division of labour.'

Metcalfe asserted that the importance of technical change has been handled in a piecemeal, empirical fashion with little attempt to reintegrate the phenomenon back into the formal framework of accumulation and structural change. What is more, very little in Keynesian theory and the rise in the 1950s of empirical macroeconometric policy and forecasting models would require any change to the above generally negative evaluation. However, the recent advances in "new" growth theory (associated with Paul Romer and others) have weakened the force of his criticism and if Metcalfe were writing to-day rather than six years ago he might not have been so pessimistic.

While the economic profession's major theorists develop and refine their general encompassing approaches to technical change, much practical empirical work takes place in the lower theoretical foothills, in the shadows of the giants. In many cases, this work can be clearly identified with some particular "school" such as neoclassical, Kaldorian, regulationist, evolutionary or "new" growth and must be interpreted within specific limitations of the approach from which it draws its theoretical and empirical relevance. This provides the rationale for our Sections 2 and 3 where we give a brief overview of the theoretical frameworks of neoclassical and alternative approaches to the analysis of growth and technical progress. We intend these two sections to provide a flavour of the theoretical background to the econometric research which we review in Sections 4 and 5. The empirical work is examined under two broad headings. In Section 4 we look at applications strictly within the theory of the firm, i.e., where the macroeconomic context in which the firm operates is ignored. In Section 5 we look at economy-wide macroeconomic applications, with specific references to macroeconometric and computable general equilibrium models.

Finally, in Section 6 we attempt to take stock of what has been achieved to date from econometric applications and what might be the likely developments to be expected in the next few years as the "new" growth theories, together with theories of endogenous technical progress, pass from the conceptual stage, through empirical testing, to the stage of incorporation into operational policy models.

2. Growth, Technical Progress and Neoclassical Theory

2.1. Neoclassical Growth Accounting

The starting point for our discussion of technical progress is the neoclassical theory of the firm. Neoclassical economic theory sees the firm, not as a collection of individuals or groups co-operating and bargaining to produce a mutually satisfactory outcome, but rather as a share-holder-controlled production function which is operated in such a way as maximizes profits. The production function describes a way of turning two or more types of inputs into the firms outputs and in the classic case of perfect competition, where the prices of the firm's inputs and outputs are beyond its control, the only decision made by the firm is the choice of a profit-maximizing level of production with a cost-minimizing combination of its inputs. Technical progress is introduced into the theory of the firm in thc following manner. The firms production function is

$$(1) \qquad Y = A(t)\,F(K, L)$$

where K and L are capital and labour inputs and A (t) is a variable called total factor productivity (TFP) which represents the state of technology. Within this formulation, technical progress means an increase in TFP. This is clearly a very wide definition since it means that technical progress consists of anything that, for a given level of factor inputs, can increase output, e.g., increased efficiency of capital inputs, increased labour quality, improvements in business organization, etc. However, although technical progress improves the firm's productive capacities, within this formulation it is a force that is purely external to the firm and does not have to be paid for.

Despite the obvious problems associated with applying the theory of the firm at an aggregate level, Solow (1957) described the role of technical progress within the economy by assuming that there existed an economy-wide production function of the form (1). The essentials of Solow's neoclassical theory of economic growth were this production function and a simple model of capital accumulation. Given this formulation, we can assess the contribution of technical progress to economic growth in the following way. Taking derivatives with respect to time gives

$$(2) \qquad \frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + A\,\frac{\partial F}{\partial K}\,\frac{\dot{K}}{Y} + A\,\frac{\partial F}{\partial L}\,\frac{\dot{L}}{Y}$$

Assuming perfect competition in factor markets and constant returns to scale we get

$$(3) \qquad \frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + \alpha\,\frac{\dot{L}}{L} + (1 - \alpha)\,\frac{\dot{K}}{K}$$

or

$$(4) \qquad g_Y = p + \alpha\, g_L + (1 - \alpha)\, g_K$$

where α is the labour share of output, g_Y, g_K, g_L are the growth rates of output, capital and labour respectively and finally p denotes the growth of total factor productivity, known also as the Solow residual.

Quantitative growth accounting exercises such as those carried out by Denison (1962) used this framework to analyse the main components of the rate of economic growth and consistently found the Solow residual to be large and positive. This work suggested that technical progress constitutes a significant part of the process of economic growth and helped indicate to neoclassical economists the importance of technical progress. Thus, the Solow-Denison approach, while failing itself to explain economic growth adequately, did provide an important impetus to both the creation of neoclassical theories of technical progress and to empirical studies of the topic.

2.2. Real Business Cycle Theory

More recently, New Classical economists have effectively abandoned their monetary business cycle theory based on adding information imperfections to neoclassical market-clearing models (Lucas (1972), (1973)) due to the theory's inability to fit the data adequately (see Barro (1989)), and have turned to the neoclassical growth model, previously seen as describing long-run phenomena, to explain also the business cycle (Long and Plosser (1983), Plosser, (1989)). In the theory of real business cycles, economic agents solve an intertemporal utility maximization problem subject to the constraints described by the economy-wide production function and capital accumulation equations of the Solow model. A positive shock to technical progress increases the marginal product of labour and thus the real wage and this prompts an increase in consumption and a reduction in leisure. The business cycle is thus caused by individuals rationally and optimally altering their levels of labour supply and consumption in response to large random fluctuations in the rate of technical progress.

Advocates of real business cycle theory have used the behaviour of the Solow residual as empirical evidence to support their view. The residual, representing technical progress, turns out to be highly correlated with output growth and this is put forward as evidence for the view that large swings in the rate of technical progress are the primary cause of the business cycle. This interpretation of the statistical correlation has, however, been strongly challenged. The interpretation of the measured Solow residual as representing exogenous technical progress would appear to be unsatisfactory for two reasons:

(i) Imperfect Competition: The interpretation of the residual as representing technical progress depends on the assumption of perfect competition. Hall (1988) has shown that if the economy behaves according to imperfect competition then the residual will exhibit pro-cyclical behaviour even if underlying technology is unchanged. The reason for this is that when output expands, imperfectly competitive firms can sell their output for more than marginal cost. Thus, measured output is rising by more than measured inputs and so the Solow residual is increasing.

(ii) Labour Hoarding: The measurement of the Solow residual does not take account of variations in work effort. During recessions, firms often keep under-utilized workers on so not to loose their firm-specific human capital. Thus measured productivity falls even though the rate of technical progress has not.

Furthermore, the notion of recession as being periods of technical regress lacks credibility. To quote Mankiw (1989):

> Recessions are important events; they receive widespread attention from policy-makers and the media. There is, however, no discussion of declines in available technology. If society suffered some important adverse technological shock, we would be aware of it. My own reading of the newspaper, however, does not lead me to associate most recessions with some exogenous deterioration in the economy's productive capacities.

It seems, then, that to attribute the vagaries of the business cycle to random fluctuations in the rate of technical progress is probably a mistake. Furthermore, the Solow residual does not represent a particularly accurate description of the short-run level of technical progress and should probably be averaged out over cyclical fluctuations before it is considered a useful indicator. More seriously, these considerations indicate that, while the neoclassical theory of economic growth may be a useful tool for thinking about the dynamics of economic growth, the macro-economic background into which it inserts the theory of the firm is an unsatisfactory one for discussing the role of technical progress in the economy.

2.3. Endogenous Technical Change

We have seen that neoclassical growth theory and, its offshoot, real business cycle theory, have invoked technical progress as a major influence on economic activity. However, a major weakness of these approaches is that they make no attempt to explain the long-run causes of technical progress, or reasons for short-term fluctuations. Indeed, the theories could easily be accused of being internally inconsistent since the private maximizing behaviour that generates everything else in these models plays no role in generating technical progress. Thus, both theories simply reduce to invoking unexplained exogenous factors and assigning economic growth to them and are relatively empty both in explaining the principal reasons for economic growth and in offering useful policy guide-lines. This section looks at the attempts that have been made to explain technical progress, and thus the process of economic growth without resorting to invoking "exogenous" factors.

Generation of External Economies

One strand of literature has endogenized technical progress simply by assuming that it is an externality generated by the accumulation of one of the factors of production. Thus, Arrow (1962) assumed that capital accumulation was directly responsible for technical progress through "learning by doing" effects. In an important recent paper, Lucas (1988) has presented models which assume that it is human capital (i.e., labour skills accumulated through education and training), which creates the external effect of technical progress. To justify this model, Lucas refers to the work of Jacobs (1986) on the economic role of cities:

> If we postulate only the usual list of economic forces, cities should fly apart. The theory of production contains nothing to hold a city together. A city is simply a collection of factors of production - capital, people, land - and land is always far cheaper outside than inside .... It seems to me that the "force" we need to postulate to account for the central role of cities is ... the "external human capital" I have postulated to account for certain features of aggregative development.

Lucas points out that this approach to economic growth has the significant advantage of being able to explain an important fact which the traditional neoclassical models could not: there are great pressures for immigration into high-income countries because immigrants can obtain higher wages, but a comparatively small amount of capital flows to low-income countries, despite the fact that the neoclassical model would suggest that lower levels of capital per worker in less developed countries would imply a higher marginal productivity of capital. Once the external effects of human capital are introduced, capital will continue to have a higher marginal productivity in the high income countries. As long as people of every skill level are more productive in higher human capital environments, there will always be pressure for immigration into high income countries. However, while the Lucas approach provides insights into the nature of the economic growth process, and while the "human capital externality" approach is an improvement on the "exogenous technical change" assumption, it is ultimately unsatisfactory in that it does not outline explicitly how and why this externality comes about.

R & D Generated Technical Progress

Recently, Romer (1986,1990b) and Grossman and Helpman (1989,1990) have developed theories of endogenous technical progress which are more strictly within the neoclassical tradition. These theories assume that technical progress is produced by a research and development (R & D) sector of the economy and that, like all other phenomena in their models, it arises as a result of profit-maximizing behaviour. Probably the key contribution to this literature is Paul Romer's 1990 paper on *Endogenous Technical Progress* which is based on the following ideas:

(i) Technical change takes the form of the introduction of new producer durables for use in final goods production and the use of these new goods does not affect the productivity of existing types of capital. Thus, final output is represented by the following adaptation of the Cobb-Douglas production function

$$(5) \qquad Y = H_Y^{\alpha} L^{\beta} \sum_{i=1}^{A} x_i^{1-\alpha-\beta}$$

Here, H_Y and L represent human capital used in final goods production and unskilled labour services respectively, while the x_i s represent the different varieties of capital goods. Output is an additively separable function of all the different types of capital goods so that one additional dollar of x_i has no effect on the marginal productivity of x_j.

(ii) The number A, indicating the range of available producer durable goods, depends on the level of public information concerning the design of these goods. The stock of designs evolves according to

$$(6) \qquad \dot{A} = \delta H_A A$$

where δ is a productivity parameter and H_A is human capital used in research. This formulation suggests that the larger the stock of designs and knowledge is, the higher the productivity of the an employee of the research sector. This is based on the assumption that information is a non-rival good i.e. that anyone engaged in research has free access to the entire stock of current knowledge. To quote Romer:

> A college-educated engineer working today and one working 100 years ago have the same human capital, which is measured in terms of forgone participation in the labour market. The engineer working today is more productive because he has the advantage of all the additional knowledge accumulated as design problems were solved during the last 100 years.

Thus, researchers play a crucial dual role in the economy. Firstly, by producing new designs they enable the production of a new good that can be used to produce output and secondly, the new design increases the stock of public knowledge and, thus, the productivity of human capital in the research sector. This is the crucial non-convexity which allows continuous economy-wide increasing returns to scale to occur.

(iii) Romer's model is completed by the specification of the R & D and producer durable sectors of the economy. Researchers sell their designs to monopolistically competitive firms, and the producer of each x_i sells the newly-designed product to final good producers. For simplicity, the model has a symmetric structure, implying that all the durable goods are supplied at the same level, $\bar{x}$.

Capital is defined so that one unit of durable goods is equal to η units of capital. Aggregate capital can then be written as $K = \eta A \bar{x}$, so, using equation (5), we can write output as

$$(7) \qquad Y = H_Y^{\alpha} L^{\beta} A \bar{x}^{1-\alpha-\beta}$$
$$= A^{\alpha+\beta} H_Y^{\alpha} L^{\beta} K^{1-\alpha-\beta} \eta^{\alpha+\beta-1}$$

We see then that the model is one of constant returns to scale in the primary inputs, (H_Y, L, K) but increasing returns to scale once the public knowledge parameter A is included. Thus, in this model, it is the public knowledge generated by R & D activities which, by continuously increasing the marginal productivity of all factors, is responsible for unbounded growth.

What, then, are the welfare properties of this model? When the balanced growth path is solved for, in which K, Y and A are all growing at the same rate, it is found that this is a sub-optimal equilibrium growth rate, with too low a level of human capital being devoted to research. This occurs for two reasons. Firstly, although a new design helps raise the productivity of all future researchers, the inventor of this design does not obtain remuneration for this benefit which he is passing on since, in Romer's terminology, the knowledge generated by the design is non-excludable. Secondly, the design is purchased by a sector that engages in monopoly pricing, thus forcing another wedge between the social product of the design and the market compensation. Thus, the social optimum level can only be achieved by subsidizing the accumulation of A.

The model of endogenous technical progress described here shows that neoclassical growth theory has made significant progress in recent years by moving from a situation in which exogenous technical progress and population growth were all that determined growth to one where the nature of the interactions between R & D, generation and production of new technologies, human capital formation and economic growth can all be discussed within a neoclassical framework. The Romer model also expands on the "human capital externality" insight of Lucas by indicating that countries which have high levels of human capital can devote higher levels of resources towards the generation of new technologies to complement old technologies and thus continuously increase the productivity of their workforce. Thus the model has a clearly identifiable positive externality associated with human capital.

Creative Destruction

Romer's theory of economic growth is centred around the assumption of the positive external effects that accompany the production of new designs. However, it ignores any possible negative externalities. This possibility, labelled "creative destruction" after Schumpeter, has been addressed by Aghion and Howitt (1990, 1991). Romer's theory explicitly assumes that all capital goods are essentially complementary whereas Aghion and Howitt focus upon the substitutability of capital goods and the introduction of a new design brings with it the negative externality of the elimination of the monopoly rents of the previous innovator. In Aghion and Howitt (1991), the effects of innovation on the labour market are also considered. In this model, the introduction of an innovation to a sector leads to the sector requiring a different type of specialised labour from that previously used and whether unemployment is increased or decreased by the introduction of productivity-enhancing innovations then depends crucially on whether the forces of complementarity are stronger than those of creative destruction.

2.4. Open Economy Issues

The literature on endogenous technical progress adds further force to two of the important insights of modern trade theory. Firstly, the theory underlines the common theme that a policy of laissez-faire may allocate too low a level of resources to R & D devoted to development of new technologies. The policy advocated as optimal is thus the subsidization of R & D activities. The most obvious way to implement this policy may be to subsidize and support those so-called *strategic* sectors which are heavily R & D oriented and which are most likely to generate positive externalities throughout the economy. It may indeed prove that the most effective ways of supporting these industries could involve protectionism or other less direct methods of flouting trade agreements. Thus, the "new growth theories" can be considered compatible with the modern theory of strategic trade policy discussed in Krugman (1986).

However, the theory can also be seen to uphold the results of greater potential gains from trade due to increasing returns, than those postulated in the traditional Heckscher-Ohlin-Samuelson theory which assumed perfectly competitive markets. The nature of the increasing returns in the R & D sector of the economy postulated by Romer is a very obvious one and implies significant room for gains from trade (Rivera-Batiz and Romer (1991)). With an R & D sector decribed by equation (6) above, we obtain a result that, unlike in the classical theory of trade, there are gains from trade even between identical economies. To quote Romer (1990c):

> Because there are no limits to the use of nonrival goods, there is no reason to have engineers in the different countries solve the same problem twice. It would be feasible for the engineers of one country to supply the whole world with the same level of nonrival goods as was produced using both sets of engineers in isolation .... a robust result is that trade in goods between similar countries will lead to a welfare-improving reallocation of resources used in research.

There are, however, problems with this approach in that it is not obvious why, even if there were significant barriers to trade in finished goods, there would be a large amount of engineers spending their time in international isolation on the same research topics as foreign counterparts. Do trade barriers have significant effects in retarding the exchange of intellectual ideas and cross-national co-operative research ventures? These problems suggest that there is significant work yet to be done on the nature of international diffusion of new technologies.

What then of smaller countries whose own expenditures on R & D are unlikely to have a significant impact on their economies? A clear implication of new growth theories is that free trade is likely to be welfare-enhancing for these countries, not just due to the *level* effects invoked in traditional trade theory due to differing factor endowments, but also because of *rate* effects associated with being able to acquire the new technologies developed abroad. Indeed, these considerations may imply important externalities associated with exporting and importing activities such as in Grossman and Helpman (1991) where technical knowledge spreads through international commodity traders. This insight also complements the discussion of the positive externalities associated with a policy of export-lead growth which has taken place within the CGE/Development literature (De Melo and Robinson (1990)). Another important issue concerns the effects of DFI by technologically advanced multinational enterprises and whether these investments have strong positive technological externalities: something which many industrial policy-makers worldwide would seem to believe given the high level of competition for attracting high-tech foreign investment (Cantwell (1989)).

3. Growth and Technical Progress: Alternative Approaches

3.1. Evolutionary Theories

Neoclassical theory is essentially static and is primarily concerned with issues of resource allocation within an economy at a single moment in time. However, technical progress is, by definition, a dynamic and evolutionary process. It is hardly surprising then that the issue of technical change is one which plays a central role in criticisms of orthodox theory by adherents of non-neoclassical paradigms. One of the most important of these is the "evolutionary" approach which questions the static underpinnings of neoclassical theory. This static approach has analogies with physics, whereas a more appropriate analogy is held to be with biology. Evolutionary economics takes much of its inspiration from Schumpeter, who saw economic activity as part of a broader context of social change:

> The essential point to grasp is that in dealing with capitalism, we are dealing with an evolutionary process ... Capitalism is by nature a form or method of economic change and not only never is, but never can be, stationary ... The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumer's goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates (Schumpter (1943)).

A major modern exposition of evolutionary ideas is contained in Nelson and Winter (1982). This approach explicitly rejects neoclassical views on the key concepts of rationality, the firm and the production function. Neoclassical theory assumes that all economic agents are rational in the sense of being able to use all possible information required to make optimal decisions. Evolutionary theory invokes the work of Herbert Simon (1959, 1965) and assumes that people are boundedly rational: since most decision problems are too complex to comprehend fully, people satisfice, in the sense of making decisions that, while they are not "optimal", may be quite adequate. Thus the firm is not a profit-maximizing machine, but rather a behavioural entity which is profit-seeking.

The nature of productive decisions are thus radically different in neoclassical and evolutionary approaches. In neoclassical theory the production function defines the full set of production techniques which is currently available, the firm is aware of all of them and chooses the optimal one; technical progress consists of a change in the production function and thus the introduction of new ways of production which were previously impossible. Alternatively, in evolutionary theory, there does exist a set of possible production techniques but only a very limited number of these are known to firms. To quote Nelson and Winter:

> What does one mean when one says that a production possibility exists even though no one is using it or has ever used it?

Nelson and Winter's firms, being boundedly rational, only know their own pattern of productive activities that they have been able to follow in the past. However, they are profit driven and thus, particularly if profits drop below certain critical levels, engage in *search* by looking at the efficiency of techniques locally similar to those they are currently using as well as *imitation* of other firms techniques in attempts to find new production regimes which are more efficient. If these search and imitation activities are unsuccessful, the current production regime is maintained. This type of evolutionary approach can be modelled using Markov processes and Nelson and Winter (Chapter 9) claim that these models provide more satisfactory explanations of the data on economic growth than the Solow-Denison approach does.

We see then that, in evolutionary theory, technical progress is not a phenomena that can be disentangled and declared exogenous from the more general process of choice of production techniques. Evolutionary theorists, however, do accept that not all technical progress is a result of this continuous small-scale search and imitation activity and that, often significant scientific discoveries are capable of producing "revolutions" in technical progress. Thus, Dosi (1982, 1988a) makes an analogy to the Kuhnian philosophy of science. "Normal" technological change consists of search and imitation activities which produce smaller improvements on bigger, revolutionary technological improvements and so technological improvements are grouped in "*technological paradigms*", historical examples of which would include steam technology, electricity and semi-conductors. An important theme in evolutionary theory thus concerns the "evolutionary selection process" by which new technological paradigms emerge and replace older paradigms, and whether the emergence of new paradigms is a random process or whether diminishing returns to old technologies heats up the search for a new paradigm, thus implying a sort of long-wave theory of technological innovation.

Evolutionary theory also implies a different view of the R & D process. Neoclassical approaches to endogenizing technical progress tend to assume that technical progress is simply something produced in a rather mechanical fashion by R & D expenditures. However, within the evolutionary approach, innovation and R & D are just examples of the uncertain "search" process: periods of successful search can be followed by periods of unsuccessful search since often firms engaging in exploratory R & D do not know exactly what type of new production technique they are searching for and so the end results are likely to be very uncertain. An important part of this research programme has concerned itself with describing the nature of the international R & D process (see, for example Dosi (1988b) and Kay (1988)).

3.2. Kaldorian and Regulationist Growth Theories

It was Myrdal's observation that the notion of an "equilibrium" towards which regions were converging was not the most relevant way to start the analysis of regional economic growth [1] and that, contrary to neoclassical growth and trade theories, the opening up of trade did not always benefit participating regions and reduce differences in comparative costs (Myrdal (1957)). On the contrary, the processes of regional growth are characterised by self-reinforcing mechanisms which tend to further magnify any initial tendencies to divergence (Arthur (1987)).

Dissatisfaction with the implications of classical or neoclassical growth theories was articulated in a series of papers by Kaldor (Kaldor (1966, 1970, 1977, 1981), who suggested economic mechanisms through which one region, benefiting from a growth

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1 In the following we use the term "region" to include regions within a national economy and countries which have economies that are regional in an international sense.

advantage relative to others, may keep that advantage permanently and thus prevent the convergence of all regional growth rates. Dixon and Thirlwall (1975) is an attempt to encapsulate the central ideas of Kaldor into simple analytic models, which are usually small and are forced to abstract from many of the complications of the real world. However, they claim to capture the *essential* economic insights needed to understand regional growth processes and are quite critical of alternative models taken from the "orthodox" (usually meaning "neoclassical") approach to the analysis of growth and technical progress.

A key element in the Kaldor model is the Verdoorn law, which posits a relationship between the growth of labour productivity (r_t) and output growth (y_t). Taking a linear approximation,

$$(8) \qquad r_t = r_a + \lambda\, y_t$$

where λ is a constant parameter (the Verdoorn coefficient) and r_a represents autonomous productivity growth or technical change.

The Verdoorn law is a vital component of the Kaldor model since it can make growth circular and cumulative: any increase in the rate of output growth raises the growth of labour productivity, lowers the growth of domestic prices (through a cost mark-up model), raises export growth (through greater competitiveness), and thereby increases output growth. For example, if for some unspecified reason a region obtains an advantage in the production of high income elasticity-type goods (perhaps through some technical or educational advance), its export-led growth rate will rise above other regions; through Verdoorn's law, this leads to higher productivity, lower domestic prices, further increased exports and still higher output growth. This is the essence of the Myrdal-Kaldor view of circular and cumulative causation.

There has been much controversy in the literature about the Verdoorn law, one of the few relationships in the alternative growth tradition that has been subjected to extensive econometric testing. For example, the direction of causation is anything but clear: higher output growth may indeed stimulate labour productivity but the econometric estimates of the Verdoorn coefficient are probably seriously biased due to simultaneity. Econometric estimates of the Verdoorn relationship have been unstable (Kennedy (1971): Chapter 7) and this calls into question its use as the "linchpin" of Kaldorian models. In particular, the high and unstable inflation of the post-OPEC oil price shocks has caused massive shifts in relative prices which were not characteristic of the pre-OPEC period during which the Verdoorn law was developed and used. Also, technical progress, (r_a in equation (8) above) is an unexplained parameter, as in the neoclassical theories.[1]

Another development which both draws from and extends Kaldor's insights is the French regulationist school (Boyer and Petit (1986); Boyer (1989)). Boyer's closed economy model consists of the following behavioural relationships:

(i) an augmented Verdoorn-type productivity relationship

(ii) an investment equation driven by a demand-side accelerator mechanism and a supply-side profit term

(iii) a Kaldorian-type consumption function, distinguishing between wages and profits

(iv) a real wage equation, driven by productivity and a Phillips curve.

So far these models have been applied mainly to closed economies, although Bertoldi (1990) is a recent extension to open economies. They tend not to be estimated econometrically, presumably due to the very long time-scale over which they are used in exploring stylised epochs of capitalist development.

Clearly the Kaldorian and Regulationist models explicitly reject orthodox neoclassical theory, building instead on the Verdoorn law as an alternative to theory of the firm. In fact a "Verdoorn type" relationship can be examined from within the neoclassical theory of the firm as a by-product of joint factor demand equations and can be shown to be a special case of these demand equations (Katz (1968); Berndt and Khaled (1979); Bradley and Prendergast (1986)). Thus, in a sense Verdoorn's law can be encompassed within the neoclassical theory of the firm, micro-foundations to it can be established (along the lines of, say, Lucas (1988)), and many of the reasons for instability in estimation can be investigated.

4. Econometrics, Technical Change and the Neoclassical Theory of the Firm

We have seen that an important focus for the literature on technical change has been the attempt to explore technical progress and the growth of total factor productivity within the neoclassical theory of the firm. The very earliest attempts to apply econometric techniques to the measurement of technical change (Solow (1957); Denison (1962)) used

[1] Bouvy and Bradley (1988) is a critique of Kaldorian models from a neoclassical and regional macroeconomic perspective.

a simple two-factor Cobb-Douglas production function with disembodied technical change represented by a time trend (equation (1) in Section 2 where the function A(t) is replaced by exp (γ_t), γ being the constant rate of disembodied technical progress). In the light of accumulated research on more sophisticated functional representations of production and cost functions that were developed during the 1960s and 1970s, econometricians now have available much more powerful tools than those used in the highly simplistic approach of Solow and Denison's early pioneering work. The key restrictive assumptions in that work were the added-value Cobb-Douglas functional form, constant returns to scale and perfect competition.

Nevertheless, these early results were quite startling, even if somewhat less credible today. What Solow showed, using his simple Cobb-Douglas approach, was that about three-quarters of US economic growth was due to increased efficiency in the use of productive inputs and not to the growth in the quantity of resource inputs. The implication was that economic growth was largely a *residual* process. Denison's subsequent work attempted to refine the definitions and measures of factor inputs, reducing the size of the residual somewhat, but maintaining the mainly residual finding.

The applied econometric research agenda for the 1960s and 1970s focussed on generalising the functional forms used in production and cost functions, thus relaxing the severe restrictions imposed by a two-factor Cobb-Douglas technology (i.e., disembodied technical change and a unitary elasticity of substitution between capital and labour). An early generalization was the CES (constant elasticity of substitution) function (Arrow et al (1961)), which permitted the introduction of biased (or factor embodied) technical change (Kalt (1978)) and allowed the (constant) elasticity of substitution to vary between zero (a Leontief technology) and one (the Cobb-Douglas case).[1]

The pace of new developments accelerated during the early 1970s as a result of the need to analyse the supply-side consequences of the first OPEC oil-price shocks (Fuss and McFadden (1978)). There was now an urgent need to incorporate multiple factor inputs (e.g., capital, labour, energy, materials (KLEM), with possible further disaggregation of each) and this required the development of more flexible functional forms such as the translog, generalised Leontief, generalised Box-Cox, and also methods of "bundling" factors in, for example, nested CES-CES functions. In addition, a much richer agenda of factor embodied technical change parametrizations became available for investigation and testing, as did vintage capital stock models.

1 Kalt found that technical change in the US over the period 1929-1967 was almost entirely labour saving, a result consistent with theoretical models of equilibrium growth and with practical policy application to the issue of "capital shortage" (Kalt (1978)).

With such a wide range of functional forms available, empirical investigators make choices on the basis of ease of estimation, goodness of fit, agreement with the basic postulates of demand theory, and robustness. So, for example, the difficult non-linearities involved in the factor demand equations that are derived using the (primal) production function were less serious in the (dual) cost function, leading to wide applications of the dual approach in empirical studies (Berndt (1981)). However, the primal approach continues to dominate applications within empirical macroeconometric policy models.

The method of generalising the incorporation of technical change from the Cobb-Douglas to flexible functional forms was developed by Binswanger (1974), who made a clear distinction between constant rates (for use with regression models over short periods) and variable rates (used to derive long-term measures). Since all cost functions contain factor price elasticities and technical change bias elasticities, if both are assumed to be constant parameters they can be estimated simultaneously using regression techniques with time series. However, Binswanger's warning about the dangers of using these constant elasticities out of sample has tended to be ignored by macroeconometric modelers:

> 'Of course, this model cannot be used to extrapolate outside of the short regression period because then the assumption of a constant exogenous rate of bias is tenuous': (Binswanger (1974), page 968).

If the factor price elasticity parameters within the cost function can be estimated from its static form (using cross-section data if available, or by some other means), then the Solow residual method can be used to back-calculate *ex post* measures of technical change bias. This can be regarded as an extension of the original Solow method to flexible functional forms, embodied technical change and bias where, in addition, the obvious crudeness of a time trend as an index of the pace of technical innovation is overcome. Binswanger, using cross-section data for US agriculture, showed that technical progress was labour saving and capital using. Furthermore, these biases were associated with very large changes in factor prices, a possible conclusion being that the direction of technical change may respond only to massive shifts in relative prices.

A pioneering implementation of this approach was carried out by Kopp and Smith (1983), who calculated *ex post* measures of specific innovations in the US steel industry and used these instead of simple time trend proxies to estimate conventional cost functions. They made use of a specially developed linear programming engineering model of steel plants to calculate the price elasticities in the absence of innovation. Using these elasticities, and introducing specific innovations to the manufacturing process in a controlled way, they back-calculated Solow residuals appropriate to each innovation. These were used to construct innovation-specific indices of technical progress which were used to estimate a conventional neoclassical cost function. They found that the neoclassical models of production are indeed good approximate descriptions of complex engineering activities and that technologically explicit indicators of technical change are superior to simple time trends. This conclusion, although interesting, is essentially circular and begs the question as to its policy usefulness in the normal situation where neither cross-section data nor fully specified "engineering process" models are seldom available and all one has is time-series data and the neoclassical production function approximation.

One of the most sophisticated applications of the production/cost function method is the attempt of Berndt and Khaled (1979) to disentangle and measure the separate contribution of technical change, returns to scale and factor substitution in trends in US total factor productivity. Their approach is to place a sufficiently systematic structure on the functional form of returns to scale and technical change so that they can simultaneously identify substitution elasticities, returns to scale and the rate and bias of technical change. This means that the measure of total factor productivity can be fully parametrized, rather than estimated as a residual of growth in outputs minus growth in inputs. The main findings of Berndt and Khaled (1979) can be summarised as follows:

(a) Regardless of the form of technical change, all restrictions of homotheticity, homogeneity and constant returns to scale are decisively rejected by the data [1].

(b) There was some evidence supporting a statistically significant non-neutral bias to technical change towards capital and energy using and labour and material saving. However, the magnitudes of the elasticities were very small.

(c) Estimates of substitution elasticities were robust over alternative specifications of returns to scale, technical change and functional structure.

(d) Estimates of returns to scale and total factor productivity are quite sensitive to model specifications. In the preferred model (non-homothetic and non-neutral), the returns to scale parameter was between 1.2 and 1.25.

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[1] Consider the elasticity of total cost (C) with respect to output (Y) along a cost minimizing expansion path, where P_i represent the factor input prices :

$$\frac{\partial \log C}{\partial \log Y} = \beta + \theta \log Y + \Sigma \psi_i \log P_i$$

Then, the underlying production technology is homothetic if $\psi_i = 0$ for all i and homogeneous of degree $1/\beta$ in inputs if in addition $\theta = 0$. Constant returns to scale in output is obtained when in addition to the above, $\beta = 0$.

These results tend to discredit the early growth accounting literature, which ascribed most of TFP growth to a purely exogenous disembodied technical change. On the basis of their findings, Berndt and Khaled suggested that the Solow residual growth accounting approach, based as it is on constant returns to scale, may result in the confusion of increasing returns (originating, say, through learning-by-doing or other externalities) with a form of disembodied technical change. If it is assumed that such learning is more highly correlated with output growth than with the mere passage of time, then the Berndt and Khaled approach will pick up this effect in terms of measured increasing returns to scale. This forces economists to look into the processes generating increasing returns and positive externalities, the econometric quantification of which will surely provide a rich research agenda for the 1990s.

5. Technical Change and Macroeconometric Modelling

5.1. Neo-Keynesian Macroeconometric Models

In the previous section we examined how the neoclassical theory of the firm has been used to examine the determinants of total factor productivity using econometric techniques. In that approach the factor inputs are taken as exogenous, as are factor prices. However, as policy modellers attempted to grapple with the OPEC-I supply-side shocks, they began to incorporate the new production function developments into their macroeconometric models, and to move away from the *ad hoc* supply-side elements of earlier Keynesian demand-side models. Indeed, leaving rational expectations aside, the only major innovation in macroeconometric modelling during the 1970s and 1980s consisted in the incorporation of theoretically consistent empirical implementations of the neoclassical theory of the firm into otherwise very Keynesian demand-oriented models.[1]

Is it necessary to step outside of the confines of the microeconomic theory of the firm and embrace economy-wide macroeconomics in order to study technical progress? The answer has to be yes, particularly if a better understanding of the wider concept of total factor productivity is to be found, together with the links between sectors and between national economies as explanations of technical change and productivity. In particular, the relatively misleading treatment of technical change seen in the real business cycle approach illustrates the problems associated with discussing this issue without an appropriate macroeconomic structure.

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[1] Good examples are Hickman and Coen (1976) (for the US); Helliwell et al. (1985a) (for the OECD) and (1987) (for Canada); d'Alcantara and Italianer (1982) (for the EC).

The problem is that, while most economic theorists may not like the fact, there is no one unifying approach to studying macroeconomic phenomena. While the Solow-Romer type of neoclassical models may prove suitable vehicles for discussing long-run economic growth, they do not provide us with an adequate description of the short to medium-run behaviour of the economy. Thus, to look at the actual behaviour of economy-wide technical change it is necessary to use conventional macro-dynamic models which can, in particular, separate the consequences of capacity utilisation changes and other short-run disequilibrating mechanisms which affect total factor productivity from the longer-run issues associated with technological change. In this part of our paper we try to describe how macroeconometric models have been used in explorations of technical change, its causes and its consequences for the macroeconomy.

Most modern macroeconomic models incorporate the concept of potential output, around which short-run fluctuations are assumed to occur. A key determinant of growth in potential output is the rate of technical progress. However, despite extensive study of the determinants of technical progress, almost all operational macromodels currently in use for routine policy analysis and forecasting still treat the trend rate of technical progress as an exogenous variable, unrelated behaviourally to any policy instruments or other endogenous variables.[1] Of course, policy analysts are fully aware that public expenditure programmes in physical infrastructure, education and R&D will influence the productivity of private sector factors (Ford and Poret (1991); also many of the papers at this conference). Nevertheless, much of this latter type of analysis is of a relatively *ad hoc* and a-theoretical kind and cannot easily be incorporated into formal sectoral or economy-wide macro-sectoral models.

So, at the end of the day, in conventional macroeconometric models, technical progress (defined as the rate of increase in output if all input quantities as well as the intensity with which they are used are held constant) continues to be represented within the production function by time trends, in spite of Binswanger's warnings. Furthermore, no economic explanation of technical change is offered.[2, 3]

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1 The HERMES, QUEST and INTERLINK models handle technical progress in this conventional way (d'Alcantara and Italianer (1982); Bossier et al. (1988); European Community (1991); Helliwell et al. (1985a)). However, recent research by van Zon (1991) and Meijers and van Zon (1991) has moved beyond the traditional parametric approach, and we shall return to it below.

2 The exogenous time trend need not be a fixed constant, but can have dummy variable controlled shifts if there is evidence that the rate of technical progress has changed. Rose and Selody (1986) assume that such a shift occurred after 1973, after which the trend rate declined. Some work has tried to link technical progress to factor and output prices (Jorgenson (1983)) but we have not seen implementations of this in operational empirical models.

3 In empirical models the simplifying assumptions of Hicks neutrality of Harrod neutrality are usually made, where a steady-state growth path does not exist unless technical progress is of the latter kind

Estimating the rate of technical progress empirically is rendered difficult because of the simultaneous changes in output, inputs and utilization rates. Any rate of technical progress which is extracted from the observed input and output data will depend on other key parameters of the assumed production structure and *vice versa*. To reduce these parameter interactions in estimation, some key *a priori* constraints are usually imposed on the production structure:

(a) constant returns to scale
(b) labour augmenting (Harrod neutral) technical change.

Aside from issues related to technical change, macromodels differ also with respect to a series of other `technical' choices, such as the number and type of factor inputs, the use of vintage or non-vintage models of the capital stock, the type of vintage model (if selected), e.g., putty-clay or clay-clay, and the functional forms implemented for the production or cost functions. So, for example, HERMES uses four factors (KLEM), a vintage putty-clay approach, and a bundled CES-CES or CD-CES production function with disembodied technical change (d'Alcantara and Italianer (1982)). On the other hand, INTERLINK uses three factors (KLE), a non-vintage putty-semi-putty approach, a bundled CD-CES production function and labour-embodied technical change (Helliwell et al (1985a)).

To illustrate the uses to which macroeconometric models have been put, we select two applications. The first uses INTERLINK to examine the productivity slow-down in the OECD after OPEC-I, where the factor intensity and time trend components of TFP growth are carefully disentangled. The second application uses a modified version of HERMES to examine the relationship between information technology, technical progress and employment, and makes an attempt to endogenise explicitly the technical progress parameters previously assigned to time trends.

INTERLINK *and the Productivity Slow-down*

The INTERLINK model was used in the mid-1980s to examine the sources of productivity slow-down in the OECD (Helliwell et al (1985b)). In the post-1973 period, labour productivity in the major OECD countries grew considerably slower than in the

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(i.e., labour embodied). In this case, labour and wages can be measured in efficiency units (the efficiency wage is simply the measured wage deflated by an index of productivity), and the steady state has a clear interpretation. Output and other factor inputs all grow at the rate of labour force growth plus the rate of technical progress and all the proceeds of technical progress accrue to labour in the sense that the real wage grows at the rate of technical progress.

earlier 1962-1973 period, the average annual growth falling by 2.5 percentage points from the pre-1973 to the post-1973 period. Rather than assign the slow-down to an unexplained residual, Helliwell et al used the INTERLINK model to try to reduce any residual factor to as small an extent as possible.

Indeed, an intellectual challenge to Helliwell was Nelson's characterisation of previous attempts to explain the productivity slow-down as showing evidence of "schizophrenia", i.e. one approach characterised by neoclassical production functions applied under the assumption of continuous equilibrium and a variety of other eclectic approaches not relying on a formal analytical framework (Nelson (1981)). Helliwell argued that this schizophrenia was both costly and unnecessary: the OECD macromodel incorporated neoclassical production functions (in order to handle factor price changes consistently) and explicitly modelled disequilibrium mechanisms (in order to handle cyclical behaviour correctly). Hence, it was possible to separate cleanly the effects of factor substitution from those of factor utilization.

The supply-side structure of the OECD model is well known and fully documented elsewhere (Helliwell et al (1985)). The aggregate non-agricultural sector is modelled using a CD-CES bundle (an inner CES capital-energy (KE) bundle combined with an outer, labour-KE, CD bundle).[1] Technical progress is Harrod neutral labour embodied, and two different approaches were adopted. In the first, the rate of technical progress was assumed constant, while in the second, a catch-up model was implemented, where all other OECD countries have rates of technical progress that converged from below to the US level. A flexible putty-clay approach is implemented, where some of the existing capital stock can be "retro-fitted" ex post. Disequilibrium mechanisms modelled explicitly include the effects on capacity utilization of unexpected demand changes, deviations from desired inventory levels and unemployment.

The OECD work confirmed the view that it was both practical and informative to study international movements in the growth of labour productivity in a way that took consistent account of factor substitution, factor utilization and long-run increases in labour efficiency. Thus, it was found that both energy prices and cyclical factors helped cause the 1962-1973 growth of labour productivity to be unusually high and the 1973-1982 growth to be unusually low. With regard to the "normal" rate of growth of labour productivity (i.e., the Harrod neutral technical progress), large international differences were found, ranging from 1.0 per cent per annum for the UK to 4.2 per cent for France (Helliwell et al (1985b), pp 163), and there was some evidence of a decline in the growth

[1] A CES-CES version was also developed when the CD outer function proved too restrictive for the data.

rate of the underlying rate of technical progress other than in the US and the UK. This prompted the development of a simple "catch-up" model, where all countries eventually converge to the US rate which itself is unaffected by the convergence process. Although the "catch-up" phenomenon could be modelled parametrically, Helliwell pointed to the obvious need for further research in this area. More recently, the theoretical work of Grossman and Helpman on issues associated with international trade and technology diffusion may provide econometric modellers with insights into how to address this issue.

HERMES/HERMIT *and Modelling Technical Change*

Probably the most sophisticated attempt to model explicitly aspects of technical change within a fully specified macroeconometric model was that recently carried out by van Zon (1991) and Meijers and van Zon (1991) using the model HERMIT (a modification of HERMES) to investigate the impact of information technology (IT) on macro variables such as employment. First they identified a weakness in the way the vintage putty-clay production mechanisms had actually been implemented in the operational HERMES models. Briefly, while cost-minimising behaviour had been assumed to guide the choice of *ex ante* marginal factor proportions, the scrapping rate of existing vintages was left exogenous for reasons of estimation manageability. However, a crucial mechanism through which IT influences the economy is by increasing greatly the productivity of *new* capital vintages, thereby lowering the profitability of *old* vintages, increasing the scrapping rate, and inducing additional replacement investment. Thus, van Zon's approach nicely complements the insights gained from the modern literature on "creative destruction" (Aghion and Howitt (1990) and (1991)).

Having separated out IT-producing sectors from the original nine-sector HERMES model, and using the assumption that the level of disembodied IT-based technical knowledge is proportional to the stock of "core-IT" capital present within a particular sector of industry, proxies are derived for changes in the level of IT-based technical progress. Furthermore, a distinction is drawn between disembodied technical progress generated by so-called `core-IT' capital and the embodied technical progress associated with the use of `applied-IT' capital.[1]

So, in the words of van Zon (1991) :

[1] Core-IT consists of the IT goods and services that are basic in the sense that their purpose is to process data/information.

'Whereas technical change fell as manna from heaven in HERMES, (..) in a process which is essentially out of the control of producers, in HERMIT one can generate productivity increases by using more IT capital. (..) So, apart from the pleasant effects of IT-based technical change, the unpleasant effects are also accounted for in HERMIT, since technical change itself is no longer a totally free good.'

Using a version of HERMIT based on the original French HERMES model, a series of policy experiments were carried out by van Zon (1991) (e.g., changing the rate of investment in core-IT) in order to compare and contrast HERMES and HERMIT, and to investigate variants of HERMIT with the IT-productivity link switched on and off. From all the experiments a clear message comes through: technical progress increases unemployment both in the short and medium term. However, van Zon stressed that his results should be taken with caution because of the absence of any productivity effect in wage bargaining in HERMES-France.[1]

From the point of view of research into technical progress within an encompassing macroeconomic framework, the lessons drawn by van Zon from his HERMES-HERMIT experiments have a wider validity. Since the notions of technical progress and factor productivity go to the very heart of the mechanisms in a macromodel, great care must be taken with all the relevant macro transmission channels.[2] In particular, it must be remembered that the neo-Keynesian modelling framework is a disequilibrium one and in the absence of clear market clearing tendencies, long-run properties are often difficult to rationalise and interpret.

5.2. Computable General Equilibrium Models

Given the well-known criticisms of neoclassical equilibrium theory as a framework for investigating technical progress (Stoneman (1987); Nelson and Winter (1982)), it may seem strange to contemplate the use of computable general equilibrium models (i.e., computational implementations of relatively static market-clearing models) for the analysis of technical change. Such models have tended to be used mainly to analyse policy issues that involve large changes in relative factor and output prices, such as tariff

[1] Dreze and Bean (1990), pp. 58-59, concluded that wage determination in European countries (including France) differed from the US in that real wages incorporate measured productivity gains quite rapidly in Europe, with short-run elasticities ranging from 0.4 to 0.8 and long-run elasticities close to 1. Measured productivity does not enter significantly in the US wage equation.

[2] In fact van Zon concluded that a purpose-built macromodel was really required for a proper analysis of technical progress, and has proposed a new model, MASTER, to that end (MERIT (1991)).

reforms, taxation reforms, and trade liberalisation (Dervis, de Melo and Robinson (1982)), but have also been used to study the process of industrialization and growth in LDCs (Chenery, Robinson and Syrquin (1986)). However, recent applications of the CGE approach have direct implications for the study of the origins and consequences of technical change.

De Melo and Robinson (1990) examined productivity and externalities in models of export-led growth. In particular, cross-country evidence indicates a positive correlation between the role of export expansion and growth in total factor productivity (TFP), consistent with the hypothesis that export expansion leads to higher TFP growth through exploiting economies of scale, technology transfer, and increasing competitiveness. Since simple growth accounting with conventional models fails to explain these phenomena, de Melo and Robinson generalise the CGE framework to include an externality linked to export orientation, where it is assumed that productivity-enhancing effects are associated with exporting.

This approach overcomes a serious shortcoming of the neo-classical model, in which TFP growth appears by magic, with no link to changes in economic structure or policy choices. Trade-externality models provide a first step towards endogenizing major driving forces generating measures total factor productivity growth in some developing countries. In addition, they illustrate the limitation of simple policy rules aimed at minimizing static efficiency losses, where, in the presence of externalities, there are potential gains arising from policy links to externalities.

In a study of trade liberalisation, Harris (1986) has developed a CGE model of an SOE with economies of scale and imperfect competition. Unlike de Melo and Robinson the scale economies are at the level of the individual plant and hence *internal* to the firm. Because they are internal to the firm, the industries in question are *necessarily* imperfectly competitive. In a study of Canada, Harris showed that the welfare gains from trade liberalization are substantial in the more general model, and of the order of four times larger than the gains estimated from the pure competitive model. Furthermore, the inter-industry pattern of adjustment is also very different.

Finally, the OECD has recently developed a CGE model (GREEN) to quantify the effects of policies designed to reduce emissions of carbon dioxide in the atmosphere (Burniaux et al (1991)). The equilibrium framework is required in order to examine the global welfare implications of different CO2 reduction scenarios, using mixtures of tax and quota policy instruments, particularly in light of the very long time-horizons involved (between 10 and 30 years). In addition to the familiar trend technical progress terms, GREEN is also intended for use as a vehicle for testing the consequences of new technologies, either imposed exogenously on the model or included endogenously in satellite sub-models. The benefits of carrying out the analysis within a model whose economic properties are fully understood within the neoclassical optimizing framework tend to outweigh the disadvantages.

The two "macroeconomic" modelling approaches, macroeconometric dynamic models and CGE models, have useful complementarities. The former have been used when issues of factor utilization and factor productivity are of interest while the latter comes into its own when the very long-run consequences (including income distribution consequences) of exogenous technical progress shocks need to be analysed. With few exceptions, neither modelling approach has tackled the question of technical progress endogeneity satisfactorily, although breakthroughs in this area must now be imminent.

6. Conclusion

The starting point for our paper was the neoclassical theory of the firm and Solow's application of it to explain the processes of economic growth. This approach produced the result that the largest part of economic growth could be assigned, not to growth in inputs, but rather to technical progress. Such a result would hardly have surprised non-neoclassical economists following in the tradition of Schumpeter, since the continuous creation of new technologies was one of the major themes he stressed. However, neoclassical theorists tended to adopt a position where they denied that technical progress was an economic process, declaring instead the large element of economic growth unexplained by input growth simply to be an unexplained residual.

In many ways this approach unnecessarily isolated neoclassical economists from economists using other approaches such as the evolutionary theories espoused by Nelson and Winter, and from the insights which these approaches produced concerning the relationships between R & D and technological progress, international trade and technology diffusion and other important topics. The emergence of the "new growth theories" in the mid-1980s, however, would appear to have moved in the direction of bridging this gap. The theoretical models associated with Romer, Grossman, Helpman and others have put the generation of technological progress back at the centre of neoclassical theories of economic growth, and applications to related areas such as international trade have been made. Indeed, a glance at the material in Dosi et al (1988) suggests that both neoclassical and evolutionary economists may have begun to research a similar set of topics in the areas of technical change, the effects of R & D, international trade and the diffusion of technology, and that perhaps these two approaches can become increasingly complementary. In addition, some of the other "alternative" theories (such as the Kaldor and Regulationist models) may now begin to influence mainstream research in a constructive way.

Since the bulk of econometric work has taken place within the neoclassical tradition, in Sections 4 and 5 we looked at how the theory has been implemented and tested in practice. Two strands were distinguished: the direct applications of the neoclassical theory of the firm in isolation (i.e., a microeconomic framework), and applications within the framework of encompassing macroeconometric or CGE models (i.e., a macroeconomic framework). The former can be seen as a full working out of the original Solow approach, where production functions of greater sophistication gradually replaced the simple Cobb-Douglas function. The motivation for this research programme arose out of the need to analyse the consequences of the supply-side shocks that hit the world economy from the early 1970s, and although the handling of technical progress became more sophisticated, it was still considered as a largely exogenous process.[1]

The second, macroeconometric, strand followed logically from the first and we have seen that the incorporation of the new neoclassical production functions into the supply sides of macromodels greatly expanded the scope of the neoclassical theory for policy and R&D analysis. In particular, the power of macro-dynamic models to disentangle the relationships between short-run TFP movements and long-run technical progress have helped to clarify analysis. However, only very recently have attempts been made to treat the process of technical change as endogenous.

Our review indicates to us that we may reasonably expect a very rapid growth in empirical studies of the causes and effects of technical progress. The new growth theories, with their explicit models of endogenous technical change, are leading to an applied econometrics of technology and R & D. While such work is likely to take place within a microeconomic framework initially, a rapid importing of new empirical models into macroeconomic and CGE models is to be expected, based on the previous pattern of behaviour.

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1 An example of another context where supply-side shocks needed to be examined is provided by the work of Catinat and Italianer (1988) on the analysis of the consequences of the completion of the internal EC market using HERMES. See also Baldwin (1989) for an alternative analysis using the new growth theories.

Of particular interest will be the manner in which economy models will come to be linked together in the future. With the rise of multinational firms and the economic and monetary unification of Europe, national economies will come increasingly to resemble regional economies and technological diffusion will increasingly take place through international movements of production activities.[1] Existing linkage mechanisms between national models, mainly through bilateral trade flows, are clearly inadequate and must be extended to take account of international investment flows and technology diffusion.

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[1] Bradley and Fitz Gerald (1988) provide a production function theoretic method of linking SOEs to the world economy through international plant location mechanisms, a process that has important additional implications for the diffusion of technical progress.

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Chapter 3 - The R&D-productivity relationship in the context of new growth theories : some recent applied research

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1. Introduction

This paper reviews some, mostly recent, studies in the applied modelling of technological change, in the light of current preoccupations concerning the relationship between technology, competitiveness and growth. A traditional approach, which generated a profusion of empirical studies, links investment in R&D to productivity increases. But whereas the early attempts limited themselves to the consideration of the effects of R&D expenditures on the residual with an extended Solow-type production function, the most recent studies have concentrated on phenomena such as spillovers of knowledge between industries or firms, i.e. on indirect effects of technical change. Besides, other technology variables have been taken into account: not just R&D expenditures but also patents or actual innovations. The new results obtained complement the earlier ones and raise new questions at the same time. How important are knowledge spillovers compared to flows of "embodied" technologies and through what channels do the externalities linked to technological knowledge accumulation travel ? Such questions are also those raised by "new" endogenous growth theories (Romer, 1986; Lucas, 1988; Amable and Guellec, 1992).

The role of technology in international competitiveness and growth has (re)surfaced with the "new" theories of international trade. This has led to a more widespread use of technology variables in empirical work on international trade, but also to a few attempts to model endogenous technical change or to incorporate technical change in macro-oriented empirical models. A very partial review of a few studies argues that, tentative as they may be, these first steps could lead to an applied macromodelling of technological change.

2. R&D Expenditures and Productivity Growth

The early growth accounting studies (Solow, 1957)[1] emphasized the importance of technological progress in the process of growth. Most of these studies perceived technical progress as a residual, unexplained by the growth of factors of production. Research and development may have been considered as a contribution to explaining the residual, but it was not regarded as a factor itself until the 1960s. The framework used is simply an extension of Solow's model, with a new factor, the stock of technical capital featured alongside physical capital and labour in the production function.

$$Y = A\, e^{\lambda t}\, K^{\alpha}\, L^{\beta}\, R^{\gamma}$$

with K the stock of physical capital, L labour, and R the stock of R&D is the trend of exogenous technical progress.

Thus specified, the growth rate of output is:

$$y = \lambda + \alpha\, .\, k + \beta\, .\, 1 + \gamma\, .\, r$$

The elasticity of production (or labour productivity or total factor productivity) to R&D may then be estimated. One may use an alternative form, with the rate of growth of total factor productivity defined as:

$$tfp = y - \alpha\ k - \beta\ 1$$

and one can estimate the following relationship:

$$tfp = \lambda + \kappa \frac{\dot{R}}{Y}$$

with :

$$\kappa = \frac{\delta\ Y}{\delta\ R}$$

approximating the change in R with R&D expenditures.

Most of the early studies found a strong positive association between R&D and productivity growth[2], be it at the firm or the industry level. More recent studies often make use of firms (panel) data. Mairesse and Sassenou have reviewed these studies, and the results they presented are summarized in Tables 1 and 2. Most of the studies present an overall cross-section elasticity of production to R&D ranging from 0.1 to 0.3, depending on whether the sample of firms includes specific sectors or not (Table 1). Unsurprisingly,

1 For a survey, see Link (1987) and Maddison (1987).

2 See Link (1987) and Stoneman (1987).

one usually finds that the elasticity to R&D tends to be higher in "high- tech" sectors than in "low-tech" ones. Times series estimates of the elasticity of production to R&D are generally much lower than their cross-section counterparts (Table 2), and the estimations

Table 1. Cross-section estimates of the R&D elasticity

	Sample	R&D elasticity
Minassian (1969)	17 chemical firms	0.26
Griliches (1980)	883 US firms	0.07
Schankerman (1983)	110 chemical and petroleum firms	0.16
Griliches-Mairesse (1984)	77 US firms	0.18
Cunéo-Mairesse (1984)	98 French firms	0.21
Mairesse-Cunéo (1985)	296 French firms	0.16
Griliches (1986)	491 US firms	0.11
Jaffe (1986)	432 US firms	0.20
Sassenou (1988)	112 Japanese firms	0.16

Source: Mairesse and Sassenou (1991).

Table 2. Time series estimates of the R&D elasticity

	Sample	R&D elasticity
Minassian (1969)	17 chemical firms	0.08
Griliches (1980)	883 US firms	0.08
Griliches-Mairesse (1983)	343 US firms and 185 French firms	0.02
Griliches-Mairesse (1984)	133 US firms	0.09
Cunéo-Mairesse (1984)	182 French firms	0.05
Mairesse-Cunéo (1985)	390 French firms	0.02
Griliches (1986)	652 US firms	0.12
Jaffe (1986)	432 US firms	0.10
Sassenou (1988)	394 Japanese firms	0.04

Source: Mairesse and Sassenou (1991).

are much more fragile. Collinearity of R&D capital and other variables with time is usually the main problem. But difficulties related to the time lags involved in the realisation of the effects of an R&D investment must also be considered. One usually assumes that a cross-section estimate gives a long term coefficient while the short term coefficient comes out of time series estimates. The former proposition holds true if one believes that the space dispersion reveals the diversity of possible positions according to a common model. The relationship observed at a specific moment tells nothing about the immediate effects of R&D expenditures on productivity. Short term effects may very well be small. On the other hand, recent work on time series has brought some new light on the distinction between short term and long term relationships. However the information gathered in panel data is most of the time insufficient to fully explore the time dimension.

Recent analyses are not limited to microeconomic data. A few papers have sought to assess the impact of R&D on aggregate productivity. The more recent findings are summarised in Table 3. Studies with sectoral data generally confirm the importance of R&D for technology-intensive activities. Some other studies work with estimates of an aggregate R&D stock, and allow for macroeconomic international comparisons. The reasons for international differences are open to various interpretations: some countries are more specialised in technology-intensive goods than others, or some "national systems of innovation" are more efficient than others. One may notice that the figures from Table 2 are markedly larger than the estimates from micro data (Table 2). Some additional macroeconomic effects of R&D expenditures are present, but problems related to missing variables may appear too. Joly (1992) estimated a production function using pooled time series and cross-section data for five countries (Germany, France, Japan, United Kingdom and the United States). The elasticity of R&D is 0,136.

Table 3. Estimates of the R&D elasticity with aggregate data

	Aggregate manufacturing sector (time series, 1960-1982)				
	Japan	USA	FRG	France	UK
Elasticity of productivity to R&D	0.33	0.08	0.27	0.06	0.06
Source: Soete and Patel (1985)					
	Aggregate manufacturing sector (time series, 1960-1987)				
	Japan	USA	FRG	France	UK
Elasticity of productivity to R&D	0.26	0.15	0.28	0.16	0.09
Source: Guellec (1991)					

Going deeper into detail, some studies have tried to assess more precisely the effects of R&D according to its use and sources. Mansfield (1980) distinguished basic from applied research and found that there was a statistically significant and direct relationship between the amount of basic research carried by a firm and its rate of increase of total factor productivity. It is as if applied research became more efficient when carried out in conjunction with basic research. In fact, the distinction between the two types of research activity may be blurred. Basic research may act as some sort of long-term R&D. Mansfield (1991), using survey results, estimated that the average time lag between academic research findings and industrial applications was about 7 years. R&D is then a device for utilizing academic research for industrial ends. The role of basic research seems to be important, since 10 % of the innovations from Mansfield's survey could not have been developed without the aid of academic research. The significance of this type of research varies widely across sectors, which does not come as a surprise (Pavitt, 1984).

The source of R&D funds is also an important issue, especially when one wants to assess the impact of government-funded R&D. Link (1981), supporting Mansfield (1980)'s findings, made a difference between government-financed and company-financed basic research. Analysing 51 major U.S. manufacturing firms, he found that both types of R&D expenditures positively influenced productivity growth, although the former seemed to have a lesser impact than the latter. However, government-financed applied research was found to have no significant influence on productivity growth. The positive impact of federally-financed basic research had been denied by earlier studies, but Link's findings rehabilitated government-sponsored research.

Making R&D from one's own laboratories and putting the new ideas thus generated in operation in one's own factory is but one way to benefit from technical progress. For many types of activity, it is indeed a minor source of technological advance. For instance, the advantages deriving from an innovation developed in one sector may be passed on to other sectors through the development of more efficient equipment. One of the most important problems is then to take account of incorporated technological knowledge in an adequate way. The measure of inter-industry flows with the help of input-output matrices (Davis, 1988 ; OECD, 1990) is a first step in incorporating indirect R&D into the analysis of technical change. The R&D intensity of a sector is no longer limited to direct R&D, performed within the sector itself, but includes also the R&D embodied in intermediary consumption. The distinction between medium technology and low technology sectors (Hatzichronoglou, 1985 ; OECD, 1986) may be blurred after such modifications (Papaconstantinou and Zaidman, 1991). However, helpful as they are, such devices remain fragile.

Input-Output tables may be used to weigh R&D expenditures and assess the inter-industry flows of technology, but other methods seem preferable. The use of patents data may be a more precise way of assessing flows of technology. Linking R&D to innovations (measured by patents), Scherer (1982) was able to estimate the inter-industry flows of technology. Productivity growth is found to be more often associated with process- than with product-R&D. R&D embodied in purchased goods is also an important source of productivity increase. Product-related R&D does not benefit the industry which it comes from as much as the industries where it goes to. Goto and Suzuki (1989) found that R&D activities of the input-supplying industries influence positively the productivity growth of user industries in Japanese manufacturing.

Taking account of non-incorporated knowledge is even more difficult. The recent literature on endogenous growth, for instance, has focused on the external effects and spillovers associated with technical change[1]. Knowledge is essentially a public good and one may expect important spillovers related to its accumulation. Jaffe (1986) attempted to measure the importance of spillovers by looking at the effects of other firms' R&D on the productivity of a firm's own R&D. Jaffe identifies the 'technological position' of a firm with the help of the technological classes in which it patents. A 'technological space' thus defined, it is possible to measure the proximity of firms and to weight the impact of other firms' R&D according to this proximity. Thus weighted, other firm's R&D expenditures define a 'potential spillover pool' for firm i: Si.

Jaffe then tests the following equation:

$$k_i = \beta_1 r_i + \beta_2 r_i s_i + \gamma_i S_i + \text{dummies}$$

with ki the new knowledge generated by firm i, ri its own R&D, si its potential 'spillover pool', all variables expressed in logarithms. k_i may be patent applications, profits or the market value of the firm. The coefficients for the patents equation are 0.875 for the firm's own R&D, 0.509 for the spillover pool and 0.352 for the interaction effect. The spillover effect is thus very large. If every firm increased its R&D expenses by 10 %, total patents would increase by 20 %, more than half of the increase coming from the spillover effect. Each firms' own R&D benefits other firms located in a neigbouring technological area. Mohnen and Lépine (1991) assessed technology spillovers with the help of a technology flow matrix which reports the use of a patent by industries which are not its producer. They found that R&D produced substantial spillovers in the Canadian industry, particularly in a few key sectors (chemicals, machinery, instruments)[2]. Table 4 summarizes the technology spillovers.

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1 See Amable and Guellec (1992) for a survey.

2 They also found that foreign technology payments and own R&D were complementary factors, which indicates that one has to built its own technology base in order to benefit from someone else's.

Table 4. The spillover effects

	Equation	Spillovers	Conclusions
Scherer (1982)	Productivity	Reallocation of R&D capital with a technology flow matrix	Importance of "used" R&D (own process and embodied) over own product R&D
Griliches Lichtenberg (1984)	Productivity	Reallocation of R&D capital with a technology flow matrix	Significance of own process and product R&D weak and unstable influence of embodied R&D
Goto Suzuki (1989)	Productivity	Other industries' R&D capital with an I/O matrix	Strong effect of input suppliers' R&D
Bernstein Nadiri (1988)	Cost	Other industries' R&D capital identified individually	Differences among industries as both spillover senders and suppliers
Mohnen Lépine (1991)	Cost	Spillover pool = weighted average of other industries' R&D stocks weights are constructed with a technology flows matrix.	Significant spillover effects. Strong inter-industry variability of spillovers
Jaffe (1986)	Patents profits and market value	Spillover pool defined with the proximity of industries in a patenting space	Strong spillover effects
Geroski (1991)	Productivity	Innovations. either used or produced	Weak spillover effects long-run effects of used innovations
Adams (1990)	Productivity	Spillover pool defined by technological proximity. Scientific articles	Long-run effects of own knowledge: 20 years. even longer-run effects of spillovers: 30years.

Other forms of knowledge may be more difficult to trace. Arrow (1962) pointed out the importance of learning by doing. The process of trial and error is a crucial issue for technological innovation for it enables firms to learn how to use innovations more efficiently. One might conceive this factor as operating altogether independently of new R&D expenditures. Initially noted in assembly line work and mass-production (Alchian, 1959, 1963), this feature was later introduced in growth theory (from Arrow, 1962, to Romer, 1990) with hardly any direct empirical investigations, a procedure that hampers a clear assessment of the origins of technological change.

The usual experience curve describes the decrease of unit cost with cumulative production according to two relations :

$$C = C_0 \, N^{-b}$$

and :

$$N = \int_{-\infty}^{t} Q(s)\, ds$$

the parameter b is easily related to the rate of decrease of unit cost when production doubles (a) :

$$b = \frac{-\log(1-a)}{\log 2}$$

Ayres (1985) gathered empirical evidence for very old and traditional production (for instance the model T Ford) as well as very recent innovations (such as memory disc drives, integrated circuits or MOS dynamic RAM). Even if the data is far from exhaustive, the trend is apparently towards reinforced experience curves. Therefore the logic of specific equipments division of labour and growing market size is ever more important in industries where product innovations are dominant. Recent research shows that learning-by- doing is very important at the firm level (Adler, 1985) and that new electronic products involve stronger experience effects than their mechanical predecessors.

Several reasons lead to believe that the exchanges of technical knowledge are more complex than suggested by simple I/O flows. The emerging socio-technical system seems to extend learning processes beyond the realm of production; it seems to include the users of the products as well. Powerful mechanical or electronic equipment and convenient software need close links between the people in charge of conceiving them and those who will use them. Learning by using has to be added to learning-by-producing. Preliminary studies suggest the importance of such interactions in orienting and monitoring the creation and diffusion of new technologies. The quality of the linkage could be one of the factors that determines the performance of national systems of innovation (Lundvall, 1988, 1989, 1990). However, a precise specification including such elements remains difficult to implement in an econometric study.

All these elements encourage applied researchers to add new variables in their regressions. Human capital has always been a variable favoured by growth accounting scholars (Maddison, 1987). Therefore, the know-how imparted to people through general education, training and retraining during professional life should be introduced in any productivity equation whenever possible. The incorporation of such determinants of knowledge growth tends to reduce the role played by R&D. In traditional growth or productivity equations, the importance of R&D typically decreases with the inclusion of other factors[1]. Variables representing "qualitative" attributes undeniably contribute to lessening the importance of R&D. For instance, Sassenou (1988) considered a sample of 296 French firms and added a few variables to the traditional productivity equation. The result is that the research elasticity drops from 0.17 to 0.12 when variables such as the proportion of engineers and the proportion of administrative clerks in total employment are introduced. Crépon and Mairesse (1991) found a research elasticity of about 0.07 when taking account of the same factors in addition to sectoral effects on a sample of 1484 French firms, a low value considering the estimates of Table 1. Taken alone, R&D expenditures may act as a proxy of very mixed effects related to human capital and learning effects. The precise assessment of their impact on productivity growth is thus made all the more difficult.

More generally, the appreciation of the innovative process could benefit from a more precise consideration of the process of technical change. Using survey data on 8220 Italian manufacturing firms on innovative activity at large, Napolitano (1991) aimed at going beyond the R&D laboratories. Actually, the consideration of innovative products or processes allowed to trail the factors of innovation. On average, R&D is only the sixth source of innovation, behind the purchase of equipment, design, proposals from employees, customer requests and staff training. Two elements mitigate this finding. First, innovations are not limited to the implementation of a radically new product or process[2]. Second, there exist important sectoral differences: high-tech sectors rely much more on R&D-based innovations. Three groups of industries may be identified, possessing similar sources of innovation[3]. Nevertheless, the role of R&D appears weakened. Within each sector (apart from petrochemicals and computers), firms which do not carry R&D do not acquire technological knowledge and skills from significantly different sources from firms which carry R&D. The presence of an R&D laboratory does not make significant difference in how technological innovation is gathered by innovating firms. Other influences (links with upstream and downstream firms) should enter the picture first.

This result has enormous implications for industrial policy. Restricting intervention to R&D encouragement is likely to miss the point since R&D activity seems to be a somewhat inadequate measure of innovativeness. It actually emphasizes the findings mentioned above on the importance of non-R&D factors, but an important limitation must be kept in mind. Napolitano's study concerns the Italian manufacturing industry, which

1 The most obvious supplementary factors are sectorial dummies : the value of the production elasticity of R&D decreases from 0.16 to 0.08 in Sassenou (1988). Including the effects of R&D externalities, the production elasticity with respect to own R&D falls to 0.08.

2 Radical innovation, as opposed to incremental innovation. For an explanation on the distinction, see for instance Freeman and Perez (1988).

3 They can be compared with Pavitt (1984)'s sectoral classification.

is characterized by its low R&D intensity and its overall orientation away from technology intensive industries (Amable and Mouhoud, 1990; Amendola and Perrucci, 1990). It would certainly be interesting to compare the Italian situation with those of Japan and the United States. One suspects that the importance of R&D may turn out to be different.

In any case, the consideration of innovations sheds a different light on the relationships between technology and economic performances. Geroski (1989) considers 79 industries in the U.K. for the 1976-1979 period and tests a total factor productivity growth equation with the effects of market penetration by foreign and domestic producers as well as major innovations, making use of the SPRU data base on innovation in the U.K. (Pavitt, Robson and Townsend, 1987; Robson, Towsend and Pavitt, 1988). Major innovations are found to have a significant effect on productivity growth. Geroski (1991) used the same data to investigate on the cross-industry effects and the assorted innovation spillovers. Sectors differ to one another according to their use and production of innovation. Some industries are typical suppliers of innovations while others rely much more on innovations developed elsewhere. It is found that the use of innovations has a larger effect on productivity growth than the production of an innovation. Innovations have a long-run effect (10 to 15 years) representing as much as ten times the size of the short-run effect. An important finding is that there are very few spillovers associated with innovations, contrary to what happens with R&D as was found in Jaffe (1986) or Mohnen and Lépine (1991). It thus seems that knowledge flows between sectors, but not that embodied in specific products, which is too user-specific. This may provide additional empirical evidence supporting the distinction between tacit and non-tacit knowledge (Dosi, 1988).

Testing explicitely the spillovers associated with knowledge (measured with scientific articles in interaction with scientific personel), Adams (1990) showed that knowledge had a very long-run effect on productivity growth. Lags as long as 20 years must be taken into account. Moreover, spillovers associated with knowledge may have even longer-run effects (30 years). One may then assume that knowledge does flow between sectors.

3. Technical Change and International Competitiveness

The relationships between technology and the economy can be grasped through different variables, expressing separate stages of the innovation process. The concern for inter-industry flows of technology that can be found in some studies points to the fact that

R&D is but one stage of the innovative activity. The effects of innovation can be observed in several areas. International competitiveness is a field where technological change is expected to play a significant role[1], especially in the light of the new international trade theories, which rely on product differentiation or increased quality through innovation to explain trade flows between industrialised countries (Dosi, Pavitt and Soete, 1990 ; Krugman, 1990).

Audretsch and Yamawaki (1988) modelled the relationship between R&D and competitiveness between the U.S. and Japan with a specific question : which components of R&D expenditures – process innovation, product quality improvements, new product or new technology, technology transfer – are most effective ? They tested a trade balance equation for 213 four digit SIC industries for 1977 with relative R&D intensities between Japanese and U.S. firms in a given industry as regressors, as well as other variables. R&D is found to positively influence Japanese trade: an additional dollar of R&D in Japan improves the trade balance by 0.15. On the other hand, the U.S. R&D expenditures are far from being as efficient, an additional dollar of R&D in the U.S. would improve this country's trade balance by only 0.025. The most effective components of R&D expenditures for the improvement of Japan's trade balance are product quality improvements and process innovation, i.e. reducing the cost of existing new products rather than developing new ones. This result may be compared to the emphasis put on product differenciation in some new trade theories (Krugman, 1990 ; Guellec and Ralle, 1991).

Guellec, Magnier and Toujas-Bernatte (1991) tested market share equations on sectoral data between 1975 and 1987 with an indicator of R&D: the share of the country in the sum of R&D expenditures of the five most developed countries of OECD, smoothed over three years. Their results for the impact of R&D on market share evolutions are given in Table 5. Amable (1991a) tested exports equations with a technology variable – foreign patenting i.e. the number of patents granted abroad for each country, either lagged or smoothed over 4 years – added to the traditional price and demand effects, in growth rates over 1961-1967 for the five most developed OECD countries, at the aggregate level. The results are displayed in Table 5. The comparison of the two sets of results manifests that it is possible to find significant positive effects of a technology variable on aggregate foreign trade equations. Both studies find a similarity in coefficients value for France and Germany, and non significant coefficients for the UK. They differ on the case of Japan, where the impact of R&D seems to be much higher than for other countries, which is not the case with the patenting indicator.

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[1] See Stoneman (1983) ch. 17.

Soete (1987) preferred to use a technology output indicator rather than a technology input one such as R&D intensity[1]. He tested a market share equation for 40 industrial sectors in 1977 with a technology variable as a regressor – the share of each country in U.S. patents over 1963-1977 in each industry – along with investment per worker, population and a distance proxy. The technology variable appeared as significant for most industry regressions. Low technology intensity sectors were the usual suppliers of non significant results. The technology intensive sectors obtained the highest coefficients, but there were a few surprises : drugs had a relatively low value of the coefficient for the technology variable whereas household appliances obtained a higher than expected coefficient.

Table 5. Technical change and foreign trade

			Coefficients:				
Source	Equation	Technology variable	U.S.	Japan	F.R.G.	France	U.K.
(1)	Market share	R&D	0.35	0.93	0.11	0.14	-0.02*
(2)	Exports	Patents	0.27 **	0.23	0.32	0.32	- *

* not significant ** trade balance equation

Sources: (1) Guellec, Magnier and Toujas-Bernate (1991).
(2) Amable (1991a).

Fagerberg (1988) developed a model of international competitiveness that takes account of the ability of each country to compete in technology. The model considers the technological determinants of competitiveness as well as the broader concept of 'ability to deliver', which depends on the diffusion of technology from countries on the world technological frontier area to the rest of the world. The model was tested on pooled cross-country and time series data with 15 industrial countries over the period 1960-1983. The technology variable used is a weighted average of R&D-based and patents-based measures. Fagerberg's results for growth in exports market shares (ME) and import market shares are given in Table 6, with TL the relative technological level of each country relative to the world technological leading country, INV the percentage of gross fixed investment to GDP, W the growth of world trade at constant prices and RULC the growth in relative labour unit costs. The technology variables (TL and TG) have the expected signs. Relative backwardness hampers net exports whereas technological activity facilitates them.

1 See Basberg (1987) for a discussion of the merits to the patents indicator.

Table 6. The foreign trade equations of Fagerberg (1988)

$$\begin{array}{lllllll} ME = & -3.25 & -\ 2.64\ TL & +\ 0.30\ INV & -\ 0.36\ W & +\ 0.25\ TG & -\ 0.34\ RULC \\ & (-2.3) & (-3.0) & (5.0) & (-5.4) & (4.7) & (-4.6) \end{array}$$

$R^2 = 0.67$ $\quad$ SER = 1.10

$$\begin{array}{lllllll} MI = & 0.88 & +\ 3.46\ TL & -\ 0.23\ INV & +\ 1.25\ GDP & -\ 0.21\ TG & +\ 0.21\ RULC \\ & (0.6) & (1.8) & (-2.0) & (7.7) & (-2.3) & (2.4) \end{array}$$

$R^2 = 0.54$ $\quad$ SER = 1.59

Source: Fagerberg (1988).

Fagerberg's technology variable was a mix of R&D and patents data. Greenhalgh (1990) introduced a more sophisticated variable in a traditional trade balance equation, so as to take account of product quality. Quality is a function of technological innovation and supply reliability. The former is represented by the number of innovations taken from the SPRU innovation data base and the latter by strike incidence. Greenhalgh's technology variable is thus defined as $\alpha_T\, e^{\delta_I I + \delta_S S}$, where I is an innovation and S is a strike. A trade balance equation was tested at the industry level for 31 industry groups over the period 1957-1981. Testing a cointegration relationship, innovations were found to promote exports in at most six industries, excluding sectors such as engineering and motor vehicles. For the ECM relationships, at most nine industries were found to benefit from trade promoting innovations.

Taking actual innovation variables involves the risk of facing the problem of cross-industry spillovers, which cannot be adequately dealt with if one cannot have quantified hypotheses about innovations I/O flows, and which seem to be more associated with disembodied knowledge. Nevertheless, Greenhalgh results lend some support to the idea that innovation facilitates trade performance.

Nothing is said about the inverse relationship though. Taking the specific case of the U.K., it has often been suggested that this country was experiencing a vicious circle or cumulative causation of decline[1], to which interactions between export success and technological success were contributing. Hughes (1986) addressed this particular problem by testing both an exports equation and an R&D equation. R&D is assumed to be influenced by technological opportunity and demand, particularly exports demand. At the same time, R&D, as a proxy for innovation, promotes exports. This leads to Hughes'

1 Kaldor (1966). Cumulative causation is from Myrdal (1957).

model, displayed in Table 7, with X the exports, Q the gross output, Y the value added, RD the domestic R&D expenditures, RD* the R&D expenditures and Y* the value added of competitor countries, HS the proportion of skilled manual labour in total manual labour, CS a concentration indicator and PL an indicator of the profit margin. The model is estimated for 46 U.K. industries in 1978.

Table 7. The trade and R&D equations of Hughes (1986)

X/Q =	3.27	+ 0.69 RD/Y	- 0.22 RD*/Y*	+ 0.819 HS	- 0.50 CS
	(3.6)	(4.3)	(-1.8)	(2.9)	(-2.1)
SER =	0.51				
RD/Y =	-2.71	+ 1.26 X/Q	+ 0.509 RD*/Y*	+ 0.839 CS	+ 0.874 PL
	(-1.6)	(3.0)	(3.3)	(2.5)	(1.8)
SER =	0.92				

The interactions between exports and R&D are as expected, there exists a cumulative causation between exports and innovation. One may also notice the importance of the manpower-qualification variable. The presence of this factor echoes the findings of the studies on R&D and productivity reviewed above.

Hughes' approach might be conceived as a first step towards the building of a more general macroeconomic model. The emphasis on the interactions between technological change and economic growth is not new (Schmookler, 1966), but not often emphasized in macroeconomic modelling. On the other hand, the studies reviewed above emphasize the variety of determinants and aspects of technological change. Therefore, technological change can take diverse forms in different areas. Considering the importance of technological change in the growth process, the need for a framework encompassing the macroeconomic effects as well as the determinants of technical change is more crucial than ever. The simple twin-determination between R&D and growth, helpful as it is, overlooks the more complex effects of technical change.

4. Macro-modelling of Technical Change : From Theory to Econometrics

Technological change has been introduced in macroeconomic analysis for a long time. There exist an abundant literature on the macroeconomic impact of technological change on output or employment growth[1], just as technical change is taken account of in productivity or foreign trade studies. For medium-term effects, one can conceive an endogenous diffusion of new equipment, according to the general macroeconomic conditions. Indeed, vintage models can depict how the pace of investment will set the pace of macroeconomic technical progress, but the improvement of each new vintage is fixed exogenously (Petit and Tahar, 1990; Antonelli, Petit and Tahar, 1992, ch.3). Such models take account of technology diffusion, but not of technology creation. However, most macroeconomic models have no sophisticated way of dealing with the determinants of long-term technical change. The effects of technology can be ascertained at various levels of macroeconomic models, but a framework for a macroeconomic synthesis is still lacking[2].

On the other hand, it must be noted that the most recent growth theories[3] concentrate on endogenous technological change, long after Kaldor (1957) and Arrow (1962). Still, the empirical tests performed with specifications inspired from these theories tend to downplay the endogenous nature of technology, sticking to reduced forms that make the distinction between "exogenous growth" and "endogenous growth" theories more difficult to establish. These models rely crucially on the existence of constant returns in a technological progress function, or a unit elasticity on accumulated factors (Amable and Guellec, 1992). Yet, such a function is rarely tested, and technology itself is almost never at the center of empirical investigations, albeit endogenous technological change is the major issue of such studies. An exception is Guellec and Ralle (1991) who, following the logic of their theoretical model in which the number of new products discovered at each period is proportional to the number of researchers, tested an equation relating technological output to the amount of resources allocated to research, for the U.S. over the period 1902-1987 :

$$y = 0.86\, y_{-1} + 2.6\ 10^{-4}\, z - 3.7\ 10^{-4}\, x$$
$$(17.6) \qquad (2.2) \qquad (-2.6)$$

1 See Stoneman (1983) ch. 12 for an overview. Freeman and Soete (1987) present a macroeconomic model taking account of technical change.

2 All the more that, in the history of economic thought, most of the errors related to "technological" pessimism derive from an incomplete analysis of the ajustment mechanisms associated with innovation. If, for instance, market size is presumed to be independent of technical change, then, any labour-saving device will produce unemployment. But long-term trends show that real income, especially wages, eventually grow more or less in line with aggregate productivity, creating therefore a moving equilibrium growth in which demand and capacity expand simultaneously. Similarly, the modern sectors with an above average rate of technical change exhibit a relative price decline, wich makes room for additional growth in demand. According to a third mechanism, real profit associated with technological leadership will turn into an incentive to invest, extend the production of new products or increase productivity. Finally, at the macroeconomic level, a more innovative country will benefit either from currency appreciation or faster growth. By comparison, partial studies concentrate on the labour saving effects of technical change, missing the macroeconomic links.

3 Reference is made here to the endogenous growth models. See Romer (1986, 1990), Lucas (1988). A survey is presented in Amable and Guellec (1992).

with y the rate of growth of the number of goods (a patents-based indicator), z the logarithm of the number of researchers and x the percentage of military expenditures in GDP. Guellec and Ralle obtain a constant rate of growth of technical progress with a fixed number of researchers. Actually, this relationship is reminiscent of earlier studies' findings, linking patenting activity to R&D expenditures[1]. Whether one should interpret this relationship as supportive of new growth theories or not is left open to debate.

In any case, it seems that progress is needed in the direction of integration of technical change in macroeconomic models. It is possible to gather the studies on the influence of technological change on exports and imports to implement a macroeconomic framework that takes account of demand effects. Boyer and Petit (1981) (Table 8) estimated a complete model which enables to compute a long-run employment multiplier of R&D expenditures. From the estimation, this multiplier is actually negative. R&D stimulates productivity by lowering the employment required for a given production. At the same time, it increases exports demand, which boosts production. But the direct, negative, effects on employment predominate over the indirect effects. Boyer and Petit (1984) confirm the low sensitiveness of aggregate demand to productivity increases.

Amable (1991a) estimated a model of growth and international competitiveness, pooling cross-country and time series data for 8 industrialised countries for the period 1961-1987 (Table 9). As well as equations for the growth rates of consumption (tci), exports (tx), imports (tm) and the share of investment in GDP (i), the model includes an equation for the growth of patents (tbr), which constitutes an attempt to model endogenous technological change. Patents grow in relation to economic activity (the growth of GDP: ty). This equation is far from being fully satisfactory, since it is a reduced form itself, and has to rely on time dummies. However, the model features a possibility of cumulative growth through technological change and competitiveness. tw is the growth of world GDP, tpr is the growth of export or import prices of a country relatively to the prices of the industrialised countries.

In a model of growth for 59 countries over the period 1960-1985, Amable (1991b) assumed that the level of education of the population was a positive function of the level of development, and that it influenced positively technological innovation, which in turn promoted growth. The model (Table 10) has four equation, one for the rate of growth of productivity (ty), as a function of the technology gap vis-à-vis the U.S. (gap), the ratio of

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1 See Griliches (1990) for a review.

Table 8. The model of Boyer and Petit (1981)

e =	5.6	-	0.43 i	+	0.54 q	+	0.002 rat	-	0.027 in1
	(3.7)		(4.4)		(4.5)		(0.03)		(1.6)
i =	12.4	+	0.26 q	+	1.3 in2	+	1.7 belg	-	1.8 uk
	(11.0)		(1.9)		(2.7)		(3.1)		(2.7)
q =	-0.4	+	0.32 ex	+	0.56 d				
	(0.9)		(6.9)		(12.9)				
ex =	4.6	-	0.57 pr	-	0.37 ch	+	0.026 in1		
	(1.2)		(1.9)		(2.4)		(0.5)		

e : rate of growth of industrial employment
i : ratio of investment to value added
q : rate of growth of value added (at constant prices)
ex : rate of growth of the volume of industrial exports
d : rate of growth of internal demand of industrial products
pr : rate of growth of productivity
rat : share of equipment investment in total investment
in1 : percentage of process innovation in total innovation
in2 : ratio of R&D expenditures to GDP with a 5 year lag
belg : dummy for Belgium
uk : dummy for the United Kingdom
ch : rate of change of the exchange rate in dollars

Pooled cross-section and time series data: six european industries over 1960-65, 165-69, 1969-73, 1973-76.

Method of estimation: FIML.

Table 9. A model of technical change and competitiveness

tci =	-2.60	+	1.54 tw	+	0.09 tbr						$R^2 = 0.71$
	(- 3.4)		(8.0)		(1.3)						SER = 1.13
tx =	-10.52	+	2.03 tw	-	0.34 tpr	+	0.40 i				$R^2 = 0.72$
	(-10.6)		(4.9)		(-3.4)		(5.4)				SER = 2.06
tm =	7.38	+	2.48 ty	+	0.10 tpr	-	0.38 i	-	0.43 tbr		$R^2 = 0.68$
	(5.7)		(8.9)		(1.2)		(-4.7)		(-3.5)		SER = 2.02
i =	22.66	+	1.41 ty	-	1.27 mili						$R^2 = 0.70$
	(22.4)		(5.8)		(-6.0)						SER = 2.57
tbr =	-2.86	+	1.97 ty	-	5.93 d6873	+	4.06 d7984				$R^2 = 0.82$
	(-3.7)		(8.4)		(-7.9)		(5.2)				SER = 1.92

LogL = - 103.37

Method of estimation : FIML

Source : Amable (1991a).

Table 10. A model of growth and technical change for 59 countries

$$ty = \underset{(-2.2)}{-0.0337} + \underset{(4.0)}{0.0444}\, gap + \underset{(2.6)}{0.483}\, eq + \underset{(1.9)}{0.0150}\, prim - \underset{(-2.8)}{0.0827}\, gov$$

$R^2 = 0.40$ SER = 0.011

$$eq = \underset{(-0.1)}{-0.012} + \underset{(2.3)}{0.771}\, ty + \underset{(5.8)}{0.0432} sspat + \underset{(2.2)}{0.105}\, gov$$

$R^2 = 0.64$ SER = 0.017

$$sspat = \underset{(1.8)}{0.695} - \underset{(-1.8)}{0.681}\, gap + \underset{(2.0)}{0.845}\, sec$$

$R^2 = 0.88$ SER = 0.12

$$sec = \underset{(4.6)}{0.625} - \underset{(-6.3)}{0.705}\, gap + \underset{(2.3)}{0.176}\, prim$$

$R^2 = 0.70$ SER = 0.12

LogL = 708.49

Method of estimation : FIML

Source: Amable (1991b).

equipment investment to GDP (eq), the fraction of the concerned population enrolled in primary education (prim) and the ratio of government expenditures to GDP (gov). Other equations concern the determinants of equipment investment, as a function of innovation (sspat, a concave function of the number of patents per inhabitant), which is itself positively influenced by the fraction of the concerned population enrolled in secondary education (sec). Resolution of the complete model allows for contrasted growth paths, and vicious as well as virtuous circles of cumulative causation. Depending on the fraction of population enrolled in primary education and on the share of government expenses (other than education), a country will eventually converge towards an equilibrium technology gap. What matters here is that innovation is linked to education and influence productivity growth.

Attempts to incorporate endogenous technical change in applied macromodelling should of course go beyond the simple frameworks exposed above. They cannot incorporate the many channels through which the innovation process takes place. At least, the questions raised by the new growth theories put the emphasis on the determinants of technical change and its mechanism of diffusion. There is no doubt that many of those determinants do not belong to the realm of microeconomics. "Traditional" macroeconomic influences (interest rates, fiscal policy,...) as well as more structural elements (the education system, industrial relations,...) are expected to matter. Besides, going beyond the blackbox of externalities means investigating the cross-effects between a macro-structure and micro-behaviours.

In this respect, endogenous diffusion of technology equipment could be introduced in applied macromodelling along with endogenous evolution of technological knowledge. Interactions between skills, education, industrial relations and economic performance are certainly worth investigating. There is no doubt that technical change possesses many aspects (productivity improvements, product differentiation, quality improvements,...). But a treatment of such aspects calls for an elaboration of statistics and indicators (Smith, 1990), which are missed on a comparable international basis.

5. Conclusion

The understanding of technological innovation has been radically altered in the recent years (OECD, 1991, ch. I). The traditional "linear" model, which represented the innovation process as a series of successive steps, from an invention to the marketing of a new product, is giving way to an "interactive" model, not precisely defined yet, which insists more on feedback effects between the different stages of innovation. In this new model, the focus of the innovative process is not as much on the R&D expenditures as in the "linear" model. In the latter, the sequence that led from R&D to innovation is guaranteed. In the "interactive" model of technical change, the links between the various stages of innovation are more complex. The consequence is that an R&D/productivity relationship now appears as little more than a reduced form. Additional elements may be taken into consideration, such as spillovers and externalities, and other determinants of technical change are taken into account, related to human capital, the quality of user-producer relationships, etc. This change has been partly reflected in applied studies. Interfirm or interindustry flows of knowledge are a major subject of contemporaneous research on productivity growth.

The current conception highlights the many facets of technological change. It does not only enhance productivity, but improves the quality of production and enables the development of new products. Such effects on the demand for goods differ from the usual price effects. They correspond to the "non price" aspects of foreign trade equations. Consequently, international trade is an area where the inclusion of technology variables may be particularly fruitful.

Finally, the inclusion of technological change in macromodelling may yield important results. First, it constitutes an attempt at estimating the overall consequences of technological change. Second, it addresses a question connected to new growth theories, which stress the importance of technological change: how is it possible to model endogenous technical change ? Progress in this direction may however be inhibited by the lack of adequate statistical data.

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Comment : *Arne Kristensen*

The paper by Professors Amable and Boyer gives an excellent review on the importance of R&D in the process of technical growth. The paper provides a thorough investigation of recent research and presents it in an illuminating way. The paper starts out with a presentation of some simple growth accounting equations and by adding further 'technology variables' they investigate still more complex equations. In the second part of the paper they review another line of work, namely the work by Fagerberg and others on the relationship between technological development and international competitiveness, and in the last section they review a few macro models in which endogenous technological development is included.

My own work is primarily on technical change at the micro level, and therefore I will concentrate my comments on the first section of the paper on the determinants of technological development at the micro level. In addition I will present an alternative theoretical framework (undoubtedly already known by the authors) which might be used in studies of technical progress.

1. Growth Accounting

For several years there has been international agreement that one of the most severe problems in the area of explaining technological change has been the acute shortage of statistical data. Therefore one must of course utilize the data already collected in an optimal way and consequently, all sorts of theoretical based analyzes must be taken into use.

However, since my schooling has been in innovation theory I have some doubts about growth accounting. In this paper, the conceptual background for growth accounting is not touched upon, but since growth accounting takes its point of departure in neoclassical growth theory, the same basic assumptions that apply to this school of thought must also apply to the concept of growth accounting.

This means that assumptions like perfect competition, full information and profit maximation must be fulfilled, and I think we can agree that this is not the case in 'real life'. In addition we have the problem of the constancy of parameters touched upon by Professor del Hoyo in his comment to the paper presented by Professor Capron.

This is probably a simplification since these assumptions undoubtedly have been modified in the reviewed studies. But I think that we should bear the connection between the neoclassical production function and the growth accounting equation in mind and be very careful when we use growth accounting for analytical purposes.

2. The R&D Measure

My next remark concerns the use of R&D as a measure of technological development. My first hesitation concerns what is called 'the stock of technical capital' or the 'stock of R&D', which, I believe, is even more difficult to measure than the stock of physical capital. You have sidestepped the problem by working in growth rates and therefore with R&D expenditures.

I think this raises some problems. First, I agree that R&D is accumulated in a 'stock of R&D/knowledge', but this stock also degenerates; knowledge is forgotten. Elements if this is even a necessary process - you need what may be called 'creative forgetting'. You must delete old knowledge to be able to absorb new knowledge.

Second, R&D is not solely (not even primarily) directed towards process innovations. In fact empirical data show, that most of the R&D performed in enterprises is directed towards development of new products rather than new processes (of course very dependent on sectors of the economy).

Third, one might argue that if we use R&D-inputs to measure outputs, we should operate with time lags - elsewhere in the paper by Amable and Boyer it is argued that the time lag on R&D might be as long as 7 years. A fourth but minor point that might be raised, is the uncertainty involved in measuring R&D (in the paper it is not clear which measure for R&D has been used in the reviewed studies (is it BERD or GERD?)). Are the different measures comparable?

3. Regressions

I find it a bit difficult to see where (or whether?) the method of analyzing technical progress changes from growth accounting to pure regressions. But I find the discussion of different factors (i.e R&D; embodied and disembodied knowledge; learning by doing;

human capital) and their impact on technical development extremely interesting and stimulating.

However, as pointed out by the authors, all these factors are highly interrelated, and this is a critical problem for the growth accounting approach, and I wonder what is the use of analyzing all these factors independent of each other. One might get a high correlation coefficient (elasticity) between growth in output or productivity and each of these factors when analyzing them independently, but once they are integrated in more complex regressions, their influence on output might be marginal.

For example (page 7 middle), the elasticity of R&D (which should be a very important factor in explaining growth) drobbs from 0,17 to 0,07 when we introduce factors such as the proportion of engineers and administrative clerks, and sectoral effects.

4. An Alternative Approach

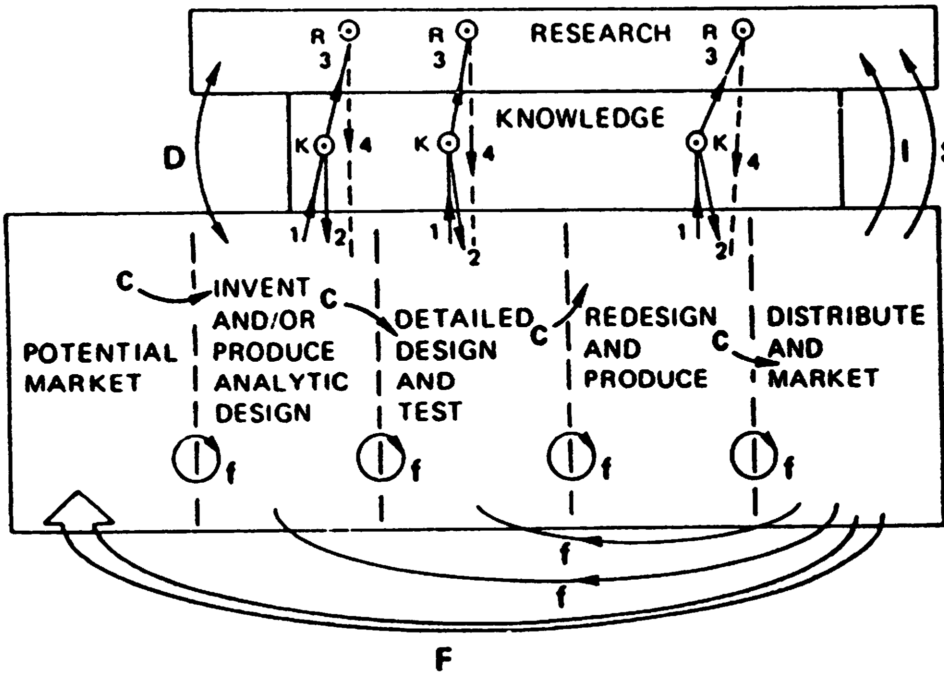
I think what we are lacking in the work described above is an appropriate model to describe the process of technical change - or as I see it, the most important component in technical change - innovation.

The authors are aware of this lack of a theoretical benchmark in the work they have reviewed. In their conclusion they write 'The traditional 'linear' model ... is giving way to an 'interactive' model, not precisely defined yet, which insists more on feedback effects between the different stages of innovation. In this new model, the focus of the innovative process is not as much on the R&D expenditures as in the 'linear' model' (page 16 middle).

I think these lines might have been written with the so-called "chain-linked" model proposed by Kline and Rosenberg (1986) in thought, and in the following I shall make a very short presentation of this model - as it is undoubtedly already known to most of the participants in this seminar - and I will use this model to introduce an alternative way of measuring innovation.

The studies reviewed above all focus on process innovation, but this model primarily concerns product innovations, and in my view product innovations are at least as important as process innovations. In fact Danish experience shows that 70% of product innovations are developed in the sector producing investment goods i.e. they constitute process innovations in other sectors. In the following I, will therefore concentrate on product innovations - a concept not easily introduced in growth accounting.

Kline and Rosenberg's 'chain-linked model'



Chain-linked model showing flow paths of information and cooperation.

Symbols on arrows : C = central-chain-of-innovation; f = feedback loops; F = particularly important feedback.

K-R : Links through knowledge to research and return paths. If problem solved at node K, link 3 to R not activated. Return from research (link 4) is problematic - therefore dashed line.

D : Direct link to and from research from problems in invention and design.

I : Support of scientific research by instruments, machines, tools, and procedures of technology.

S : Support of research in sciences underlying product area to gain information directly and by monitoring outside work. The information obtained may apply anywhere along the chain.

The three central boxes in the 'chain-linked model' constitute what we may call the central elements in the linear model:

invention --> design --> production

However both potential market and realized market have been added to the model. And even more important, a series of feed-back mechanisms and loops have been included. Research is no longer seen as the initiator of innovation, but rather as an activity linked to all steps in the innovation process.

In the model it has been realized that knowledge already accumulated in the enterprise plays a central role. It is not until a problem that cannot be solved by exploiting the existing knowledge-base arises that research-projects are initiated.

The model, as pictured here may be further refined, as one must realize that some knowledge is "sticky" and therefore cannot be grasped and explored. A second change could be to add learning to research as a source of knowledge. Today (as pointed out by eg. G. Dosi in several places) learning is playing an increasingly important role i the innovation process; learning adds important information to the knowledge pool of the enterprises.

It is obvious that this model cannot be applied to empirical studies in any simple way. However, the model specifies some of the variables which should be examined when we want to analyze what I believe is one of the dominant determinants of economic growth, namely innovation. The variables could eg. be market-factors (customers, market research, exhibitions and so on) or internal factors (key persons in the enterprise, production department, top management, and of course the R&D department). Other important variables are innovation expenditures other than R&D (eg. expenditures for design, tooling up and marketing of innovations).

In fact I think this is what Mr. Napolitano and his colleagues have done in the Italian survey referred to in the paper. This is also what we have done in a recent Nordic study of industrial innovation. Like our Italian colleagues we find that when we are looking at R&D-performing industry, R&D plays a significant role; but it is not the most important factor in the innovation process - and I am convinced that you would find a similar picture in the US and Japan - and not a different picture as suggested in this paper.

The Nordic survey - as well as the Italian - contains many other facets of the innovative activities of firms, but I think it would go to far to present more material from this survey. This approach, however, is being adopted by OECD and EEC, and we may expect to see larger and more coordinated so-called "innovation surveys" in the future.

However, as mentioned earlier, these studies primarily focus on product innovation, and I therefore think that process-oriented studies like those reviewed in this paper will continue to be of importance also in the future.

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Chapter 4 - Quantitative Methods for the Assessment of the Economic Impact of R&D Investment

Frank R. Lichtenberg

1. Introduction

The basic model that has been most widely used to assess econometrically the economic impact of R&D investment is a production function generalized to include the stock of "knowledge capital" as a factor of production:

$$Y(t) = F\ (K(t), L(t), Z(t)) \qquad (1)$$

where Y = real output; K = physical capital service flow (usually assumed to be proportional to the capital stock); L = real labor input (e.g. hours worked)[1]; and Z = knowledge capital. Just as fixed capital is a distributed lag function of investment in plant and equipment (INV), knowledge capital is a distributed lag function of R&D investment (RD). Assuming geometric depreciation,

$$K(t) = \Sigma_i\ (1 - \delta_K)^i\ INV(t\text{-}i)$$
$$Z(t) = \Sigma_i\ (1 - \delta_Z)^i\ RD(t\text{-}i) \qquad (1a)$$

Let us assume that the production function (1) is Cobb-Douglas, and that there constant returns to scale with respect to the conventional inputs K and L:

$$Y = K^{\alpha}\ L^{1-\alpha}\ Z^{\beta} \qquad (2)$$

Knowledge capital is assumed to be a pure public good, whereas physical capital is a "congestible" good. Therefore to double output we need double only the quantities of the conventional inputs. β is the elasticity of output with respect to the stock of knowledge capital, and is the key parameter for measuring the impact of R&D or knowledge capital. Taking logarithms and differentiating with respect to time,

$$Y' = \alpha\ K' + (1 - \alpha)\ L' + \beta\ Z' \qquad (3)$$

where a prime after a variable denotes its growth rate, e.g. $Y' \equiv (d \ln Y) / dt$. From (3), the rate of labor productivity growth (Y' - L') is determined by the rate of physical capital

[1] For simplicity, we ignore issues related to "labor quality" or human capital.

deepening (K' - L') and by the growth rate of the knowledge capital stock (Z'):

$$Y' - L' = \alpha\ (K' - L') + \beta\ Z' \qquad (4)$$

Z' also influences the growth rate of total factor productivity (TFP). TFP is defined as the ratio of output to an index of conventional inputs:

$$TFP \equiv Y / (K^{\alpha} L^{1-\alpha})$$

Hence

$$\begin{aligned} TFP' &= Y' - [\alpha\ K' + (1 - \alpha)\ L'] \\ &= \beta\ Z' \qquad (5) \end{aligned}$$

Equation (5) implies that the growth rate of total factor productivity is equal to the growth rate of the knowledge capital stock times the elasticity of output with respect to knowledge capital. The objective is to estimate β. Suppose that we have time-series data on the following variables: Y, L, K, and RD. (As we discuss below, there may be serious problems with accurately measuring some of these variables, particularly Y.) To calculate TFP', we require an estimate of α, and to calculate Z', we require an estimate of δ_Z. Most analysts have been willing to assume that the conventional factors are paid the value of their marginal products, and therefore that α may be set equal to capital's share in total production cost (or national income), s_K.[1] Then TFP' can be estimated by TFP' = Y' - (s_K K' + (1 - s_K) L').

Getting a reliable estimate of δ_Z is more difficult. One feasible approach is (i) to calculate the Z series using the accumulation equation (1a) under alternative assumed values of this parameter; (ii) to estimate eq. (5) using these different series; and (iii) to select the δ_Z value which provides the best fit of the TFP growth equation (5). Griliches and Lichtenberg (1984) took this approach using industry level data for U.S. manufacturing, and found that $\delta_Z = 0$ provided the best fit.

If we are willing to assume that $\delta_Z = 0$, i.e., that knowledge capital does not depreciate, then eq. (5) can be re-expressed in an even simpler form.

$$\begin{aligned} TFP' &= (dY / dZ)\ (Z / Y)\ (dZ / Z) \\ &= (dY / dZ)\ (dZ / Y) \\ &= \Pi\ (RD / Y) \qquad (6) \end{aligned}$$

[1] Paul Romer has argued that the elasticity of aggregate output with respect to physical capital substantially exceeds capital's share in national income (about 30 %), and that there are increasing returns with respect to conventional inputs. However Mankiw, David Romer, and Weil have argued that the apparently high capital elasticity disappears when human capital is accounted for.

where $\Pi \equiv (dY / dZ)$ = the marginal product of knowledge capital. Since the rate of depreciation is zero, the net change in the knowledge capital stock (dZ) is equal to gross R&D investment (RD). Eq. (6) says that the rate of TFP growth (output growth controlling for the growth in conventional inputs) equals the ratio of R&D investment to output times the marginal product of knowledge capital.

Under our assumptions, Π may also be interpreted as the rate of return to investment in R&D. Suppose that a firm spends an extra dollar on R&D this year. Since knowledge capital does not depreciate, its stock will be $1 higher in every future year. If the marginal product of knowledge capital is Π, its output (revenues) will be \$ Π in every future year. Hence, Π is the rate of return on R&D investment. Because the labor and capital engaged in R&D are usually already included in the conventional input measures L and K -- that is, they are "double-counted" -- Π represents the *excess* rate of return to R&D investment -- the additional return received for employing these factors in R&D, rather than in ordinary production.

Equation (6) has been estimated on data at a number of levels of aggregation -- national, industry, firm and line of business -- for a large variety of sectors and samples. For a survey of some of these estimates, see Lichtenberg and Siegel (1991) and Griliches (1991). These estimates could be used to forecast the effect of changes in the R&D/GNP ratio on the economy's rate of productivity growth.

2. Spillovers

The preceeding discussion did not acknowledge the possibility that the private and social rates of return to R&D investment may differ due to the existence of "knowledge spillovers", or imperfect appropriability. Griliches (1991) has recently formulated the following simple model of R&D spillovers. The production function of firm i is postulated to be

$$Y_i = X_i^{1-\mu} Z_i^{\mu} Z_a^{\Omega}$$

where Y_i = output of firm i; X_i = an index of conventional inputs of firm i; Z_i = knowledge capital stock of firm i; and $Z_a \equiv \Sigma_i Z_i$ = aggregate knowledge in the industry. (For simplicity, Griliches assumes that there are constant returns with respect to the firm's own inputs, including its knowledge stock.) Firms are assumed to benefit not only from

R&D they have performed themselves, but also from R&D performed by other firms in the industry.

Griliches shows that the preceeding equation leads to the following relationship between *aggregate* output and inputs:

$$Y_a = X_a^{1-\mu} Z_a^{\mu+\Omega}$$

The elasticity of firm i's output with respect to its own knowledge capital stock is μ (assuming the firm is small relative to the industry), whereas the elasticity of industry output with respect to the industry's stock of knowledge capital is $(\mu + \Omega)$. Because firms do not appropriate all of the returns to their innovative efforts, the social elasticity (and rate of return) exceeds the private elasticity (and rate of return). Whether the coefficient on R&D-intensity in a productivity equation should be interpreted as a private or a social rate of return depends upon the level of aggregation of the data upon which the equation was estimated.

3. Does R&D Intensity Affect the Level or the Growth Rate of Productivity ?

For our purposes, the most important implication of the model described above is the hypothesis, represented by eq. (6), that the growth rate of TFP depends upon the fraction of output devoted to R&D investment. Recall that the key feature of this model was the relatively symmetric treatment of R&D investment and fixed investment. It is therefore worth noting that in the Solow growth model, the steady-state *level* of (labor) productivity depends upon the saving rate, but the growth rate of productivity does not.

Mankiw, Romer and Weil analyze the following model:

$$Y(t) = K(t)^{\alpha} (A(t)\, L(t))^{1-\alpha} \tag{7}$$

where A denotes the level of technology. L and A are assumed to grow exogenously at rates n and g:

$$L(t) = L(0)\, e^{nt}$$
$$A(t) = A(0)\, e^{gt}. \tag{8}$$

A constant fraction of output, s_K, is assumed to be saved. The model implies that the quantity of capital per effective unit of labor, $k \equiv K / (A\, L)$, converges to a steady-state value $k^* = [s_K / (n + g + \delta_K)]^{1/(1-\alpha)}$. Steady state income per capita is

$$\ln (Y(t) / L(t)) = \ln A(0) + gt + (\alpha / (1 - \alpha)) \ln (s_K) - (\alpha / (1 - \alpha)) \ln (n + g + \delta_K). \qquad (9)$$

An economy with a higher saving rate s_K will have a higher level of productivity at any given t, but not a higher productivity growth rate: $(d \ln (Y(t) / L(t))) / dt = g$, which does not depend on s_K.

Let us now generalize the model to include knowledge capital. Whether or not the fraction of output devoted to R&D, $s_R \equiv RD / Y$, influences the growth rate, as well as the level, of productivity, depends upon how we specify the model. Suppose we generalize their model as follows:

$$Y(t) = K(t)^{\alpha} Z(t)^{\beta} (A(t) L(t))^{1-\alpha-\beta} \qquad (10)$$

This equation emdodies the (possibly noninnocuous) assumption that there are constant returns with respect to all three factors. The equation for steady state productivity (assuming for simplicity that $\delta_Z = \delta_K$) is then

$$\ln (Y(t) / L(t)) = \ln A(0) + gt + (\alpha / (1 - \alpha - \beta)) \ln (s_K) + (\beta / (1 - \alpha - \beta)) \ln (s_R) - ((\alpha + \beta)) / (1 - \alpha - \beta)) \ln (n + g + \delta_K). \qquad (11)$$

Contrary to equation (6), productivity *growth* does not depend on R&D intensity (s_R).

But suppose that instead of replacing eq. (7) by eq. (10) and maintaining eq. (8) -- the assumption of exogenous technical progress -- we preserve eq. (7) and add the assumption that the parameter g in eq. (8) is a function of R&D intensity. In fact, g might be viewed as synonymous with TFP growth so that we might assume that

$$g = TFP' = \Pi (RD / Y) = \Pi s_R \qquad (12)$$

By substituting eq. (12) into eq. (9), we can see that under these assumptions, in the steady state the growth rate as well as the level of per capita income is increasing in s_R.

4. Errors in Deflators

In order to obtain consistent and efficient estimates of the rate of return to R&D investment and of the marginal product and output elasticity of knowledge capital from equations (5) and (6), we require reliable TFP series. As equation (5) reveals, TFP' will be correctly measured if and only if the rate of real output growth Y' is correctly measured. Y' is usually calculated as the growth rate of nominal output V' minus the growth rate of an output price index P':

$$Y' \equiv V' - P' \tag{13}$$

The measurement of nominal output growth V' is relatively unproblematic. What is far more difficult is the partitioning of V' into its 'desirable' and 'undesirable' components, Y' and P', respectively. It is obvious from equation (13) that given V', if we overestimate the growth rate of the output deflator by 5 percentage points, we will underestimate output and productivity growth by 5 percentage points. More generally, errors in output deflators will result in errors in the measurement of TFP'. If these errors are uncorrelated with Z' and with (RD/Y), then the *efficiency* (precision) of estimates of β and Π will be reduced, but the estimates will still be consistent. There is good reason to believe, however, that errors in deflators are not orthogonal to R&D investment.

The principal source of errors of measurement of long-run price change is *product-quality change*. We define the growth rate of product quality, $Z^{*'}$, as the difference between the growth rate of the effective quantity of output $Y^{*'}$ and the growth rate of the number of units sold, Y':

$$Z^{*'} \equiv Y^{*'} - Y'. \tag{14}$$

For example, Y' might represent the change between 1982 and 1992 in the number of microcomputers shipped by the computer industry. Because the quality (speed, memory size, etc.) of the average microcomputer shipped has increased dramatically in the last ten years, Y' substantially understates the real output growth of the computer industry. The growth in the price of effective output (the 'quality-adjusted' price) may be defined as

$$P^{*'} \equiv V' - Y^{*'} \tag{15}$$

The change in price per unit sold equals the sum of the change in price per unit of effective output and the change in quality:

$$P' = P^{*'} + Z^{*'} \tag{16}$$

The accurate measurement of quality change -- hence of real output and productivity growth and inflation -- poses serious difficulties, and it is safe to say that the time series produced by government statistical agencies do an imperfect job of accounting for quality change. Until a few years ago, estimates of real GNP in the U.S. national income accounts were based on the assumption that the computer industry's output deflator was constant over time ($P_t = 1.0$ for all t ==> $P' = 0$). Research by Robert Gordon and others on computer prices using the 'hedonic approach' (regressions of computer prices on computer characteristics) has revealed that the effective price of computing has declined at an average annual rate of about 14% over the last few decades ($P^{*'} \approx -.14$). The Bureau of Economic Analysis has now revised their real GNP estimation procedure to reflect Gordon's findings. Naturally, this has led to upward revisions of estimates of real output growth in the computer industry since 1960.

The U.S. Bureau of Labor Statistics (BLS) -- the agency responsible for the construction of producer price indexes (PPIs) -- attempts to adjust for quality change by "linking in" new products and discontinuing old products in the PPI. Indeed, the extent to which BLS introduces and drops products from an industry's price index over an extended period is a reflection of the incidence of quality change in the industry. In Lichtenberg and Griliches (1989) we presented estimates for a few industries of the ratio of the number of products introduced into the industry price index during an 8-year period to the total number of products ever included in the index during the period. The value of that ratio ranged from 0% for the tobacco, furniture, and printing and publishing industries to 43% in electrical equipment and supplies and 59% in rubber and plastic products.

Estimation of a 'multiple indicators' model of price change indicated that the producer price indexes used to deflate nominal output adjust for some, but not all, product quality change. According to our estimates, the average annual rate of quality change was 0.9%, and one-third of this was not accounted for by the PPI. Consequently, true (quality-adjusted) productivity growth exceeded productivity growth estimates based on the PPI by an average of 34%.

Our study also provided empirical support for the hypothesis that an important *cause* of quality change is product-oriented (as opposed to process-oriented) R&D expenditures undertaken by industry, and therefore that Z^* and (RD/Y) are positively correlated. We postulated a "quality-change production function" of the form

$$Z^{*'} = \theta_1 \text{ OWN.RD} + \theta_2 \text{ SUP.RD} + \varepsilon \qquad (17)$$

where OWN.RD = product-oriented R&D performed within the industry divided by industry sales, and SUP.RD = product-oriented R&D 'relevant' to the industry performed by its suppliers of capital and materials, divided by industry sales. Although $Z^{*'}$ is not directly observable, we were able to estimate the parameters θ_1 and θ_2. The estimates were (t-ratios in parentheses) .302 (5.1) and .738 (2.5); the R^2 was .394. Since R&D investment appears to have a significant positive impact on product quality change, and product quality change is not completely accounted for in the price indexes used to calculate output and productivity growth, we would expect estimates of the economic impact of R&D (β and Π) to be biased towards zero.

5. Diversification

The upshot of the previous section is that failure to properly account for product quality change may undermine the consistency of estimates of the rate of return to R&D investment. We show in this section that failure to properly account for the industrially diversified nature of firm operations may reduce the efficiency of estimates of the rate of return to R&D investment derived from estimation of eq. (6) using firm-level data.

Many large R&D-performing firms conduct operations in a number of industries, or lines of business (LBs). For example, in 1985 84% of the 6505 (relatively large, publicly-traded) American firms included in Standard and Poor's Business Information Compustat II SIC file had more than one LB. 31% had more than 5 LBs, and the mean number of LBs was 5.5. Unfortunately, though, data on output and inputs by firm by LB are not generally publicly available; only consolidated company data (e.g., total company sales or employment) are reported. Therefore many analysts attempting to construct firm-level TFP series have been forced to assume that the firm operates in a single industry -- the industry of its largest LB. This approach increases the noise component of measured TFP and reduces the precision of estimates of Π.

To see this, consider the following simple example of a firm that operates in two (4-digit Standard Industrial Classification) industries. Let V_i = the firm's nominal output in industry i (i = 1, 2) and P_i = the price deflator for industry i. If $V_1 > V_2$, then industry 1 is considered to be the firm's major LB, and under the conventional methodology (based on consolidated company data) industry 1's price deflator would be used to deflate the entire company's sales:

$$Y = (V_1 + V_2) / P_1 \tag{18}$$

The "true" or correct measure of real output is, however,

$$Y^* = (V_1 / P_1) + (V_2 / P_2) \tag{19}$$

It is clear that Y and Y^* will grow at different rates if there are changes in the relative price of the two industries' outputs. Similar issues are associated with the measurement of the real *input* of diversified firms.

It is reasonable to hypothesize that $TFP' \equiv Y' - [\alpha K' + (1 - \alpha) L']$, the productivity growth measure based on Y', will be subject to greater measurement error (and exhibit greater variance) than $TFP^{*\prime} \equiv Y^{*\prime} - [\alpha K' + (1 - \alpha) L']$, the productivity growth measure based on $Y^{*\prime}$. Lichtenberg and Siegel (1989) were able to test this proposition since they were able to calculate both TFP' and $TFP^{*\prime}$ for a sample of 115 large R&D-performing companies. They also estimated eq. (6) using the two alternative measures of the left-hand-side variable; we refer to the corresponding estimates of the coefficient on (RD/Y) as Π and Π^*, respectively.

As expected, the sample standard deviation of TFP' was 29% larger than that of $TFP^{*\prime}$. The estimates of Π and Π^* were (t-ratios in parentheses) .079 (1.70) and .086 (2.28), respectively. The two point estimates are similar, but the standard error of Π is 23% larger than the standard error of Π^*. Indeed, Π^* is significant at the .05 level, but Π is not. Properly accounting for the industrial diversification of firms results in substantially more efficient estimates of the rate of return to their investments in R&D.

6. Heterogeneous R&D and Aggregation

So far we have treated R&D investment as homogeneous, i.e., we have not been concerned with distinctions between different "types" of R&D, such as basic research vs. development, and privately vs. publicly funded R&D. Yet a number of studies suggest that these distinctions are very important, and that there may be very different rates of return to different components of total R&D. Lichtenberg and Siegel (1991) ran productivity growth regressions on firm-level data in which R&D was disaggregated into basic research (BASIC), applied research (APPL), and development (DEVEL), and obtained the following results (t-ratios in parentheses):

$$TFP^{*\prime} = \text{const.} + \underset{(13.1)}{1.34}\,(BASIC/Y) + \underset{(1.1)}{.11}\,(APPL/Y) + \underset{(0.2)}{.01}\,(DEVEL/Y)$$

The estimated rate of return to basic research is enormous -- 134 % -- much larger than the return to applied research and development. In fact, only the basic research coefficient is statistically significant.

They also estimated a model in which industrial R&D was classified by source of funds (company funds (CRD) vs. federal funds (FRD)):

$$TFP^{*\prime} = \text{const.} + .35\,(CRD/Y) + .03\,(FRD/Y) \qquad (20)$$
$$\qquad\qquad (13.1) \qquad\qquad (0.8)$$

The estimated rate of return to company-funded R&D is positive and highly significant, but we are unable to reject the null hypothesis that the return to federally-funded R&D performed in industry is zero. Most federally-funded industrial R&D is defense-related, and problems associated with measuring, and adjusting price indexes for, quality change may be particularly severe in military industries. Thus the difference between the estimated returns to company and federal R&D may be overestimated. However there is evidence from case studies that the return to U.S.-government-sponsored *civilian* R&D programs has also been very low:

> The history of [six] federal R&D commercialization programs [studied -- communications satellites, photovoltaics, supersonic transport, breeder reactors, space shuttle, and synthetic fuels --] is hardly a success story. On the basis of retrospective benefit-cost analysis, only one program [communications satellites] achieved its objectives and can be regarded as worth the effort. But that program was killed... [1]

Hence the rate of return to R&D investment may depend upon who is sponsoring the activity, whether or not it represents basic research, and other conditions. What if we ignore these complications in econometric practice, treating R&D as homogeneous ?

If we estimate eq. (6), will we obtain an estimate of the (weighted) *average* return to different types of R&D investment ?

To investigate this, suppose that the "true" productivity-determination equation is as follows, instead of eq. (6):

$$TFP' = \Pi_1\,(CRD/Y) + \Pi_2\,(FRD/Y) \qquad (21)$$

Since RD ≡ CRD + FRD, eq. (6) is a restricted version of eq. (21), in which the restriction $\Pi_1 = \Pi_2$ is imposed. It can be shown that if eq. (21) is the true model, the probability limit of the coefficient from the (misspecified) regression (6) is

$$\text{plim}\,\Pi = w\,\Pi_1 + (1 - w)\,\Pi_2 \qquad (22)$$

where $w \equiv (1 + \Gamma\mu) / (1 + \mu^2 + 2\Gamma\mu)$, Γ = the correlation coefficient between (CRD/Y) and (FRD/Y), and μ is the ratio of the standard deviation of (FRD/Y) to the standard deviation of (CRD/Y). Eq. (22) reveals that plim Π is a weighted sum of Π_1 and Π_2; the

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[1] Cohen and Noll (1991, 365).

weights sum to 1 but do not necessarily lie in the unit interval. Thus, plim Π need not be bounded by Π_1 and Π_2.

We have estimated the "restricted" model (6) using essentially the same sample of firms used to generate the estimates shown in eq. (20). The estimate (t-ratio) of Π is .09 (2.3). Despite the fact that about two-thirds of industrial R&D is company funded, this figure is much closer to the estimated return to federally-funded research (Π_2) than it is to the estimated return to company-funded research (Π_1). This turns out to be attributable to the fact that (FRD/Y) varies much more across firms in the sample than (CRD/Y), and also because these variables are essentially uncorrelated. The moral of this exercise is that we need to exercise caution in interpreting the coefficient of an aggregate when the coefficients of its components are believed to differ.

7. Effects of Government Policy on Private R&D Investment

Even if, as the evidence cited above suggests, government R&D does not contribute directly to industrial productivity growth, a nation's government policies may affect productivity indirectly, by influencing private R&D spending. A number of previous studies indicate that certain government policies have important effects on the rate and direction of private innovative activity.

Changes in public R&D spending may affect private R&D expenditure via both the price and quantity of private R&D inputs. Therefore a positive correlation between public and private R&D *expenditure* does not necessarily imply that there are positive "knowledge spillovers" from public to private R&D, or that publicly-supported R&D contributes to productivity growth in the private sector. For example, increases in public R&D may drive up the prices of inelastically-supplied technical resources, and thereby "crowd out" private R&D investment. To determine the private R&D response to public R&D, it is therefore important to distinguish between the impact of public R&D funding on the *quantity* and the *price* of private R&D inputs.

There are three principal ways in which the government promotes R&D dedicated towards public goods (e.g., national defense and space exploration): (1) conducting R&D in government laboratories; (2) contracting with firms, universities, and other organizations; and (3) sponsoring design competitions, and offering "prizes for innovation." (What factors determine which arrangement should be used for any given R&D project?) In the U.S., at least during certain periods (e.g., the defense buildup of the early 1980s), a significant fraction of "privately-funded" R&D (non-contract R&D performed by industrial firms) appears to be oriented towards public-sector goals, especially national defense. "Private R&D" is not synonymous with "civilian R&D."

In the U.S., government sponsored industrial R&D is merely the "front end" of a much larger procurement process. Failure to recognize this may result in incorrect inferences about the impact of government R&D on private R&D. Public procurement of goods and services other than R&D may also have an important impact on private R&D -- perhaps a larger impact than government R&D. The effect of procurement on private R&D depends on the method of procurement -- competitive versus noncompetitive -- which is related to the phase of the procurement cycle -- early versus late.

The government may influence the amount and type of private R&D by offering tax credits or other subsidies, although the historical effectiveness of these is not well understood. In some cases, to determine the effective (as opposed to nominal) rate of subsidy provided by tax or accounting rules, it is necessary to evaluate these rules in a dynamic (as opposed to static) setting. This is true in the case of the U.S. Defense Department's Independent Research and Development policy.

Other aspects of the tax system, not specifically directed towards R&D, may nevertheless have indirect effects on it. Some people have argued that American business shifted from equity finance to debt finance in the 1980s because interest payments are deductible expenses and dividend payments are not. There is some evidence that increases in leverage are associated with reductions in corporate R&D spending.

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Comment : *Antonio Cardone*

Prof. Lichtenberg has given us a very good survey on quantitative models commonly used for the assessment of the economic impact of R & D investment on productivity growth.

The fundamental relationship analysed in Prof. Lichtenberg paper is the one between Total Factor Productivity (TFP') and the ratio of R & D investment to output through the marginal product of knowledge capital (TT).

Under the assumption of a zero depreciation rate for knowledge capital, the parameter TT may also be interpreted as the rate of return to investment in R & D. To be more precise, because labour and capital engaged in R & D are usually already included in the measures of K and L, TT represents the excess rate of return to R & D investment - i.e., as Prof. Lichtenberg says, the additional return for employing these factors in R & D, rather than in ordinary production.

If we introduce the distinction (1) between technical progress and technological progress, we may say that while the impact of technical progress is captured by K and L, that of technological progress is captured by R & D expenditure.

We recall that :

$$TFP' = Y' - [a\ K' + (1 - a)\ L']$$

where X' = d in X / d t.

This means that in order to get a correct measure of the TFP' series we need not only a good measure of real output growth, but also of K' and L'. If it is so, then Prof. Lichtenberg analysis on the properties of parameter estimates should perhaps take into account also the problems raised by quality changes in capital and labour inputs.

Other problems arise when we look at the variable R & D investment and consider its heterogeneity, i.e. whether publicly or privately funded, whether financing basic or applied research programs.

Prof. Lichtenberg shows that when it is believed that the coefficients of the components of R & D expenditure differ, than caution should be used in interpreting the coefficient of the aggregate.

In particular in the paper are reported two regressions according to which comes up that while basic research has a large and significant impact of TFP', for government funded R & D the null hypothesis of a zero rate of return cannot be rejected. This finding is explained saying that "the rate of return to R & D investment may depend upon who is sponsoring the activity, whether or not it represents basic research, ...".

Now, it might well be that the quality of the public R & D is not the same as that of private R & D being the first more away from the market place that the second, so that when we look at the relationship postulated amongst TFP, on one side, company funded R & D and government funded R & D, on the other side, in fact we are looking at two qualitatively different types of R & D activities, the first with a more direct impact on factor productivity, because directly targeted at that, the second less so.

Because, as an example, public funding is generally available for pre-competitive R & D activity, it turns out that, in order to be able to obtain an impact on productivity, and hence on competitiveness, the firm needs not only to carry out further R & D activities, but it also needs the skills involved in converting R & D results in increased market share and then production.

In Italy (2) we carried out a research on the results of schemes supporting firm R & D activities, comparing the performance of firms whose R & D was supported versus firms which did not receive any public support to their R & D activities. From the results of that research, we drew the conclusion that what was discriminating was not whether R & D funding was public or company originating, but whether the R & D programmes were more or less oriented towards the market (basic research versus applied research and development). That's to say that, in out case, basic research supported by the government had less impact on productivity growth than applied research supported as well.

We find, then, the results reported in Prof. Lichtenberg paper on the problem of heterogeneous R & D puzzling : suppose that there is a relationship between financial sources of R & D activities (government versus company) and type of R & D activities (basic versus applied), then when regressing TFP on BASIC/Y and APPL/Y and then TFP on CRD/Y and FDR/Y, we should find that when BASIC/Y is a good explanatory variable for TFP, also FRD/Y is a good explanatory variable for TFP.

If we go on bearing in mind this relationship between R & D funding sources, public versus company, then also the effect of government on private R & D can be reassessed. It might be that even if there is no appreciable direct effect of government funded R & D on TFP growth because of the type of research carried out with public funding, still there is an indirect effect via company funded R & D. If we look at the problem from a static point of view, then, as Prof. Lichtenberg says, the problem is one of finding out whether there is any crowding out effect on private R & D investment when public and private R & D activities draw on the same stock of given resources. But, from a dynamic point of view, it might well be that public funded R & D activities are such to represent a pre-requisite for private funded R & D : i.e. public funded and company funded R & D are complementary goods. Some dynamic is then needed in the models described by Prof. Lichtenberg.

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Chapter 5 - The Applied Econometrics of R&D Public Funding : What's That For ?

Henri CAPRON

1. Introduction

It is common knowledge that public authorities repeatedly stress the key role of science and technology policy to restore growth in developed economies. However, while those within governmental spheres may believe that structural change and economic recovery cannot be attained without an efficient science and technology policy, the latter has only very recently been thoroughly integrated as a structural competitiveness instrument of economic policy. Besides, as public decision-making tools, existing macroeconometric models have not been designed to measure the effects of technological innovation. Yet, techniques being at the heart of economic growth, macroeconomics does have something to do with the public management of technological change. Performance in economic activity stems from technology and technological change implies transformation of economic structures : it causes asymmetrical improvements in factors productivity and constantly hampers the equilibrium mechanisms of the economy.

So, the growing awareness of the direct effects of the technological race between industrialized countries enhances the importance of technology assessment as an instrument of public policy decision-making, technology assessment referring to many types of programmes or projects ranging from monitoring to systematically analyzing whether policies implemented to promote technological capabilities have had any impacts. Hence, the question that arises is : So far, have quantitative methods been really well suited for evaluating the economic impact of R & D policies ?

In order to answer such a question, it is helpful to see how empirical economic analysis deals with technological change. Although the question of how technology and economics relate to one another is not a new one, empirical studies of this relationship are much more recent. Very often methodological short cuts are used to measure the impact of technological change. Without going into an extensive critical review of all these methods, the second section shows to what extent technical change has remained a mystery in economic analysis and consequently in macromodels. Further in the section, we sketch some prominent quantitative attempts at getting inside the black box. Our review is limited to the models which have tried to disentangle the relationship between economic performances and R & D investments. These basic models constitute the conceptual background against which the main attempts to ascertain the economic impact of public R & D funding are built. The third section of this paper focuses on the assessment of the impact of public R & D expenditure. We first stress how useful it would be to have a better grasp of the economic impact of public R & D investments, which enhances the need of quantitative assessment as an instrument of public policy decision-making. The rest of the section is devoted to an overview of econometric studies aimed at measuring the impact of publicly-funded R & D resources on both productivity and private R & D investments. A large part of the studies dealing with publicly-funded R & D can be classified into one of the two following categories : production approach or demand approach.

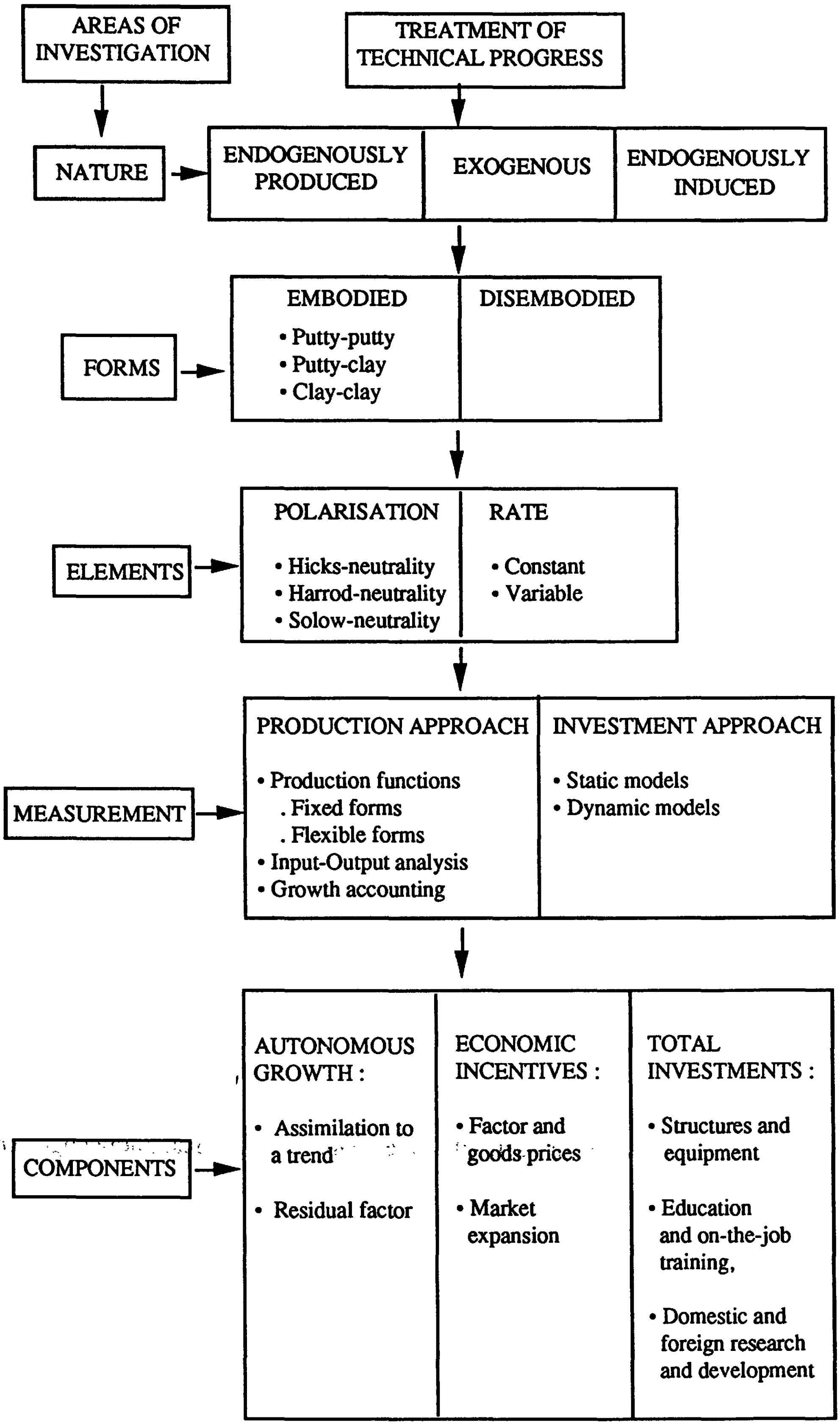
2. The Macroeconomic Analysis of Technical Change

2.1. The Neo-classical Background

Very extensive surveys of the literature on the role of technical progress in economic development have been made by Nadiri (1970), Kennedy and Thirlwall (1972), Nelson (1981) and Stoneman (1983). All these reviews underline the reductionist tendency of the neoclassical paradigm that regards technical progress as exogenous to the economic system and does not consider technology to be one of the main ingredients of the production function. Production theory is a statement of interaction and interdependence of inputs such as labor, material and capital investments needed to produce an output. There is no real attempt to describe what goes on inside the production process. Despite thirty years of effort made to overcome this naïve hypothesis, technical progress still remains a vast black box in macroeconometric models.

A summary of the alternative macroeconomic conceptions of technical progress is presented in Figure I. In the production theory, it is the technical relationship between production factors that carries in itself all the relevant technological knowledge. The origin and nature of technical change do not matter : only the economic effects of the implementation of technology have something to do with economics. The production functions used in empirical investigations arise from this neo-classical paradigm. From a general viewpoint, most attempts to assess the impact of new technologies are based on a simplified formalization of technical progress. However, the choice of a production technology is at the heart of the framework of global macroeconomic models because it profoundly conditions the overall structure of macro-relationships.

Figure I - A synthetic view of the macroeconomics of technical progress



In most empirical studies, the technological variable is taken into account by the addition of a trend to production or factor-demand functions, technical change being only a function of time. Within the neo-classical tradition of an exogenously produced technical progress, the effects of technical progress are typified according to their neutral or biased character : Harrod - neutrality when technical progress is labour - augmenting, (i.e. for a given capital stock, the production of a same quantity of output requires less labour input); Solow - neutrality if technical progress is capital - augmenting, (i.e. it increases capital efficiency); Hicks - neutrality in the case of product - augmenting technical progress, (i.e. when the efficiencies of both traditional production factors are identically increased). It is considered immaterial (or equivalently disembodied) in so far as it is unrelated to current investment decisions. One form of production function, the Cobb-Douglas, is consistent with these three classes of technical change. The disembodiment hypothesis leads to inadequacies in explaining the role of technical change in the process of capital accumulation and as a consequence in the process of economic development : technology is a by-product that comes from nowhere, is costless and has nothing to do with economic dynamic.

By and large, empirical analyses are based on one of the three following production functions : the Cobb-Douglas, the constant elasticity of substitution (CES) and the transcendental logarithmic (translog) one. Each of these production functions has its own specificities and includes the preceding ones as particular cases. The first two are fixed functional form production functions which are additive homogeneous and impose stringent limitations on substitution patterns [1]. The third one belongs to the so-called category of flexible functional form production functions. In a nutshell, such functions enable to overcome the limitations of the traditional approach by allowing quadratic and interaction terms in the explanatory variables. Their key features are that they characterize the production function by means of a dual formulation such as cost function and that they generate explicit demand and supply functions [2]. Alternatively to production functions, factor demand functions can be derived from the profit maximization rule. The resulting investment approach is based on both static and dynamic models according to the hypotheses made about the equilibrium [3].

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1 The literature reports a lot of CES-cousin functional forms among which the non-homothetic CES, the generalized CES, the nested CES, the induced-CES (IES) and the VES (variable elasticity of substitution). For a survey, see, e.g. Capron (1992b).

2 An alternative formulation is the generalized Leontief parametric form which uses the square roots of explanatory variables rather than the logarithms.

3 See, for example, Bernstein (1986) and Mohnen, Nadiri and Prucha (1986) for recent applications to R & D investment.

Despite the high sophistication of the production theory and the abundance of empirical models, the real measurement of technical change, while it has noticeably progressed, faces methodological stalemates [1]. Hence, there is a well-known identification problem between the effects of technical change and the effects of economies of scale. Technical progress is intrinsically linked to the technical characteristics of production processes and to the game of economic forces : efficiency, nature and variability of technical change, substitution properties, returns to scale and their distribution among factors, depreciation rate of physical capital and the embodied technical change, movements of factor and goods prices, market expansion structure, patterns of consumers' tastes and preferences, education and on-the-job training are all elements which have something to do with technical change and affect production processes.

The input-output framework has also been largely used for evaluating the overall impact of technological change on the economy. Input-output coefficients allow to take into account the proximity between industries. Capturing the interconnections between industries enables to measure global (direct and indirect) impacts of a shift in both inputs and outputs of a sector on other sectors [2]. This shift can be the introduction of a new innovation whose backward and forward impact one tries to trace. Yet, although the input-output analysis is a powerful method for recording the effects of technical change, its rigid structure and the scarcity of data seriously limit its application field.

The growth-accounting approach has been extensively used for evaluating the sources of economic growth. The first measures of total factor productivity have shown that the growth of production factors did not explain a large part of the economic growth. The resulting residuals were mostly interpreted as the impact of technical progress and called the measure of our ignorance. Despite substantial improvements of this method [3], it is based upon very stringent hypotheses and if it gives a disaggregated diagnosis of the economic evolution, it remains silent on how economy works.

In the disembodied hypothesis, the structural elements of physical capital are independent of technical change : all vintages of equipment are equally affected by changes in technology. This assumption is relaxed with vintage models which allow technical progress to be embodied only in new generations of equipment and material. With such en-

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1 A survey of econometric studies of production functions was carried out by Wilson (1984). His main conclusion is that, despite numerous reserves, the econometric analysis of production functions is the only source of information available for measuring the effects of technical change. However, its results must be cautiously interpreted.

2 See, for example, Carter (1990) and Wyckoff and Sakurai (1992), as well as the discussion of Sato and Ramachaudran (1980).

3 For a survey, see Maddison (1987).

larged basic assumptions, technology can be assumed to be putty-putty, putty-clay or clay-clay according to whether substitution between traditional factors (i.e., labor and capital) is respectively permitted just ex-ante or both ex-ante and ex-post, or just ex-post with regard to the current period of decision. But in these models too, technical progress is regarded as manna from heaven : technological knowledge is implicitly assumed to be a public good, which neglects that innovative activity yields proprietary advantages. Besides, these models ignore the property of "technological variety" which allows quality improvements of all the capital stock and not exclusively of new capital goods. In spite of the very high degree of mathematical sophistication of the embodiment hypothesis, the subsequent models do not really improve the explanation as to how technical change causes growth. As quoted by Nelson (1981) "research, guided by the neo-classical paradigm, has reached a stage of sharply diminishing returns".

In the search for sources of technical change, the idea of mutual causation through inducement mechanisms has been largely supported [Binswanger and Ruttan (1978)]. Models of induced innovation identify the origins of growth as a result of economic forces interacting with each other. According to this concept, the rate and direction of technical change would be essentially determined by factor and goods prices and market expansion. The most important argument against using such a conception of technical change is that it does not come near explaining the intricacy of technology creation.

To sum up, these neo-classical views have failed to provide an adequate understanding of the economics of technical change. Recently, the neo-Schumpeterian school [Nelson and Winter (1982)] has rejected these neo-classical approaches by arguing that technology is really the main driving force of economic change, the process of technological change being an evolutionary process which is :

- interactive because technology-push, demand-pull and their interaction are at the source of innovation;
- cumulative because technical change is the result of a feedback mechanism which leads to improvements in organizational and technical capabilities;
- institutional due to the fact that innovation no longer occurs at random but is the result of an organized activity;
- and disequilibrating because innovation is a continuous activity which permanently improves both processes and products.

The main contribution of the neo-Schumpeterians has been to emphasize that technological change is actually a social process. This implies rethinking large parts of economic theory and, among other things, explicitly introducing technology in macromodels.

2.2. Return to the Sources of Growth

Technological innovation costs money, requires material supports and consequently, macromodels must show explicitly how the various factors involved interact when used for explaining disequilibrium phenomena generated by technical change. With this in mind, meta-production functions [1] incorporating research and development investments have been estimated in order to capture the effects of technological change upon the growth of output. From a production function viewpoint, the use of R & D expenditures (technology-input measure) has the advantage of reflecting both imitation and innovation activity while the other possible candidate variable, patenting activity (technology-ouput measure), only reflects innovation process. But more fundamentally, a broader concept of capital is needed for evaluating the contribution of technological progress to economic growth.In a suggestive study on the explanation of differences in growth between countries, Fagerberg (1988) pointed out that one has to distinguish between 'active factors' (which are the real engines of growth), and more 'passive factors' which, though "permissive to" growth, cannot themselves be regarded as causal, explanatory factors. Creation, diffusion and exploitation of technology are the active sources of growth and imply both material and immaterial investments.

From this point of view, the notion of total capital, developed by Kendrick (1976) in the frame of his growth accounting exercises, seems very attractive. So, more attention should be paid to what he has called the "hidden investments", i.e. human and knowledge investments. Hence, the total capital gathers all categories of investment : physical investment in new structure and equipment, human investment realized through formal education, on-the-job training and knowledge investment carried out for improving and reinforcing technological competitiveness. The inclusion of total investment in macromodeling would noticeably improve our understanding of economic growth [Capron (1988)]. This new concept has been implemented by Capron (1990) in a small-scale macromodel of the Belgian economy for the period 1963-1985 [2]. A new search for the best structural equation for this model gives the following result :

$$QL_t = \underset{(8.36)}{e^{-16.29}} \; \underset{(2.36)}{SL_t^{\,0.27}} \; \underset{(7.65)}{K_{t-2}^{\,0.85}} \; \underset{(1.20)}{H_{t-4}^{\,1.20}} \; \underset{(3.76)}{e^{-0.09\,t}}$$

$$\bar{R}^2 = 0.99 \qquad DW = 1.44$$

[1] The use of the prefixe "meta" is very illustrative of the marginal status of technology in the production theory.

[2] In the structural equations of the model, the R & D capital stock is also a determinant of both manufacturing employment and export and the educational capital stock an explanatory variable of the R & D investment.

where Q_{L_t} is the hourly labor productivity, S_{L_t} the physical capital stock per labor unit (corrected by the rate of use of production capacities), K_t the R & D capital stock, H_t the educational capital stock and t the time.

As can be seen, the R & D capital stock and the educational capital stock significantly influence labor productivity and their elasticities are higher than the elasticity of physical capital. The labor productivity elasticity of R & D appears high compared to the elasticities reported by other studies. Yet, a large part of them consider firm or industry data and, consequently, only measure the direct effect of these investments on the productivity of performing companies or industries. At the aggregate level, the estimated coefficient picks up both direct and indirect effects. The productivity impact as measured by a macroeconomic model is likely to reflect the spillover effects as well. The very high coefficient obtained for the educational capital stock shows the vital impact of education on labor productivity.

Alternative investigations of these data in order to split up the total R & D stock between private R & D stock and public R & D stock have given the following result :

$$Q_{L_t} = \underset{(9.67)}{e^{-14.35}} \; \underset{(1.95)}{S_{L_t}^{0.31}} \; \underset{(4.65)}{K_{P,t-1}^{0.58}} \; \underset{(6.80)}{K_{G,t-3}^{0.24}} \; \underset{(3.13)}{H_{t-5}^{0.94}} \; \underset{(2.70)}{e^{-0.08\,t}}$$

$$\bar{R}^2 = 0.99 \qquad DW = 1.87$$

where the subscripts P and G for the variable K respectively refer to private R & D stock and public R & D stock. All the variables are significant, showing that all the elements of total capital influence the evolution of the output. Yet, these results may be contested by arguing that, in fact, both educational and R & D variables will seize upon a trend effect. In other words, the observed correlation might be spurious. To confirm the initial estimates, an alternative model based upon the growth rates has been tested :

$$\dot{Q}_{L_t} = \underset{(2.15)}{-\,0.09} + \underset{(1.95)}{0.34\,\dot{S}_{L_t}} + \underset{(2.77)}{0.64\,\dot{K}_{P,t-1}} + \underset{(2.25)}{0.21\,\dot{K}_{G,t-3}} + \underset{(2.31)}{1.11\,\dot{H}_{t-5}}$$

$$\bar{R}^2 = 0.46 \qquad DW = 2.53$$

The estimated coefficients remain significant and their values are not noticeably different from those obtained in the "level model". These results confirm the importance of both private R & D investments and educational investments in the explanation of the labor productivity growth in Belgium. If we compare these results with the estimates obtained by Levy and Terleckyj (1983) for the U.S. private business sector, we observe that our elasticities for both private and public R & D investments are about twice their values. While such an observation calls for further research, the divergence may perhaps be explained by some structural characteristics of the two economies. Belgium does not invest a significant amount of its R & D expenditure in defense and the percentage of R & D expenditure in the GDP is largely inferior to the percentage observed in the U.S. Indeed, unlike large countries which are principally concerned with the mastery of the whole technological spectrum, small countries are under strong pressure to specialize in particular technological fields so as to acquire competitive advantages on international markets. These elements may partially explain the high elasticity observed for Belgium.

This example illustrates that technological variables are as vital in macromodels as economic ones and that these models are facing the challenge of adapting their structure to integrate the actual driving forces of economic growth.

2.3. The Applied Economics of Endogenous Technological Change

The most commonly used approach to the estimation of productivity models considers a Cobb-Douglas meta-production function involving besides the traditional production factors, labor and physical capital, a measure of R & D capital stock :

$$Q_t = A\, e^{\lambda t} L_t^{\alpha} K_t^{\beta} R_t^{\gamma}$$

where Q_t is the production output, L_t is the labor, K_t is the physical capital, R_t is the R & D capital stock, t = the time index and A, λ, α, β and γ are the parameters to be estimated.

As for the net physical capital stock, the measure of the net capital stock of R & D is generated by using the perpetual inventory method :

$$R_t = S_{t-i} + (1 - \delta)\, R_{t-i}$$

where S_t is the R & D expenditure at constant price, i, the lag between R & D investment and its first effect on production, and δ is the depreciation rate of R & D investment. At this stage, we face a treble problem : the choice of the R & D deflator, the research gestation time and the measurement of the depreciation rate for R & D investments.

From such a general equation, alternative specifications can be obtained :

1. The production-function specification in log form

$$q_t = a + \lambda t + \alpha l_t + \beta k_t + \gamma r_t$$

2. The growth rate-function specification

$$\dot{Q}_t = \lambda + \alpha \dot{L}_t + \beta \dot{K}_t + \gamma \dot{R}_t$$

3. The partial productivity-function specification

   In some studies, the preceding equations are simplified by measuring the labor productivity function :

$$(q_t - l_t) = a + \lambda t + \beta (k - l) + \gamma r_t$$

$$\dot{Q}_t - \dot{L}_t = \lambda + \beta (\dot{K} - \dot{L}) + \gamma \dot{R}_t$$

   on the basis of the hypothesis of constant returns to scale with, as a consequence, $\alpha + \beta = 1$.

4. The total productivity-function specification

$$(q_t - \alpha l_t - \beta k_t) = a + \lambda t + \gamma r_t$$

   or alternatively,

$$(\dot{Q}_t - \alpha \dot{L}_t - \beta \dot{K}_t) = \lambda + \gamma \dot{R}_t$$

   In such an approach, it is usual to assume constant returns to scale and to impose that the conventional input elasticities are equal to their respective shares in total cost.

These alternative specifications require to evaluate the R & D capital stock. Such an evaluation implies having historical data about R & D investments and knowing the rate of depreciation of these investments. These issues raise a lot of problems. Generally, data are not available over a sufficiently long period, which entails that the initial R & D capital stock has to be defined arbitrarily. There is also a high degree of arbitrariness in the real value of the depreciation rate to be taken into account. This value can vary over time, be different from one sector of activity to another and change depending on research orientations. To overcome these complications, we can reparameterize these equations. Considering the output elasticity of R & D :

$$\frac{\partial Q_t}{\partial R_t} \cdot \frac{R_t}{Q_t} = \gamma$$

we can write :

$$\frac{\partial Q_t}{\partial R_t} \cdot \frac{R_t}{Q_t} \cdot \frac{\Delta R_t}{R_t} = \frac{\partial Q_t}{\partial R_t} \cdot \frac{\Delta R_t}{Q_t} = \rho \frac{\Delta R_t}{Q_t}$$

where $\rho = \partial Q_t / \partial R_t$ is the rate of return to investment in R & D and ΔR_t is the first difference of R & D capital so that :

$$\Delta R_t = S_t - \delta R_{t-1}$$

where δ is the rate of depreciation of R & D capital and S_t is the R & D investment at time t. If we hypothesize that δ is zero or close to it, we can write :

$$\gamma \dot{R}_t \simeq \rho \frac{S_t}{Q_t}$$

So, a new alternative formulation of specifications containing $\dot{R}_t$ can be obtained by substituting $\rho \frac{S_t}{Q_t}$ for $\gamma \dot{R}_t$.

However, it must be noticed that :

- In aggregated studies the R & D inputs are generally not subtracted from the conventional measures of capital and labor. Thus, there is a double counting problem. In such a case, the estimate of ρ represents the average excess of social over private returns [Griliches and Lichtenberg (1984)], i.e. excess returns above and beyond remuneration to traditional factors.
- Moreover, the estimated rate is a gross rate of return that does not take into account the depreciation rate. So, we cannot avoid the problem of measuring the depreciation rate if we want to know the net rate of return to R & D investments.
- While, in the equations expressed in terms of elasticity, the ratio between the marginal productivity and the mean productivity of R & D investment is constant, in the equation defined in terms of intensity of R & D investment the marginal productivity of R & D investment is supposed constant.
- Although the deterministic versions of the four groups of equations are equivalent, they are not stochastically equivalent once we use the OLS estimation procedure.
- The interpretation of coefficients will be different depending on the level of data aggregation. Hence, in studies which make use of panel data (firm level), the estimated coefficient for the rate of return is often referred to as the private return. In cross-sectional analyses of sectoral data, as sectoral R & D investments are the explanatory variable, one can assume that the estimated coefficients measure both the private effect and the intra-industrial spillover and will be interpreted as the social return to R & D investment [1]. For example, to measure the total impact of R & D at the firm level, one can

[1] Such an interpretation is criticized by Nelson (1988). He argues that the cross sectional correlation between R & D intensity and productivity growth largely reflects differences in technological op-

construct three variables that represent respectively the own R & D, the intraindustry spillover (i.e. the sum of R & D stocks of all other firms in the industry) and the interindustry spillover (i.e. the sum of R & D stocks of all other industries) [1].

In a recent survey, Mairesse and Sassenou (1991) have provided a broad picture of the main studies making use of panel data. With a view to completing their qualitative evaluation, a regression analysis has been conducted on the coefficients that they have gathered in several successive tables. These coefficients are the estimated results of output elasticities of R & D and rates of return to R & D. In their tables, they report information about data characteristics : number of enterprises covered by the sample, period considered, industry sector, reference country, industry dummies or not, nature of the output analyzed (total or partial factor productivity, sales or value added).

A regression analysis has been performed on the estimated coefficients summarized in their study. The distribution of these coefficients is represented in figures 2 and 3 with a confidence interval of one standard deviation [2]. To explain these coefficients, the main data characteristics have been introduced as explanatory variables. Two alternative estimation methods have been used : the ordinary least square and the weighted least square. To obtain an unbiased estimate of the mean value of elasticities, a first weighted least square regression has been realized whose weights are the inverted variances of the estimated coefficients. However, as the number of observations used in the studies may also have something to do with the estimated coefficients, an alternative weighted least square regression has been performed by using the number of enterprises covered by the sample.

The tested variables are defined as follows :

- the inverse of the number of observations taken into account in each regression analysis (number of firms);

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portunity and that differences in appropriability make the relationship noisy. According to him, there are serious flaws in the econometric measurement of the rate of return.

1 Actually, measuring the spillover effects of R & D is not easy at all. Several approaches have been developed in the literature, each having its advantages and drawbacks. For a survey, see Mohnen (1990).

2 These distributions follow the order of the studies about the output elasticities of R & D listed in tables 1 and 2 by Mairesse and Sassenou (1991) and those in table 4 about the rates of return to R & D. Yet, as the rate of return reported for Odagiri's study is very suspicious (value of -0.47), this estimate has been eliminated from the sample.

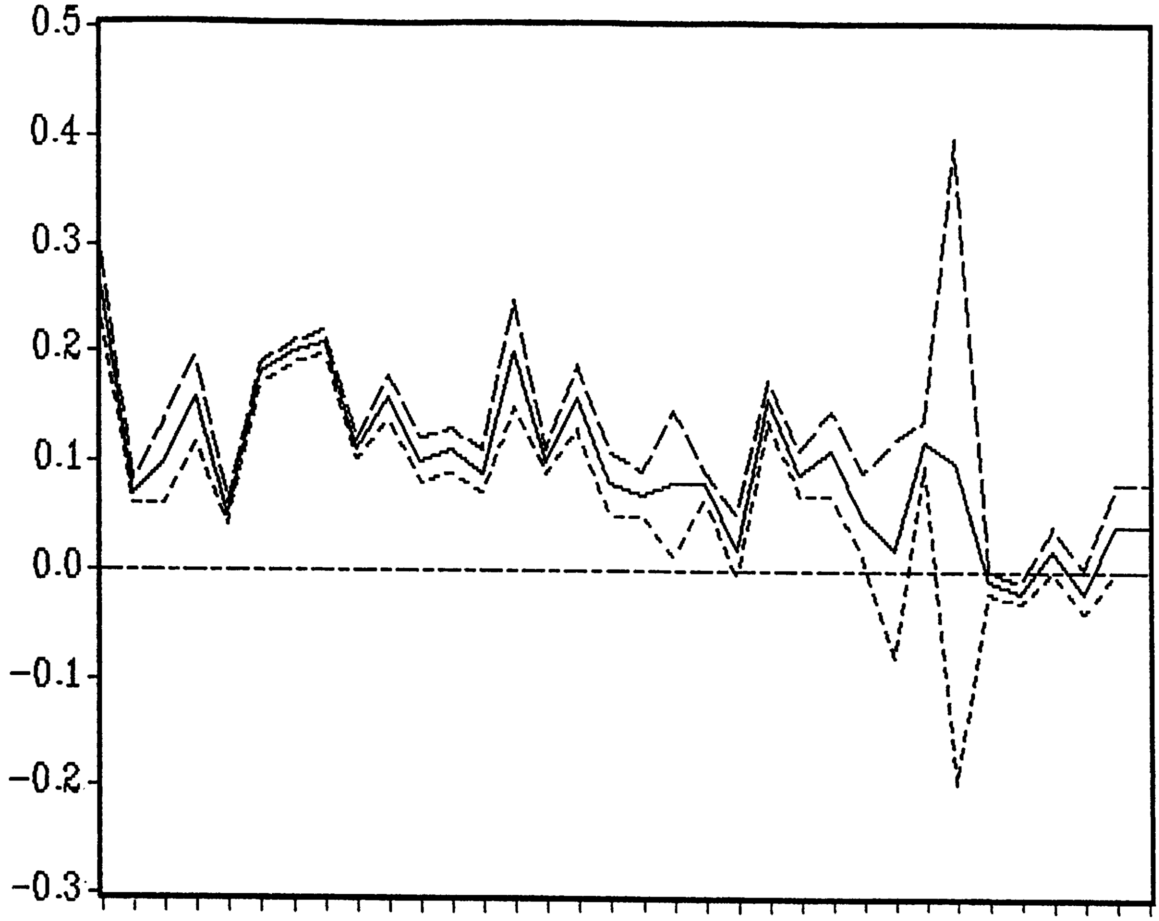

Figure 2 - Survey of output elasticities of R & D

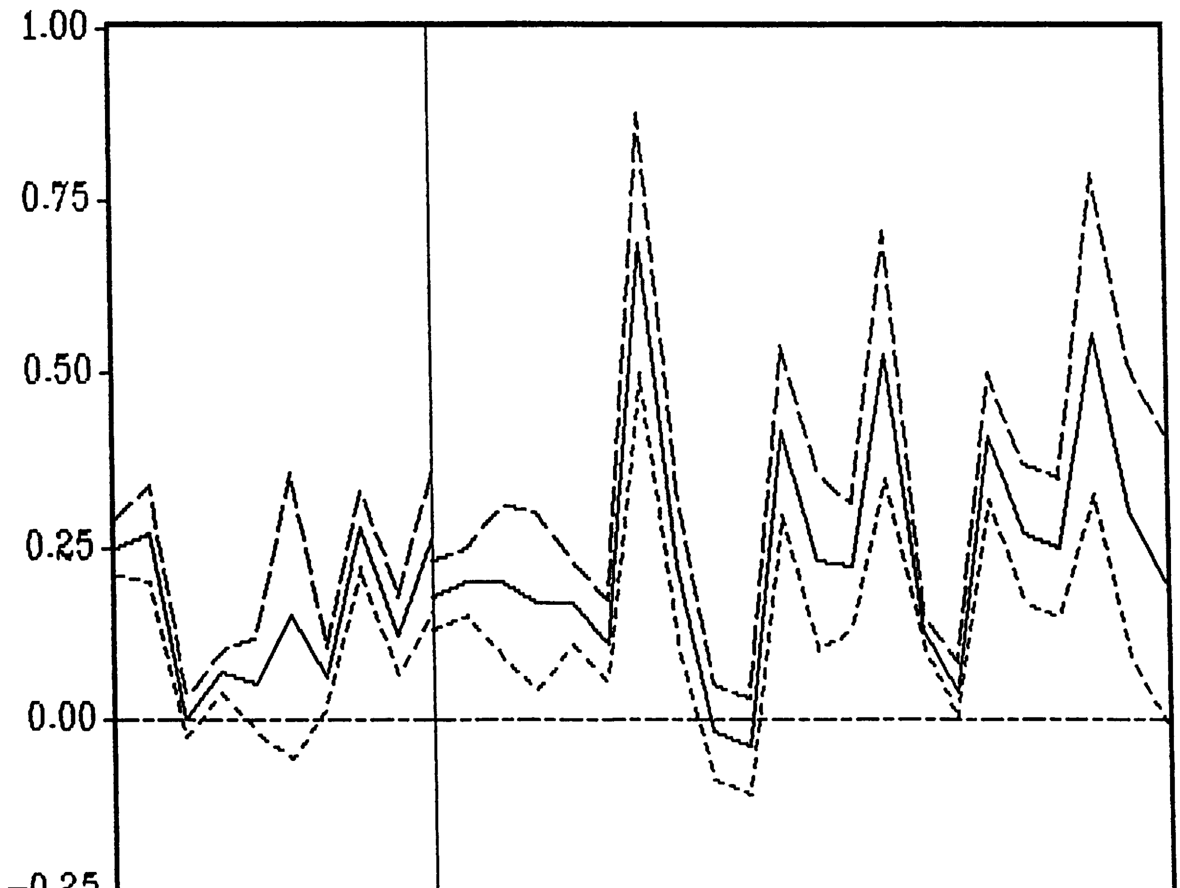

Figure 3 - Survey of the rate of return to R & D

- the average period of estimation refers to the average year covered by the sample;
- the "industry dummies" variable is a dummy taking the value one for the "within industries" estimation in cross-section analyses and zero otherwise;
- "Japan" is a dummy variable for the analyses on Japanese data;
- "US" is a dummy variable for the analyses on US data;
- "scientific sectors" is a dummy variable for the analyses restrained to scientific sectors;
- "cross-section analyses" is a dummy variable for cross-section analyses;
- TFP_S is a dummy variable for analyses whose dependent variable is a measure of the total factor productivity based on gross output;
- TFP_{VA} is a dummy variable for analyses whose dependent variable is a measure of the total factor productivity based on net output;
- "value added" is a dummy variable for analyses whose dependent variable is the value added.

For the analyses listed in the second sample, when the dependent variable is a measure based on gross output, the R & D intensity is calculated as the ratio of R & D investment or capital to gross output. Similarly, when the value added is used, it is for the measurement of both the dependent variable and R & D intensity. The number of observations for each sample is respectively 34 estimates for the output elasticities of R & D and 32 estimates for the rate of return on R & D.

The regression estimates are listed in table 1 and 2. These results can be summarized as follows :

- firstly, regarding the estimates of the output elasticities of R & D :
  - . data characteristics play an important role in explaining divergences in the estimated coefficients;
  - . all things being otherwise equal, the mean value of output elasticity of R & D is about 0.07 - 0.10;
  - . the number of observations, the average period of estimation and the industry dummy do not significantly influence the estimated output elasticity of R & D;
  - . cross-section analyses show a measure of elasticity superior to that obtained from time-series analyses (+0.07) [1];
  - . the dummy variable for Japan is significantly negative which indicates that time-series analyses do not allow to conclude in favour of a significant impact of R & D for this country (contrary to cross-section analyses);

[1] For a discussion of these divergences, see Mairesse and Sassenou (1991).

Table 2. Estimates of rates of return on R & D

Methods of estimation	Constant	Inverse of the number of observations	Average period of estimation	Industry dummies	Japan	TFP_S	TFP_{VA}	Value added	R^2
OLS	0.33 (6.93)					-0.19 (2.31)	-0.12 (2.00)	-0.27 (2.78)	0.27
	0.48 (4.35)	1.06 (2.23)	-4.96 (1.18)	-0.14 (3.16)	0.15 (3.39)	-0.15 (2.55)	-0.28 (5.16)	-0.35 (4.74)	0.69
WLS (inverted variances)	0.20 (3.67)					-0.08 (1.43)	-0.13 (2.24)	-0.22 (1.75)	0.74
	0.37 (6.41)	1.54 (2.62)	-7.68 (4.45)	0.04 (1.47)	0.13 (2.77)	-0.06 (1.72)	-0.17 (4.31)	-0.34 (4.01)	0.92
WLS (number of observations)	0.28 (9.11)					-0.15 (4.55)	-0.16 (1.07)	-0.22 (2.74)	0.87
	0.42 (2.03)		-2.47 (0.30)	-0.16 (4.12)	0.13 (2.76)	-0.06 (1.78)	-0.28 (2.66)	-0.32 (4.85)	0.95

Table 1. Estimates of the output elasticities of R & D

Methods of estimation	Constant	Inverse of the number of observations	Average period of estimation	Scientific sectors	Cross-section analyses	Industry dummies	Japan	U.S.	R^2
OLS	0.04 (0.47)	1.51 (1.36)	1.29 (0.49)		0.07 (4.11)	-0.03 (1.08)	-0.06 (2.41)	0.01 (0.37)	0.59
	0.07 (4.66)	1.11 (1.70)			0.07 (4.27)	-0.03 (1.27)	-0.06 (3.07)		0.58
	0.07 (4.67)	1.12 (1.70)		0.02 (0.72)	0.06 (3.16)	-0.03 (1.24)	-0.06 (3.13)		0.59
WLS (inverted variances)	0.16 (1.40)	4.07 (1.34)	-2.90 (0.67)		0.05 (2.33)	-0.005 (0.10)	-0.08 (2.73)	-0.07 (2.30)	0.83
	0.09 (3.43)	3.27 (1.51)			0.05 (2.26)		-0.10 (3.72)	-0.05 (2.56)	0.82
	0.06 (2.79)			0.05 (2.16)	0.06 (2.75)		-0.06 (2.53)		0.79
WLS (number of observations)	0.03 (0.57)		1.39 (0.83)		0.04 (2.31)	-0.01 (0.46)	-0.05 (1.75)	0.03 (0.99)	0.65
	0.07 (6.89)				0.04 (2.36)		-0.06 (3.22)		0.62
	0.04 (1.45)			0.08 (1.83)	0.03 (1.84)		-0.02 (0.74)	0.08 (1.79)	0.68

  . the other explanatory variables (scientific sector and US dummies) give mitigated results;

- secondly, turning to the estimates of the rates of return on R & D :
  . data characteristics also explain a large part of the divergences;
  . all things being otherwise equal, the average value of the rates of return on R & D is 0.36;
  . the higher the number of observations, the lower the rates of return on R & D;
  . contrary to the previous case, the Japan dummy is significantly positive, which indicates a higher rate of return for this country (+0.15);
  . the measure of output proves to be an important measurement problem for the evaluation of the impact of R & D investments : gross output gives higher estimated values than net output (+0.35), total factor productivity based on gross output (+0.28) and total factor productivity based on net output (+0.15); while the measures of the rate of return based on value added give similar results whatever the dependent variable (value added or total factor productivity based on value added) may be, the use of sales for the measurement of the dependent variable gives significantly lower estimates when the total factor productivity based on sales is introduced as the dependent variable instead of sales;
  . estimation within industries (i.e., with industry effects captured by industry dummies) significantly affects the estimates of the rate of return (-0.14);
  . the period covered by the sample does not play a significant role;
  . the introduction of industry dummies reduces the estimated rate of return.

In a nutshell, the econometric evaluation of the impact of R & D on economic growth allows to conclude that there exists a significant relationship between the two investigated variables. The data characteristics explain a large part of the divergences between the estimates. Yet, some important methodological problems remain, among which the choice of the explanatory variable, data requirements and the search for the most appropriate specification.

3. Assessing the Impact of Public R & D Expenditure

3.1. Hows, Whys and Wherefores of Impact Assessment

The huge implications of governmental involvement in the competition for technological mastership and the considerable controversy about the real efficiency of public intervention in this field have led to a growing demand for evaluation of the real impact of innovation programs. Although the need for more information about the effects of public support of R & D activities has long been debated, it is only recently that empirical quantitative works have been multiplied.

So, how science and technology resources should be allocated so as to have a maximum impact on economic growth has become an important focus for technology assessment. The answer to such a question should be based on both qualitative criteria of evaluation and formalized quantitative methods. Although qualitative methods of evaluation produce useful guidelines for the organization and implementation of R & D policy, they are not suited to measure the economic impacts of public R & D programmes quantitatively. As pointed out by Roessner (1989), "efforts to evaluate government programs intended to stimulate industrial innovation through various types of R & D subsidies are confronted immediately with serious design and measurement challenges".

If we glance at the normative literature on the economic analysis of technological change, we can conclude that, in the present state of the art, although it provides a good understanding of some basic factors, so far it has given practitioners little ground to build on. Hence, some economists argue that governmental funding of R & D is likely to reduce private R & D expenditure because firms may receive support from the public sector for projects they would otherwise finance themselves. Taking an opposite stance, others say that publicly-funded R & D is complementary to and stimulates privately-funded R & D. Futhermore, little is known about the efficiency of alternative forms of public intervention. As a consequence, innovation policy may be said to be today more a matter of faith than of understanding [Rothwell and Zegveld (1988)].

The R & D policy must rest on an appropriate set of actions aimed at influencing or controlling factors which restrain the technological performances of firms. The fuzzy and uncertain nature of R & D policy makes the assessment of the impacts of the instruments used a major analytical issue. Hence, if governmental action induces only small additional private R & D expenditure, then, to justify public intervention the social return must be relatively high. Conversely, if public subsidization results in high additionality and high private return, but with weak positive externalities (the subsidized firm appropriates most of the benefits of the research), then the government must wonder whether its intervention is meant to compensate for market failure and whether the overall economic benefits outweigh the costs. Hence, the design of appropriate policy instruments should be based on the following economic rationale :

- the support should be additional in the sense that the generated activity would not have occurred in a similar form or at all without public intervention.

- the support should result in greater social benefits than otherwise.
- the support should provide higher extra benefits than its opportunity cost.

Given that these outcomes cannot be a priori guaranteed, the economic effects of R & D policy actions have to be evaluated ex post. In case of ex ante impact assessment, since the changes in the exogenous circumstances are unknown, it is difficult to define the reference situation.

The purpose of impact assessment is to have information about the costs, the benefits and the effectiveness of the implemented policy. The impact analysis may cover different and complementary objectives :

- quantitative and qualitative effects on firms' R & D activities (spin-off effect).
- impact on the economic performance(s) of firms (productivity effect)
- impact on the economic performance(s) of industries (spillover effect).
- impact on the economy as a whole (global effect).

To date, only a few empirical studies have endeavoured to estimate the economic impact of R & D policy. Three different types of economic assessment methods are used. The first is the case study. Case studies always leave open the question of how representative they are. Their results are often only valuable for a specific context and any generalisation is a highly risky experiment. The second method consists in surveys conducted among those who have been concerned by the policy. Surveys may provide detailed information on factors influencing decision-making processes and on perceptions of a subsidization policy. However, this method often suffers from lack of accuracy in the way questionnaires are built and measurement errors, which may cause perceived effects to be mistaken for actual ones. An other limitation of the first two methods is that they usually cannot provide information about the effects on variables in a causal chain, they are very costly and time consuming. The third method is the use of econometrics to emphasize the relationship between subsidization and R & D intensity across firms as well as between publicly-financed R & D and productivity performances of firms. This method allows to estimate only direct effects of policy instruments on an impact variable. All these methods belong to the class of micro-studies, they are complementary and they are able, within their own limits, to add some pieces of information to our present puzzle of knowledge about the intricate interdependences between innovative activities and economic performances.

The third method can also be used for two other types of studies : mesostudies and macrostudies. Hence, it is useful to cluster the third method in micro-econometrics, meso-econometrics and macro-econometrics. As far as mesostudies are concerned, input-output models can be used to calculate the effects of technical change on production and demand. Although input-output analysis is a very useful method of recording the effects of public R & D policy, its usefulness is seriously limited by its rigid structure and the scarcity of data. Conversely, macromodelling as a tool for macrostudies is not restricted to recording transactions between industrial sectors. The causal chain of interdependencies can be reproduced by introducing causal variables among the explanatory variables. Only with such an approach can one measure the direct and indirect effects of public policy, provided, however, data are available on a large number of variables. An alternative approach is to combine input-output analysis and macromodels, which is now largely used in the existing macromodels. So far, there does not exist any macromodel that has been designed to deal with public R & D policy. Developing such a model will imply endogenizing private R & D investments and identifying their relationship with publicly-funded R & D investments and the other economic variables. Despite many bottlenecks, macromodels can be adapted so as to be used as a tool for the ex post assessment of R & D public programmes. The outcomes of the econometric pin-point approaches can certainly be very helpful in the implementation of extended macromodels [1].

The efficiency of direct subsidization of private R & D by government and tax-credit public policies is a very controversial subject. In a survey of the production function approach, Griliches (1979) asked different questions concerning the real contribution of publicly-funded R & D to productivity growth : are the returns to government-financed R & D similar to those of company-financed R & D ? Does Federal R & D substitute for or complement private R & D investment ? What are the spillover effects of government-financed R & D ? As the rationale for government funding industrial R & D is more and more questioned, it is of major importance that we should improve our knowledge of the interaction between public and corporate funding of R & D and the contribution of public funding of R & D to economic growth. To date, a number of analyses give some pieces of information on this issue.

Except for the early study by Blank and Stigler (1957), which used an indirect R & D manpower-based approach to analyzing the effects of publicly-funded R & D on industrial R & D, the recent literature has essentially focussed on two direct approaches :

- The productivity approach which measures the respective effects of privately-funded and publicly-funded R & D expenses on the growth rate of output, so giving an evaluation of the output elasticity of public R & D or of the rate of return to public R & D.

[1] A taxonomy identifying the areas to be investigated for an extensive policy assessment is suggested by Capron (1992a).

- The investment approach which measures to what extent public R & D allocations influence privately-funded R & D expenditures, the idea being to look at whether, by doing its own R & D and funding private R & D, a government affects (positively, negatively or not at all) the privately-funded R & D and the magnitude of the effect.

Tables 3 and 4 present a summary of the main studies developed in the framework of these two alternative approaches. A review of some complementary approaches is also synthetized in table 5. In a nutshell, four groups of models have been distinguished : the probabilistic approach, the supply approach, the patent approach and a group "miscellaneous". Each of these studies aims at specific objectives dealing with efficiency issues about public R & D policy [1]. For the sake of space, only some of these studies will be discussed in this review.

3.2. How Productive is the Public Financing of R & D ?

In successive studies using alternative measures of total factor productivity growth, Terleckyj (1974, 1980a, 1980b) found that privately-funded R & D was significantly associated with industrial productivity growth but that government-financed R & D was not. Besides the own sectoral R & D variables, he introduced a measure of borrowed R & D investment obtained by crossing the own R & D expenditure and an input-output matrix. His results show that the spillover effects of privately-financed R & D are very important whereas the indirect effects from publicly-financed R & D are not significant. However, from a more extensive study, Griliches (1980a) concludes that he was unable to discover any direct evidence of the superiority of company-financed R & D as against federally-financed R & D in affecting the productivity growth. This observation results from a comparison of estimates obtained by using alternatively total R & D growth rate and company R & D growth rate. In a more recent study, Griliches (1986) tested the hypothesis of a differentiated impact of private and public R & D expenditure more directly. He found that privately-financed R & D expenditure has a significantly larger effect on private productivity than federally-financed R & D.

Wondering about the change in the relationship between the total factor productivity growth and R & D stock observed by Griliches (1980b) during the 1970's, Griliches and Lichtenberg (1984) used new data to show that the relationship between productivity intensity and R & D intensity did not really disappear but was obscured by the productivi-

1 Except Rosenberg's article which is very marginal with regard to our concern.

Table 3 - Impact of publicly-funded R&D on productivity

Study	Sample	Specification [1]	Additional variables	Results
Leonard (1971)	16 industry groups United States (1957-63)	- correlation analysis between research intensity and measures of industrial growth	- sales, assets, net income, net worth, net plant, production and equipment, value added, real output, productivity	- significant only for commercially oriented industries (14 industry groups) - economically inefficient, excessive allocation of R & D resources to defense and space uses
Terleckyj (1974, 1980a, 1980b)	20 manufacturing industries United States (1948-66)	- Cobb-Douglas TFPG [2] - alternative measures of productivity growth due to extensive adjustments of capital stocks - government R & D intensity and R & D embodied in purchases from other industries	- non-government sales, relative unionization rate, cyclical component and human capital - private R & D intensity and R & D embodied in purchases from other industries	non-significant impact
Mansfield (1980)	20 manufacturing industries United States (1948-66)	- Cobb-Douglas TFPG - government-financed applied R & D intensity	- distinction between basic and applied research, relative number of union members and R & D pay-off expectations	non-significant impact except for R & D pay-off expectations
Griliches (1980b)	883 companies United States (1957-65)	- Cobb-Douglas PFPG - growth rates of total R & D expenditures and company R & D expenditures	- approximated physical capital, "quality of data" variables	- no direct evidence of the superiority of company-financed R & D as against federally financed R & D - additional evidence that federally financed R & D is biased towards large companies and is concentrated in industries with the lowest rate of return

[1] TFPG = total factor productivity growth.
PFPG = partial factor productivity growth.
TFP = total factor productivity.
PFP = partial factor productivity.

[2] Some measures have also been derived from a translog production function including intermediate inputs.

Link (1981)	51 manufacturing firms United States (1973-78)	- Cobb-Douglas TFPG - government-financed basic and applied R & D intensities	- company-financed basic and applied R & D intensity and relative number of union members	only government-financed basic R & D has a significant impact
Levy-Terleckyj (1983)	private business sector United States (1949-81)	- Cobb-Douglas PFP - ratio of government R & D capital to fixed capital - distinction between government contract R & D and other government R & D	- unemployment, fixed capital and company R & D	only government-contract R & D significant but much smaller effect than that of the private R & D
Cunéo (1984)	84 enterprises of the heavy sector and 98 enterprises of the scientific sector France (1972-77)	- Cobb-Douglas PFP - ratio of R & D capital to labor with a distinction between enterprises receiving more than 1 % of their R & D investment from government and others. An additional constant variable is also introduced for these enterprises	- fixed capital, basic R & D investment and basic R & D investment dummy	significant impact with level effect
Griliches-Lichtenberg (1984)	27 manufacturing industries United States 3 subperiods (1959-68), (1964-73), (1969-76)	- Cobb-Douglas TFPG - government R & D intensity	- private R & D intensity	non-significant impact
Reiss (1990)	27 manufacturing industries United States (1969-76)	- Cobb-Douglas TFPG - distinction between outlying and nonoutlying industries - governement R & D intensity	- private R & D intensity	significant impact except for outliers (missiles, engines, computers and farm machinery)
Griliches (1986)	500-1000 enterprises United States (1966-77)	- Cobb-Douglas PFPG - R & D growth rate and ratio of company-financed R & D stock to total	- basic research and capital services - alternative results presented for the production function and the gross profit rate	significant implicit impact

Levy-Terleckyj (1989)	telecommunications industy United States (1958-85)	- Cobb-Douglas and CES production functions - government R & D stock	- labor, capital and private R & D stock	significant impact for the Cobb-Douglas
Klette (1991)	1268 establishments Norway (1976-85)	- generalized TFPG - publicly-financed R & D	- manhours, ownership	non-significant impact reported
Lichtenberg-Siegel (1991)	over 2000 companies United States 3 subperiods (1973-76), (1977-80), (1981-85)	- Cobb-Douglas TFPG - federally-funded R & D	- company-funded R & D	non-significant impact

Table 4 - Impact of publicly-funded R&D on private R&D investment

Study	Sample	Specification	Additional variables	Results[1]
Nadiri (1980)	11 manufacturing, 5 durables and 6 non durables industries United States (1966-75)	- derived demand model for private R & D investment - government-financed R & D	ratio of wage to user cost of capital, output level, lagged employment, lagged capital, lagged utilization rate and lagged private R & D investment	- spin-off effect in manufacturing and non durables industries (.09, .02) - crowding-out effect in durable industries (-.04)
Carmichaël (1981)	46 firms in the transport industry United States (1976-77)	- capital asset pricing model for private R & D investment - government-financed R & D	- sales - distinction between small and big firms	crowding-out effect (-.08)
Levy-Terleckyj (1983)	private business sector United States (1949-81)	- private R & D investment function - government-financed R & D investment and distinction between contracting R & D, reimbursed overhead R & D and other R & D	output, taxes, unemployment, weighted average age of the R & D stock	- spin-off effect of government contract R & D (.27) - non-significant effect for reimbursed and other R & D
Levin-Reiss (1984)	20 industries United States (1967, 1972, 1977)	- behavioral model for private R & D intensity - government-financed R & D intensity	relative basic R & D expenditures, industry age, concentration index, new and improved products-oriented R & D	spin-off effect (.10)
Scott (1984)	3387 lines of business United States (1974)	- company R & D intensity - government-financed R & D industry	alternative results presented for company R & D investment with sales as explanatory variable	spin-off effect (.08)
Switzer (1984)	125 enterprises United States (1977)	- flow-of-funds model for private R & D investment - government-financed R & D	lagged R & D, concentration index, change in sales, financial variables	non-significant effect

Lichtenberg (1984)	991 enterprises United States (1967, 1972, 1977)	- company R & D intensity - government-financed R & D intensity - company R & D intensity changes - federal R & D intensity changes		spin-off effects on 1967 and 1972 and crowding-out effect in 1977 (.05, .10, -.22) crowding-out effect (-.48, -.17, -.26)
	12 manufacturing industries United States (1963-79)	- company R & D changes - federal R & D changes	lagged independent variable	non-significant impact
		- company R & D employment changes - federal-funded R & D employment changes	lagged independent variable	crowding-out effect (-.30)
Link (1982)	275 manufacturing firms United States (1977)	- company R & D intensity and relative composition of R & D between basic research, applied research and development - government-financed R & D intensity	relative profits, diversification index, concentration index and ownership form	spin-off effect (.09) and reallocation from basic and applied research toward development
Mansfield-Switzer (1984)	25 firms engaged in energy R & D projects United States (1979)	estimates by R & D officials of the effects of federal funding		asymmetric dynamic spin-off effects (.12 for an increase and .69 for a cut in federal funding)
Lichtenberg (1987)	private business sector United States (1956-83)	- private R & D investment - federally funded R & D	GNP decomposed between federal expenditures and other GNP components	spin-off effect (.33) canceled by GNP decomposition
	1987 firms United States (1979-84)	- company R & D investment - federally funded R & D	sales decomposed between government and non-government sales	spin-off effect (.13) canceled by decomposition
Lichtenberg (1988)	169 firms United States (1979-84)	- company R & D investment - R & D - non R & D and competitive - non competitive government procurement	non-government sales data span a major defense buildup	- non R & D contracts at least as well as incentive as R & D contracts - large crowding-out effect for non - competitive R & D - non-significant effect for competitive R & D

Holemans-Sleuwaegen (1988)	236 companies Belgium (1980-84)	- company R & D investment - government-funded R & D with a distribution between foreign-owned companies and domestic companies - dummy variable for firms not receiving public support	sales, employment, royalties and fees, concentration index, foreign-owned companies dummy, diversification index	non-supported firms dummy significantly positive, significant spin-off elasticity (0.35)
Antonelli (1989)	80 firms Italy (1983)	- company R & D investment - ratio of public subsidies to total R & D expenditures	profit, size, export, growth rate of profit, diversification dummy, average ratio of US R & D expenditures to sales	significant spin-off elasticity (0.37)
Levy (1990)	private business sector 9 OECD countries (Italy, Japan, Germany, Sweden, Netherlands, France, Switzerland, UK, USA) (1963-84)	- private R & D investment - government-financed R & D	GDP estimation based on Box-Cox transformation with pooled data	significant positive impact except for : - UK and Netherlands : negative impact - Italy and Switzerland : no impact

1. Note : values between parentheses are the estimated impacts.

Table 5. Other studies of publicly-financed R & D

Study	Sample	Specification	Additional variables	Results
Probabilist approaches				
Switzer (1985)	40 energy-related R & D projects United States (1973-80)	- probability of spin-offs - idea originator binary variable	firm R & D intensity, research activities, separation binary variable	spin-off probability of .17 for projects not involving firm in the generation of the idea
Bhanich Supapol (1990)	40 government R & D contracts in fields of transportation Canada (1984-5)	- probability of commercial benefits - proportion of public financing R & D - binary variable for government utilization - binary variable for industry-initiated contracts	contract and contractor characteristics	- higher probability of commercial benefits for industry-initiated contracts - no effect for government utilization - "U" form for the impact of the public financing R & D ratio
Supply approach				
Seldon (1987)	Softwood plywood industry United States (1950-80)	- output supply - persons devoted to research and experiment station personnel	price, wage, user cost of capital, lagged total revenue	net positive social gains from government research
Seldon-Hyde (1991)	Softwood lumber industry United States (1950-80)	- output supply - government scientist and engineer person-month	price, wage, user cost of capital	net positive social gains from government research

Patent approach				
Evenson (1984)	15 industries United States (1964-78)	- national patents - proportion of government funding	R & D, proportion of basic research, proportion of "development"	significant positive impact
Miscel-laneous				
Rosenberg (1976)	100 companies United States (1964)	- behavioral model of innovative activity by explaining the company R & D employment intensity - shipment fraction in heavily R & D subsidized firms	concentration and entry barrier dummies, market share, firm's revenue, technological opportunity	additional stimulus for innovative activity
Meyer-Kramer (1990)	1924 enterprises Germany (1978-81)	- R & D personnel expenditure - dummy variable for participation in government R & D programme during the years 1979-81	turnover, trend	significant positive impact

ty slowdown. Yet, if the intensity of private R & D expenditure was found to be highly significant over the three subperiods considered, there appeared to be no significant relationship between the intensity of federal R & D expenditure and subsequent growth in productivity. In a methodological paper about the search for outliers, Reiss (1990) reviewed some of Griliches and Lichtenberg's results and provided clues as to why federal R & D has been found non-significant. Furthermore, he argued that low estimates of the return to R & D was also due to the presence of outliers. From a selective analysis of outlier diagnoses, he identified four outliers out of a sample covering 27 manufacturing industries. The regression results for the nonoutlying sample show how much the exclusion of these anomalous observations dramatically affects parameter estimates. Indeed, his results report a significant estimate of the social excess rate of return to private R & D equal to 26 percent (against 35 percent for the full sample) and a significant estimate of the social excess rate of return to federal R & D equal to 18 percent (against a nonsignificant 1 percent for the full sample) [1]. For the four outlying industries, no coefficient is significant. This study illustrates how cautious one must be when one analyzes such flawed data as total factor productivity growth. In the measurement of productivity, a better status is allowed to traditional production factors than to knowledge investments. What the R & D data are asked to do is explaining residuals, a real challenge.

On the basis of a French panel data analysis, Cuneo (1984) makes some very interesting observations that we can summarize as follows. First, the effects of publicly-funded R & D only become positive when it exceeds a certain threshold of total expenses of R & D per capita. Below this threshold, enterprises which do not benefit by government-supported R & D are more productive than enterprises which do. Above this threshold, the level of R & D activities seems to be sufficient to ensure a return to government support. The estimated relative thresholds are two for the heavy industry and four for the scientific industry, i.e. the R & D capital stock for enterprises benefiting by public support must be respectively twice and four times as big as the average R & D capital stock of the sector involved. Second, the publicly-funded research lengthens the research process, thereby involving firms in long-term research. A last interesting study that should be mentioned is that made by Evenson (1984) who found that government funding increases inventive output.

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[1] A similar result is observed by Leonard (1971) in his correlation analysis of R & D intensity and measures of industrial growth. When he takes the federal R & D into account, the correlations prove to be non-significant. However, when both aircraft and missile and electrical equipment industries are omitted, a significant positive relationship appears between federal R & D and sales.

3.3. Public Financing, an Incentive to Industrial R & D ?

Empirical studies of the effect of public R & D expenditure on private R & D investments may be classified as either aggregate time-series, industry-level cross-section or firm-level cross-section. In the first class, there is the study by Levy and Terleckyj (1983) who estimated that government R & D expenditure leads to spinoff of private R & D. Link (1982), Levin and Reiss (1984), Scott (1984) and Switzer (1985) obtained a similar estimate from industry-, firm- and line of business-level cross-sectional data. These results have been contested by Lichtenberg (1984) who presents new estimates which differ from the other ones with respect to both methodology and implications : there is a partial crowding-out effect of government-supported R & D. Alternative results obtained by Levin and Reiss (1984) and Lichtenberg (1988) suggest that competitive intensity and technical competition in procurement of R & D contracts stimulate private R & D investment considerably. Conversely, non-competitive R & D procurement and R & D procurement in concentrated markets tend to highly crowd-out private R & D investment. Hence, the relationship between government - financed and company - financed R & D is more subtle than global analyses reveal. The allocation process of publicly-funded R & D and market structures influence the efficiency of public R & D programmes.

More fundamentally, Lichtenberg (1987) suggested that a part of the relationship between federal and private R & D might be statistically spurious. He provides arguments and evidence that the models are misspecified. As a result of this misspecification, the coefficient estimated for the impact of federal R & D on private R & D will be misinterpreted. Arguing that the hypothesis of identical coefficients for sales to the federal government and sales to other customers is far too restrictive, he proposes to split the sales, the most commonly used explanatory variable, by distinguishing between the government-oriented sales and other sales. His theoretical argument is based on a distinction between the supply price and the demand price of privately-produced innovations. From the empirical test which completes his analysis, he concludes that the real effect of federal R & D funding on privately-funded R & D expenditure is in fact attributable to variation in the government's share of output.

Is it not logical that outside-financed R & D does not show any separate effects on private productivity ? It can be argued that outside R & D may be absorbed as public goods, i.e. can be internalized without cost. Such an argument has been developed by Levy (1990) to explain why governmental R & D investment does not seem to significantly influence private productivity. Indeed, government R & D is a free good once the government pays for it and, hence, it will be used to the point where the value of its marginal product is zero. So, by ignoring that governmental R & D is given away, previous studies have confused zero value of marginal product with zero marginal physical product. If government-financed R & D can be employed at zero wage and if the output is measured in value terms, the equilibrium conditions imply that the value of the marginal product of government R & D must be zero. On the other hand, if the supply of private R & D is an upward sloping function of its marginal physical product, an increase of government R & D investment will increase the private R & D supply. He tested this hypothesis by estimating the impact of public R & D on private R & D for a cross-sectional sample of nine OECD countries, data covering the period 1963-1984. His empirical results indicate that the supply hypothesis is verified in the case of five countries (US, Japan, Sweden, Germany and France). But in Italy and Switzerland, public R & D investment does not appear to influence private R & D and, in the UK and the Netherlands, a significant negative effect was even measured.

Another alternative approach is that studied by Seldon (1987) and Seldon and Hyde (1991). They suggested to extend the supply approach to calculate the return to research investment in terms of consumer and producer surplus. Their measurement methods are based upon an estimate of the parameters of a demand and supply system. Compared to the estimate of a production function, their method allows an indirect evaluation method of the rate of return to governmental R & D.

4. Conclusion

In a nutshell, there is not much evidence from either the productivity or the investment approaches that government support of R & D adversely affects both private R & D efforts and economic growth. Perhaps the main problem with these approaches is that they are only partial steps in the process of policy evaluation. Other steps also need further investigation.

Besides, one can wonder if the econometric analyses reviewed above are really well suited for evaluation purposes. In other words, can such studies be of any help for policy makers or do they only remain "an academic game" ? The policy relevance of such investigations has been questioned by Griliches (1984) in his introduction to one of the master-pieces in this field. His conclusive comment is : "However, we have not provided, except indirectly, many policy handles. Nor is it likely that we will do so in the future. This is not because we do not want to be helpful to the National Science Foundation or the rest of the policymaking establishment, but because what we are studying is not really amenable to short-run policy intervention or manipulation" (Griliches (1984, p. 18)). At the same time, Nelson (1982) concluded from a cross-industry analysis that the most promising route towards stronger knowledge was through case studies because formal models were not well enough suited to give better conclusions than qualitative judgment analyses.

Most efforts in the econometrics of R & D have been devoted to measuring the impact of overall and industrial R & D. The public R & D is often included in models as an explanatory variable without the measure of its impact being the actual objective of the undertaken analysis. Whereas the objective underlying private R & D investments are well-known, public investments in R & D pursue several, sometimes contradictory, objectives. Hence, the welfare measurement aspect of private R & D noticeably differs from that of the public counterpart. Public R & D expenditure is multiobjective-oriented. How much defence-oriented public R & D investments are guided by economic criteria ? Space-oriented public R & D is also motivated by other than strictly economic objectives. Only public support to civil private R & D is fully part of the economic rationale. In the case of the first two categories of R & D, insofar as one accepts that they are a result of a social choice based on extra-economic criteria [1], one need not be very sorry if their economic impact is negligeable. Conversely, knowing if public support really boosts up and does not crowd out private investment is an essential economic issue. So far, a lot of econometric studies have exclusively considered public R & D expenditure as a whole, which certainly accounts for the high variability of results.

Actually, little attention has been paid to the adaptation of econometric methods to the specific conditions of impact analysis of R & D policy. The econometric approach is certainly an efficient tool for ex post evaluation of the effectiveness of public R & D management. However, the survey of the two most developed topics in this field, both productivity and investment approaches, shows that this method has its shortcomings and limits. It must be seen as one instrument in the tool box of technology assessment techniques. Despite their complicated nature, structured quantitative analyses of the impact of R & D policy, which are in general feasible, must be viewed as a necessary and essential component of the assessment process.

[1] It does not mean that the measure of their economic implications does not make sense.

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Comment : *Juan Del Hoyo Bernat*

First of all, I would like to thank the organizers of this meeting for their very kind invitation to participate and to comment on the paper presented by prof. Capron.

Secondly, I would wish to congratulate prof. Capron for both his interesting paper and for his very clear presentation.

In his presentation, prof. Capron has concentrated both in the theoretical and the empirical aspects of the quantitative evaluation process of R&D. I agree with most of the ideas presented in the paper about the difficulties in evaluating the usefulness of econometric methods to quantify the effects of R&D expenditures.

My comments are directed firstly to stressing some general aspects related to the estimation process that leads to the actual estimates of the structural coefficients that, in my opinion, are frequently overlooked. This inadequate practice is the main justification for the great diversity in results. Finally, I will make some comments on the paper presented by prof. Capron.

In general it is accepted that there is a double purpose when modelling a system. The first is to obtain structural knowledge about the system while, the second, is prediction. Now, as all of the members of the audience know, to achieve these objectives some basic hypothesis concerning the model under study must be fullfilled.

To achieve the goals, and in particular the structural one, the model to be estimated must be correctly specified in the sense that not only the functional form of the equations should be correct but also the relevant set of explanatory variables should be included. Moreover, the usual hypothesis about absence of multicollinearity, heteroskedasticity and autocorrelation should also be accomplished.

Closely related to the correct specification hypothesis we find the one associated to the constant structural coefficients of the model. Nevertheless, in most empirical works nothing is said about wether or not this assumption is actually achieved after estimating the model.

I think that the failure to verify this important hypothesis constitutes a major drawback for the vast majority of empirical work, especially when time series constitutes the main source of data for estimating the parameters. In particular, if we consider that when the R&D expenditures achieve positive results, changes should be expected in the structural coefficients representing the responses to the input variables. These variations on the structural coefficients may be registered and, if present, proper actions should be taken to modify the final models.

Therefore the sample period before and after the begining of R&D projects is unlikely to have the same structure and, as a consequence, if we try to estimate both periods with the same coefficients we will end up with a mixture of them instead of the adequate estimates of the coefficients.

In my opinion this specification error is one of the main reasons that justifies the diversity of empirical results so far obtained.

Also, if we consider that the main effects of R&D should be related with the trend components of the dependent variables under study, a good strategy could be to split each of the variables under study into two orthogonal aditive components: trend and residual. This will mean that the two components do not share common frequency bands.

The actual information contained in the trend component will depend on the particular method used for its estimation. In particular, the trend may include more or less information related to the medium-term components depending on the bandwidth of the filter choosen to estimate the trend. In any case, the trend will summarize the long term evolution while the residual component will represent the short term information. See, for instance, NG. and Young (1990) or García Ferrer and del Hoyo (1991).

The previous considerations are relevant when we consider that a model relating properly extracted trend components is usually non linear while, in general, most of the applied work in R&D has been developped estimating linear relationships. As can easily be understood, this misspecification is also related to the problem implying the hypothesis of constant coefficients.

Two further problems may be added to the previous ones when interpreting the empirical results so far obtained by different researchers. The first one is the difficulty to interpret the theoretical meaning of the individual estimated structural coefficients independently from other jointly estimated coefficients of the model. It should be noticed that when the explanatory variables of the regression model are not orthogonal the interpretation of the individual coefficient is not an easy task due to the correlation structure among the explanatory variables. This problem is easily shown if the coefficients are estimated recursively and a plot of such recursive estimates is presented.

Then, if we have difficulties in giving structural meaning to the estimated coefficients, and if we can not interpret them independently from the other coefficients, we may conclude that it is not uncommon to find such a diversity in the estimated results concerning the effects of R&D as a whole, or when it is separated into public and privately financed components.

The second problem that I would like to point out, is the fact that the usual test of hypothesis is performed with the distribution of the estimated coefficients under the usual null hypothesis. If the residuals are presumed to be gaussian, and there are no problems related to the regressors, then it is possible to use the t-distribution. When such assumptions are not valid the usual asymptotic results are called for.

Therefore it should be usefull to verify the empirical degree of gaussianity for the distribution of the residuals and this is a task that is seldom performed in most of the empirical examples. Moreover, If our comments about non constant coefficients are accepted, the asymptotic results are not applicable because the distributions are non-stationary.

Also notice, that the presence of outliers, as reported in one of the examples shown by professor Capron, may also invalidate the verification procedure.

In pages 9-10 of his paper, Prof Capron, presents the results of several estimated relationships to illustrate that, in order to explain hourly labor productivity, the physical capital stock per unit of labor, public and private R&D capital stocks and the educational capital stock, among other variables, are relevant. I think that many of my previous comments may be relevant to his work and, if the proper tests are performed, the resulting conclusions, that seem to me are very reasonable, could gain stronger support.

Now, I would like to ask prof Capron some questions related to his paper. In particular, and related to his empirical estimates, it would be very useful to know: how many degrees of freedom, how have the specific lags of the explanatory variables been detected, and why not to present more complete tests of autocorrelation as the Ljung-Box or other related ones.

Conclusions

Two main conclusions of the applied Econometrics for measuring the R&D effects are:

1) Most of the empirical studies give empirical support to the conclusion that R&D expenditures are productive. But it is very difficult, in most of the studies, to give precise meaning to the estimated coefficients.

2) There are significant differences in the estimates presented by the researchers. In particular, different results are obtained in cross-section and time series analysis as well as at the firm and industry level.

As an explanation of these results, when dealing with time series the following reasons are advanced:

a.- Many empirical results so far obtained may be lacking of sound statistical support as a result of problems in the specification of the estimated models.

b.- The relevant relationships among the original variables or their trend components may be nonlinear.

c.- The structural coefficients may not be time invariant.

d.- The structural interpretation of the estimated individual coefficients may be difficult.

e.- Formal tests on the estimated residuals should be performed in order to validate the verification process on the estimated coefficients.

Therefore, the statistical quantitative methods employed to ascertain the effects of R&D expenditures should be taken with great care.

Finally I wish to congratulate Prof. Capron again for his very interesting paper and to the organizers of this meeting.

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Part Two

The Measurement of Technological Activities in Models and Case Studies

Chapter 6 - Evaluation of the Effects of Technological Trends on Employment in Sectors of the Economy with Technology-Specific Indicators

Jürgen Blazejczak and Dietmar Edler

1. Introduction

In evaluating the economy-wide effects of an ensemble of new technologies either direct technological information in engineering terms or non-technology-specific indicators of innovative activity can be utilized. Each approach has its advantages and disadvantages.

To evaluate the economic consequences of technological change one has most frequently utilized indicators of innovative activity which are non-technology-specific (see the examples in Schettkat, Wagner (1990, p. 6)). This serves as an advantage because aggregation and the application of formal methods are thus made possible. Yet it also is a disadvantage because each indicator approximates only one aspect of technological change. If, for example, input indicators like R&D-expenditures are utilized, the fact that these activities may show varying degrees of efficiency under different circumstances is disregarded. The use of output indicators (like export shares) on the other hand makes implicit assumptions on the effects of new technologies, e.g. on international competitiveness. In addition, the use of non-specific indicators is contradictory to the aim of distinguishing specific directions of technological change.

These drawbacks can be overcome by the application of technological information in engineering terms. Once the problem of translating such information into economic, i.e. cost, categories has been solved, they represent a singular bridge from the present to the future. In section 2 it is shown how this can be achieved.

Investigations based on such information are, however, typically micro-oriented, i.e. limited to a single production process. Any generalization or aggregation of the results obtained in such studies is dangerous in that interactions with other new technologies are not taken into account. A formal treatment of these problems, e.g. by statistical methods, is not feasible. If one still regards an attempt as worthwhile to take advantage of technology-specifc information in describing the economy-wide effects of an ensemble of new technologies, judgement has to be relied on. Such an attempt is described in section 3 of the present paper.

The applications reported here refer to a projection of the changes in the sectoral structure of employment in Germany in the 1990's which are to be expected if the diffusion of new technologies is accelerated.

2. Modelling Innovation Diffusion in a Dynamic Input-Output Framework

To project the dynamics of the diffusion of a single new production process on the sectoral level, a dynamic input-output model can be utilized. The technological interrelations between sectors of the economy are described in a consistent way within the input-output framework. Input-output analysis therefore has the capacity to capture the impact of new technologies on a sectoral level. In it's dynamic version it is also capable of modelling the impact on the process of investment. Viewing the introduction and diffusion of a new technology into the technological structure of an economy as a prototype of a dynamic economic process, it is obvious that the step from static to dynamic input-output analysis marks an important methodological improvement. The first empirical study using a dynamic input-output approach for this type of question was by Leontief and Duchin (1986) for the US. This model has been adopted and applied for the FRG by Edler (1989), (1990a), 1990b).

Departing from

$$x = (I-A)^{-1}y$$

in the dynamic model final demand y is seperated into investment and other components. The determination of investment and its consequences for the production capacity of the economy is made endogenously dependent on gross output. Formally this may be expressed by matrices of capital coefficients for capacity expansion B and for replacement R.

Employment e_{kj} by sector j and occupation k can be determined by E = Lx where L is a matrix of labour coefficients l_{kj}.

The introduction of new technologies means that new goods, e.g. industrial robots, have to be produced. For the production of industrial robots it can be assumed that the goods of the new technology are produced in a completely new, additional sector. In formal terms this means that time series of additional rows and columns have to be derived for the coefficient matrices A, B, R, and L as well as for the vector of final demand others than investment y. The new columns represent the input (cost) structure for the production of industrial robots, that is, the deliveries of intermediate and investment goods from other sectors and the labour input of different occupational categories necessary to produce one unit of goods of the new technology. The additional rows determine the output (sales) structure of the new sector, that is, how many units worth of industrial robots are used in a specific sector to produce one unit of goods. The row parameters are crucial for modelling the diffusion process of robots.

But this is only the first step in modelling the impact of the new technology. The diffusion of industrial robots changes the production process of the user industries, depending on the rate of adoption of the new technology. In other words, use of intermediate inputs from various sectors and labour input may change as well as the structure and level of investment. The structure of investment will change not only because of the investment in new technology but also because the goods of the old, supplanted technology phase out. All these effects are a function of the rate at which industrial robots are adopted, and they must be appropriately modelled along the time axis. This amounts to a modification of a large set of elements of A, B, R, and L year by year.

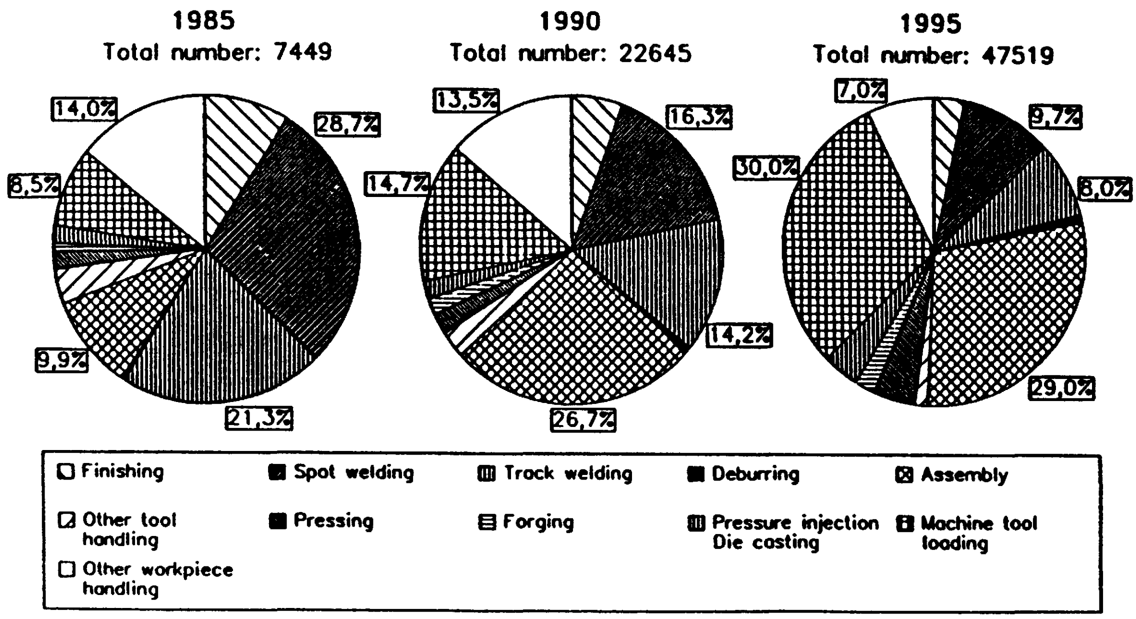
The necessary parameters to describe the formal process of diffusion of industrial robots within the framework of the dynamic input-output model were constructed out of a pool of primarily micro-oriented data originating from different sources like publications, sample surveys, and in-depth interviews with technical and marketing experts (for details see Edler 1989). In some instances it turned out that the available data were not adequate for the specific requirements of this approach, so reasonable and well-documented assumptions had to be worked with.

To measure the impact of the diffusion of industrial robots from 1980 to 1995, a baseline projection without the introduction of robots was made. Then an alternative simulation accounting for the introduction of robots was performed. The effects of this new technology can then be evaluated by comparing the two simulations.

Since the effects - in particular the employment effects according to occupation - differ substantially from one functional area of application to the other, eleven types of industrial robots were distinguished. The changing number of robots installations of each type per one million DM of investment for each sector was modelled exogenously year by year. As the model endogenously describes investment the projected diffusion of industrial robots by area of application and user industry is partly determined endogenously.

In total the simulated stock of robots increases from 7,500 units in 1985 to 22,500 units in 1990 and 47,500 robots in 1995. The importance of different areas of application is shifting significantly. In 1985 spot-welding and track-welding robots were clearly dominant. In 1995 assembly and machine-tool loading robots account for most of the installed robots, with welding robots in third place.

Figure 1. Stock of industrial robots in 1985, 1990, 1995
- By robot types -



There is also a significant change in the use of robots in each industry. Whereas the motor-vehicles industry used about 60 per cent of all robots in 1985, its significance decreased steadily. By contrast, the share accounted for by electrical engineering and other industries grew during the process of diffusion.

The simulated diffusion of industrial robots results in a pronounced decrease of employment in the economy as a whole. While for each vintage of robots the positive effects of production are mostly restricted to one year, the year of production, the negative employment effects of using robots unfolds over the robot's entire lifespan. The dynamic overlay of this mechanism for consecutive vintages results in negative employment effects after the first two years of the diffusion process. This negative impact rises quickly to over 48,000 persons in 1990 and to just under 110,000 persons in 1995.

This overall impact can be separated:

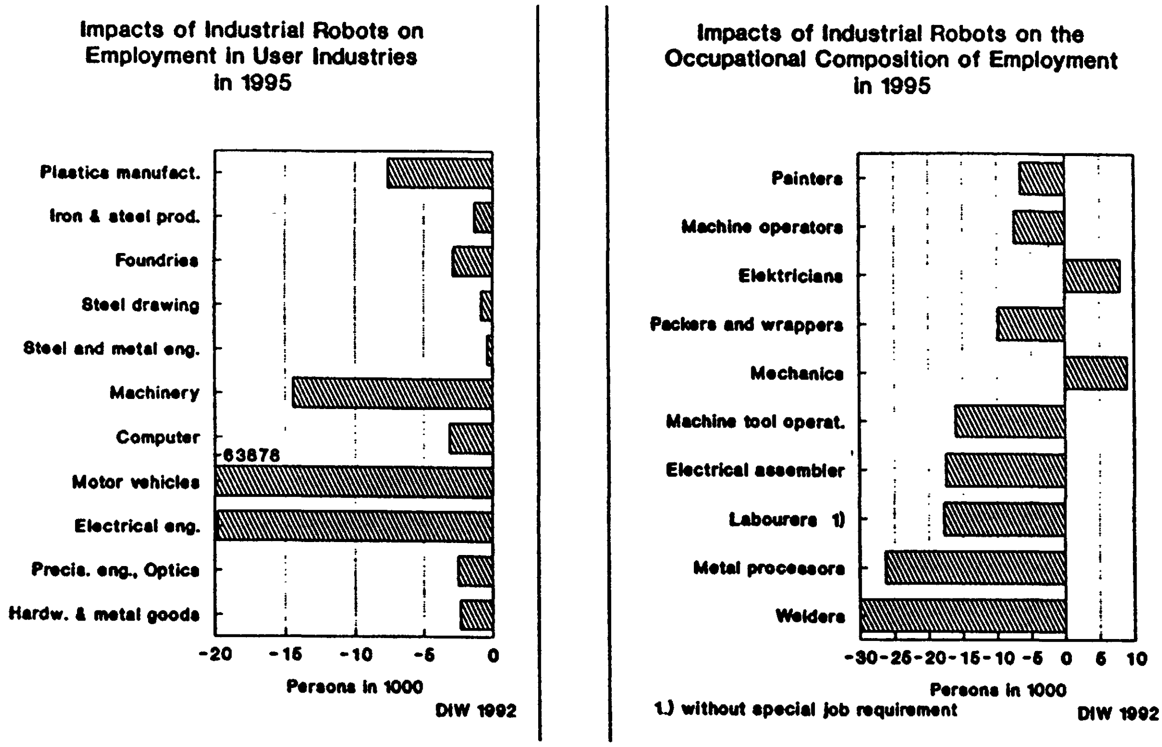
- Direct producer effects measure the direct employment effects in the newly defined sector called 'production of robots'.
- Indirect producer effects are the employment changes in other industries due to the interindustry transaction for intermediate and capital goods.
- Direct user effects are the changes in employment that are directly connected to the use of robots in the user industries.
- Indirect user effects include the adoption-specific changes for intermediate goods and investment caused by the use of robots.

In 1995, for example, the direct and indirect producer effects yield additional employment of 20,000 persons, while the direct and indirect user effects add up to an employment decrease of 130,000 persons. The overwhelming impact arises from the direct user effects. Neglecting the indirect effects, however, would be a serious error.

The diffusion of industrial robots affects employment in different sectors to a different extent. The main effects occur in industries using robots, above all in the motor vehicles industry and - especially in later years - in the electrical engineering industry. But indirect repercussions influence nearly all sectors, particularly those industries in which indirect producer and user effects are cumulative, such as some service industries. Moreover, it is interesting to note that in some user industries negative user effects are dominated by indirect producer effects during the first years of the diffusion process. This is true, for example, for precision engineering and optics and for electrical engineering, the main producers of intermediate goods for the robot-producing sector.

The diffusion of industrial robots has considerable effects on the occupational structure of employment. Positive effects are to be found primarily in those occupations that are related to robot maintenance: mechanics and electricians, for example. The largest increase in relation to the baseline projection concerns computer experts, who benefit from producer and user effects. Other more highly qualified occupations like electrical and mechanical engineers as well as technicians in these fields profit mainly from producer effects. Large negative employment effects occur for those occupations that are directly affected by the use of robots. Welders suffer the largest loss in employment. Generally jobs are lost in occupations with comparably low qualification requirements. Skilled workers such as machine-tool operators, are also affected, but to a much lesser extent.

Figure 2. Impacts of industrial robots on employment



In the results reported so far important effects are still missing, notably those mediated through price, income and redistribution mechanisms. While a formal treatment of these effects is not possible at the present state of modelling, an attempt has been made to indicate the magnitude of some of them.

The introduction of a new technology alters the level and structure of production costs in the user industries. The decrease in labour costs with robots is considerably greater than the increase in other costs, making production costs lower than those with old technology.

It is assumed, first, that the total amount of cost reduction is used to reduce prices and, second, that those price reductions are completely compensated by an increase in demand for those goods. In other words, unitary elasticities for prices in relation to costs and for demand in relation to prices are assumed. These two relations seem to be an upper limit for both elasticities.

Taking into account compensating effects in this way results in markedly lower but still negative employment effects of industrial robots. As the assumptions are at the upper limit of elasticities that may be expected in reality, it is unlikely that industrial robots have an overall positive impact on employment. In addition it can be noted, that even under favourable assumptions concerning the compensatory effects there remains a serious effect on the occupational structure of the economy. There is a clear tendency that occupations with comparably low skill requirements are in danger while more qualified jobs with specific qualification requirements may gain from this new technology.

3. A Technology Evaluation Scheme

If - in evaluating the economy-wide effects of technological change - an attempt to even crudely translate direct information on new technologies into economic terms is regarded worthwhile, the problem of focusing judgement has to be solved. The use of a "technology-evaluation-scheme" is proposed for this purpose, based on sectors of the economy, fields of application of new technologies, and mechanisms through which new technologies influence key economic variables. Rated impacts of each field of application via each mechanism for each sector can then be ascribed an ordinate value, with a further round of judgment to aggregate over different technologies, mechanisms and sectors. The underlying belief is that judgement can be "controlled" by a systematic structuring of the problem, which allows one to formalize the process of deriving final conclusions as comprehensively as possible.

The feasibility of such an approach has been attempted by trying to evaluate the isolated effects of new technologies on the structure of employment - as described by changes of shares of employment by sector - in the FRG in the nineties (DIW 1989, Blazejczak 1991).

Obviously, it is impossible to even approximately take into account the abundant variety of new technological developments. One can, however, try to identify basic technologies like microelectronics which are believed to bring about - in combination with each other and traditional technologies - new solutions in many areas. Detailed catalogs of basic technologies have been established. Examples are US-Department of Commerce (1987) and Ministerium für Wirtschaft, Mittelstand und Technologie Baden-Württemberg (1988).

Basic technologies are universally applicable. Therefore, it is difficult to assess their importance for sectors of the economy. This seems more feasible - though by no means easy - if the point of departure is the area of application (or function) within the production process where basic technologies act together and in combination with traditional technologies, thus bringing about product and process innovations. For example, new technologies will probably bring about a broader as well as more intensive application of flexible automation to many more production processes. They include, for example, handling of parts, control of machinery, physical processing of parts as well as chemical transformation of materials.

The "importance" of these areas of application - disaggregated as desired - for different sectors can be judged at various degrees of sophistication. In a first attempt those sectors can be identified which produce or apply new technologies or are affected by the substitution of their traditional products.

This does not specify the economic variables with respect to which importance is defined. For this purpose e.g. the effects on employment can be broken down into effects on productivity and on production. This still does not allow for a step by step follow-up on the effects of the introduction of new technologies on employment. Therefore, economic mechanisms have to be identified through which productivity and production are affected.

New technologies affect productivity in various ways:

- They permit the automation of additional production processes. This potential varies sector by sector. In some sectors automation has already been carried so far that further progress would seem to be difficult to achieve in the medium run.
- They save labour by reducing the likelihood of interruptions in the production process and by making quality control more reliable. Again, these indirect effects vary from sector to sector.
- They offer new possibilities to take advantage of increasing returns to scale either by allowing the production of larger lots, particularly of innovative products, or by favoring concentration. In some sectors installations are already large; the accomplishment of further scale-effects is difficult in these areas.
- They make possible organizational change which increases productivity; in several service sectors, for example, they allow the passing on of performances to customers or deliverers.
- They reinforce dynamic competition, thus creating pressure for process innovations in sectors which were unable to gain competitiveness by product innovations. This implies a lowering of pressure to rationalize for sectors with many product innovations.
- Enterprises which do not cope with the pace of technological change are forced out of the market. In those sectors where such restructuring takes place, additional productivity effects occur.

This procedure permits in a ranking with respect to the strength of each of these effects for sectors of the German economy expected during the nineties as is demonstrated in table 1. Values attributed to different mechanisms are not comparable within the same sector, that is, they include no weighting.

The overall effect on sectoral labour productivity of new technologies expressed as deviations from the average effect over all sectors are believed to be particularly high for electrical goods and manufacturing of precision and optical instruments followed by a group comprising plastics production, manufacturing of office machinery and automatic data processing equipment, manufacturing of road vehicles, manufacturing of aircraft and spacecraft and particularly low for energy and water supply as well as mining and tobacco processing followed by agriculture, forestry and fishing, crude oil processing, manufacturing of pulp and paper and building. It should be noted that further sophistications and elaborations could be thought of. Thus professions and/or qualifications could be introduced as an additional dimension when evaluating productivity effects. Likewise production effects of new technologies can be broken down (for details see Blazejczak (1991)).

To find out how an accelerated diffusion of new technologies, as compared to a normal pace for the introduction of new technologies, shifts sectoral employment in the German economy until the end of the century the summary findings on sectoral productivity and production effects were translated into numerical form in a simple way. The average effects for all sectors were found from an aggregated econometric model (Blazejczak, 1987, 1990). Then a lower or higher effect was attributed to the individual sectors in such a way as to obtain the average effect and simultanously preserve the ranking of sectors. The most important result - shown in figure 3 - is a positive correlation between sectoral productivity and production changes: in those sectors where accelerated innovation causes high productivity gains, the increase in production growth is generally high.

4. Concluding Remarks

In this paper we have presented two approaches which allow to evaluate the effects of technological trends on employment in sectors of the economy. Both methods have been succesfully applied for Germany, thus demonstrating that it is possible to rely on a large and rich set of different, primarily technology-based information on one hand,

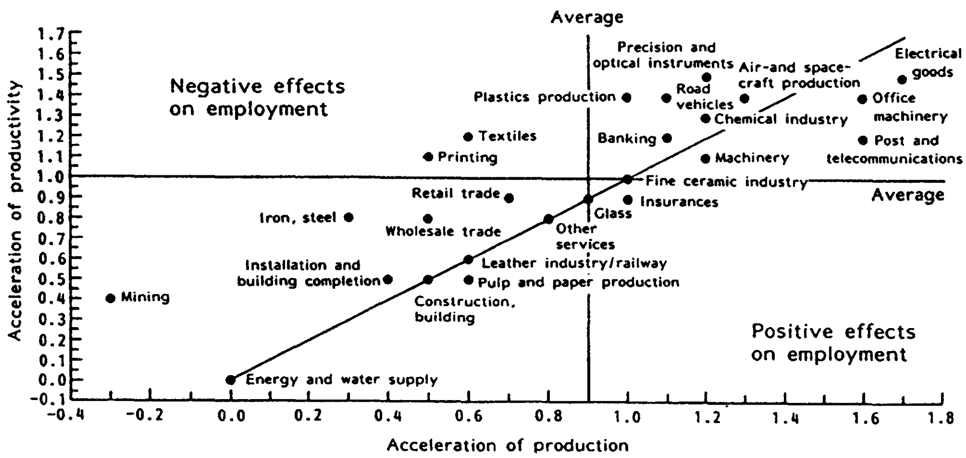
Table 1. Indicators for above or below average acceleration of productivity growth through increased innovative activity

Economic sectors	Possibilities for automation (assessment)[a,b]		Achieved level of automation (assessment)[a]	Possibilities for productivity—increasing organizational change (assessment)[a]	Possibilities[c] for achieving positive scale-effects		Already achieved positive scale-effects (assessment)[a]	Negative scale effects (assessment)[a]	Lower pressure to rationalize through product innovations (assessment)	Summary assessment[d]
	Direct substitution possibilities	*Indirect effects of productivity*			*Production of larger lots (assessment)[a]*	*Larger installations (assessment)[a]*				
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
Agriculture, forestry, fishing	2	3	2	1	2	1	1–2	2	1	−2.0
Energy and mining										
Energy and water supply	1	2	3	1	2	1	3	1	0	−3.0
Mining	2–3	2	2–3	1	2	1–2	2–3	1	1	−2.5
Manufacturing industry										
Chemical industry (incl nuclear fuel)	3	3	2	1–2	3	2	2–3	2	3	+1.5
Crude oil processing	1	2	3	1–2	2	1	3	1	1	−2.0
Plastics production	2–3	3	1	1–2	3	2–3	1–2	3	3	+2.0
Rubber processing	2–3	3	1	1–2	2–3	2	2–3	2	2	0.0
Stones and clay	2–3	2	1–2	1–2	1–2	2	1–2	1	1–2	−1.0
Fine ceramics	3	3	1	1–2	2–3	1–2	2	3	3	0.0
Glass	2–3	3	2	1–2	2–3	1–2	2	3	3	0.0
Iron and steel	2–3	3	2	1–2	2–3	1–2	3	2	2	−0.5
Non-ferrous metal production	2–3	3	2–3	2	2–3	2	2	3	3	+0.5
Foundries	3	2–3	2	2	2	2	2	2	2–3	0.0
Drawing and rolling mills	3	2–3	2	2	2–3	2	1–2	2–3	2	0.0
Structural metal production, rolling stock	2–3	2–3	2	2	2–3	2	2	3	2	−0.5
Machinery	3	3	1–2	2	2–3	2	2	3	3	+0.5
Office machinery, automated data processing equipment	3	3	3	2–3	3	2	2–3	1	3	+2.0
Road vehicles	3	3	2–3	2–3	3	1–2	2–3	1	3	+2.0
Shipbuilding	2–3	2–3	2	2	2	1–2	2	2	2	−0.5
Aircraft and spacecraft production	3	3	3	2–3	3	2	2	2	3	+2.0

Notes:
[a] 0 — non-existent; 1 — small; 2 — existent; 3 — large. [b] Under consideration of the achieved level of automation (column (3)). [c] Under consideration of positive scale effects already achieved (column (7)). [d] + above average, − below average acceleration of productivity; the intensity is indicated on an ordinal scale of 0 to 3.

Source: Blazejczak (1991, p. 598).

Figure 3. Differences in the average annual rate of change 1987 to 2000 in regard to the reference scenario in percentage points



Source: Blazejczak (1991, p. 601).

and to make use of a quantitative, formalized tool for analysis on the other hand. Both methods depend on judgement based on technological and economic expertise. The degree of necessary judgement differs. The need of judgement is - naturally - limited in the case where only a very specific technology is analysed whereas more judgement is necessary in the approach, where the effects of a broad ensemble of technological trends on the overall economy are evaluated.

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Comment : *Luis Delgado*

This very interesting paper deals with the topic of evaluating the economic effects of new technologies at two levels. At a macroeconomic level the choice of the intersectorial flow of goods as a non-specific indicator allows the use of a formal treatment relating final demand with production. The effect of innovative activity on key economic variables such as productivity and employment can then be analyzed.

At a microeconomic level, the authors try to develop a sort of semiformal method by using a dynamic input-output model including the impact on the process of investment. The methodological improvement adopted, separates investment and other components in the final demand.

The method has to rely on a large extent on micro-oriented data such as results of surveys and in-depth interviews with economic and technical agents. Therefore, some assumptions to fit the data with the requirements have to be worked with. Though a richer analysis can then be made, a method to check the validity of the assumptions made, i.e. a sort of sensitivity analysis quantifying the margin of error of the assumptions before the conclusions have to be changed, would improve the utility of the method as an analytical tool to check the economic effect of specific technologies.

In the case studied, the impact of the introduction of industrial robots on employment, besides the assumption made, i.e. direct translation of cost reductions to prize reduction, other alternatives are of course possible for the entrepreneurs.

In both levels of analysis the final conclusion on the effect of new technologies on employment is negative. The consideration of the effect of the alternative, i.e. no introduction of new technologies is however not taken into account.

In their third part, the paper proposes a Technology Evaluation Scheme. Again "judgements" and assumptions which can be very much controversial have to be made. As an attempt to control these variables, a systematic structure of the problem formalizing the conclusion derivation process is intended. Identification of the economic mechanisms and their importance affecting the economic variables : employment, productivity, production ..., is then crucial for the model.

Besides the above mentioned lack of sensitivity analysis of the method, the ranking of the economic mechanisms, including organizational changes increasing productivity, can be a discussion point on the proposed scheme.

In summary, the paper presents important methodological improvements to analyse the economic effects of new technologies. Further improvements of the models, including sensitivity analysis and the possibility to take into account other effects not initially considered, can contribute to enlarge the range of application of the proposed models.

Chapter 7 - Innovation, Technical Progress and Policy Impacts

Lothar Scholz

1. Introduction

The German Federal Ministry of Research and Technology launched in 1984 the so called 'META[1]-Study' to improve the theoretical and empirical knowledge relevant for policy impacts and assessing the relation between employment and technology. In phase I a synoptical report on the state of the art was submitted (Friedrich and Ronning, 1985). In phase II nine research institutes worked together following a micro-, meso- and macro-approach (Matzner and Wagner, 1990). The focal point of the research team of the ifo Institute for Economic Research was the analysis at the meso-level using the data base of the ifo Innovation Survey (Penzkofer, Schmalholz and Scholz, 1989).

The guidelines of the research work were:

- theoretical impact of technological innovations on technical progress in the economic sense;
- impacts on employment of different types of innovators;
- direct and indirect quantitative impacts of innovation activities;
- innovation-flow impacts on growth and employment for sectors of industries and final demand.

The construction of an innovation-flow matrix on the basis of survey results was characterized as an "important contribution to the input-output analysis of technological change" (Duchin, 1990, p. 215). Such matrices could be used as components for disaggregated macro-economic models, in which innovation activities are used as specific explanatory variables of technical change, employment and economic growth.

2. Theory of Technical Progress and Innovation

From a theoretical viewpoint the fundamental work of Solow (1957) and many other economists was very helpful for understanding the way in which technical change

[1] The shorthand expression 'meta' was used in the meaning of a follow-up and joint project of nine institutes from different disciplines and specific 'schools'.

takes place and how it leads to technical progress in the economic sense. However, in identifying the rate and direction of technical progress as a residual in aggregate production functions, a "measure of ignorance" has to be admitted (Abramovitz, 1956, p. 11). This residual is influenced by many factors which do not fit the well-accepted definition of technical progress (Ott, 1959, p. 302):

(1) production of new, i.e. up-to-that-time unknown products (product innovations);
(2) change of production techniques (process innovations) resulting in the production of a given quantity of products at lower costs or a higher quantity at the same cost level.

They are the sources of technical change.

The necessity of isolating qualitative changes in technology and differentiating between product innovations and process innovations has been apparent for more than thirty years. However, there was no adequate way of measurement (Nelson, 1981). For this reason the ifo Institute for Economic Research launched its Innovation Survey in 1979 (Reinhard and Scholz, 1979). The META-Study made it possible to structure and analyse these data in such a way that new results on innovation, growth and employment have been achieved. While the basic data represented only a period of eight years, which is too small for time series analysis, cross-section analysis of the ifo innovation data could be applied and has led to a better understanding of technical, economic and social change in the economy and society (Ronning and Warnken, 1990; Schettkat, 1990).

For product and process innovations to emerge, new knowledge or a new combination of already existing knowledge with findings in the natural and social sciences or engineering results for technical developments are needed. Inventions and their further development to market-oriented innovations are necessary but not sufficient conditions for technical progress in the economic sense, because technical progress is only the result of the acceptance and diffusion of new products or new production methods in the economy. Therefore, both must be measured: the input (generation of innovation) and the output (diffusion of innovation) of technological innovation activities.

A first step in the history of innovation research was to select defined technologies and analyse their innovation and diffusion process (Nelson and Winter, 1977). This approach provided an insight into the length and specific effects of incentives as well as barriers to these processes. But there is no answer to the question of whether these "historical" descriptions and findings might be generalized and used for forecasting future developments (Scholz, 1974). Controversial findings (Rogers, 1962; Schmookler, 1966) and the incapability of identifying and analyzing all the relevant innovations which determine the basis of technological change at a given time or period (Oppenländer et al., 1971; d'Alcantara et al., 1986), meant that a new approach was needed (Oppenländer and Scholz, 1982; Schmalholz and Scholz, 1985).

3. Innovation Activity Approach

Since 1979 a representative panel of about 5000 firms in the German industry relating to about 300 product groups is asked to answer, on a voluntary basis, standardized questions about their innovation activities every year. The general definition of product and process innovation is congruent with the above-mentioned definition of technical change. However, the questionnaire includes different criteria for gaining more insight into the type of innovation activities, e.g.:

- innovation expenditures (financial dimension);
- innovation objectives (strategic dimension);
- R&D variables (know-how dimension);
- technology variables (technical dimension).

There are two different concepts to measure innovation (OECD, 1990):

- the technology use approach and
- the innovation activity approach.

The technology use concept is based on specific new technologies or innovation projects analysing their impacts on employment and economic development. It is comparable with the case study approach which is very useful if one is interested in specific impacts of innovations. The innnovation activity concept is business oriented analysing the intensity and structure of activities of enterprises with respect to product and process innovations. It is complementary to the concept of the measurement of R&D, however, it includes development activities, e.g. design, which are excluded in the R&D definition of the "Frascati Manual" (OECD, 1980), too. Furthermore, there are other activities, e.g. tooling up and industrial engineering, manufacturing start-up and marketing for new products, which are necessary to introduce innovations on the market. The innovation activity approach, which was used for the ifo Innovation Survey already in 1979 (Reinhard and Scholz, 1979) is proposed in the "Oslo Manual" (OECD, 1992) as the basic concept for Innovation Surveys in OECD member countries. The necessity to get more information on tangible and intangible investments with respect to innovation was one central result of the Technology Economy Programme (TEP) of the OECD commissioned by the Council of Ministerial Level in 1988.

Innovation results from qualitative changes in technology. Quality cannot directly be measured and aggregated by quantitative methods. However, innovation expenditures should correspond to an adequate return in the diffusion phase of new products or on investment in process innovations. Bearing this hypothesis in mind, the innovation expenditures are used as a quantitative input indicator for the innovative activities of firms generating product innovations. Process innovations in the form of investment for rationalization are a special kind of innovation expenditures.

4. Measurement of Innovation Input and Output

There are studies that use R&D expenditures as an indicator of innovation (Erber and Horn, 1990). That might be adequate if one is interested in R&D based innovations and their long-term impact on growth and employment in a general sense. R&D data only indicate the existence of activities which generate new scientific and technical know-how; they say nothing about

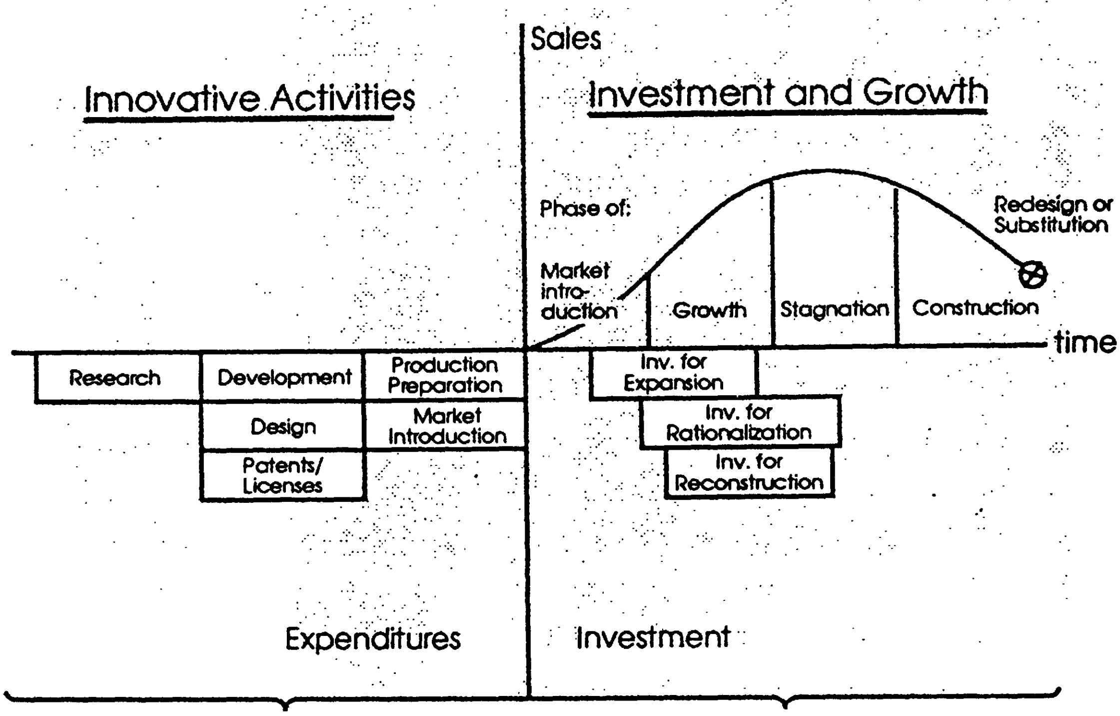
- if and when that know-how is implemented in the economy;
- the diffusion process of that knowledge;
- activities and other sources of innovation like licences or design;
- product- or process-related R&D expenditures.

However, studies that analyse the sectoral and intersectoral impact of new technologies on growth and employment must provide answers to these questions.

R&D activities lead to an accumulation of technical know-how, but without production preparation and market introduction activities, that amount of know-how will not stimulate technical change at all. Production preparation expenditures include investment linked to product innovations. This type of investment is a central indicator of innovative market-widening effects that are the potential base for further investment in expansion, rationalization and reconstruction at a later time, that is, in the diffusion phase of these new products.

Figure 1 illustrates for sectors of industry how the gestation period of innovations differs and how long the diffusion phase lasts before products are redesigned or substituted by "new" ones. This effect largely depends on what is defined as "new". From a technological viewpoint each technical change within a given product or production process will lead to a new solution. However, it is questionable if such technical changes are

Figure 1. Innovation, investment and product life-cycle



Average loss of time between first idea and market introduction (responses in %) for: | Average loss of time between market introduction and innovative product change

	5 and more years	3 to less than 5 years	1 to less than 3 years	less than 1 year	less than 1 year	1 to less than 3 years	3 to less than 5 years	5 and more years
Producer Goods	1	45	52	2	34	5	17	44
Investment Goods	1	7	45	47	25	24	27	24
Foodstuffs, Beverages	0	11	34	55	12	21	46	21
Consumer Goods	5	34	50	11	6	22	30	42

time

Source : ifo-Innovation Survey, 1984 (special question).

really relevant from an economic viewpoint with respect to a specific market. Therefore a scientist has to be very cautious in generalizing and aggregating empirical findings for specific technologies and innovations based on case studies or surveys of technology use.

5. Incremental Innovation Output Ratio and Technological Epochs

The "incremental **capital** output ratio" is a measurement for analyzing the relationship between unspecified investment activities and growth. This approach was modified in the META-Study using an econometric analysis to create an "incremental **innovation** output ratio" for German industry as a whole, with innovation expenditure data extending from 1962 through 1986. In general, the degree of statistical significance was quite good. However, the regression analysis of short-term and long-term time lags between innovation expenditures and growth yielded no significant results. What might be the reason? Was the data base for the estimated innovation expenditures for the years 1962 to 1978 incorrect, although it was reconstructed with the help of the R&D statistics and data from the ifo Investment and ifo Innovation Survey? We do not believe that the data are the problem. Two other hypotheses seem to be far more relevant: (1) Either the growth rate, structure or direction of technical progress itself changed in West German industry in that particular period of time or (2) other sectoral, national or international factors highly influenced the interdependencies between innovation and growth. The traditional statistical data base rules out an analysis and distinction of these influences because these data include the "net effects" of technical change and other factors. They give us no useful explanatory variables for the structure of technology.

Brown and De Cani (1963) declared that technical progress is "a basket of components" that can change over time and will lead to different "technological epochs". Therefore, one has to measure this basket of technologies more directly because production functions describe only an "abstract technology".

The ifo Innovation Survey isolates some variables (Scholz, 1977) of this "abstract technology" to better understand the components of this unknown technology basket. Product- and process-innovation activities, their general structure, that is, the innovation mix with respect to single firms or a whole industry, and the innovation expenditures are such variables. This approach cannot identify the effects of individual technologies. The bundle of innovation activities (Rogers and Shoemaker, 1971, p. 171) persued by the firms are measured for their unspecified innovation mix in the form of so-called envelope curves. This measurement concept does not lead to aggregation problems that are indeed insoluble for isolated effects of individual technologies, such as industrial robots and numerically controlled machines.

6. Direct Employment Effects of Innovation

It is a widely accepted hypothesis that innovation has a positive impact on growth and employment. However, this hypothesis has not yet been tested on an adequate data base. Therefore, four types of firms were isolated in the ifo Innovation Survey sample:

(i) non-innovators;
(ii) pure process innovators (including investment for rationalization);
(iii) pure product innovators;
(iv) combined product and process innovators.

For the period 1979 to 1986 the ifo innovation data show that all types of innovators were more or less influenced with respect to their growth by the economic slowdown following the second oil price shock in 1980 to 1982. However, there are significant differences between the type of innovators and changes in their sales and employment figures. Type (iv), i.e. combined product and process innovators, showed the most positive effects on sales and employment growth (see Figure 2 and 3). They were followed by product innovators and process innovators. Non-innovators were last on the list, as expected. Although these time-series results have only a base of eight years so far and are heavily influenced by other factors beside technical change, the hypothesis that innovation influences growth and employment positively is probably true for the company level (Penzkofer et al., 1989).

However, the positive development of innovators may result from the poor performance and losses of non-innovators in the relevant markets. In that case innovation would be a zero-sum game from an economic viewpoint. These questions must be analysed for specific markets at a later time to identify the effects of innovation on competition at the national and international levels. However, cross-section analysis on the level of branches of industries which include heterogeneous markets generally produced the same results as those found at the company level.

These results correspond to the qualitative structure of innovation activities of firms and industries without differentiating the quantitative rate of innovation. The ifo Innovation Survey includes questions on the proportion of innovation expenditures

Figure 2. Growth of sales for types of innovators, 1979-1985

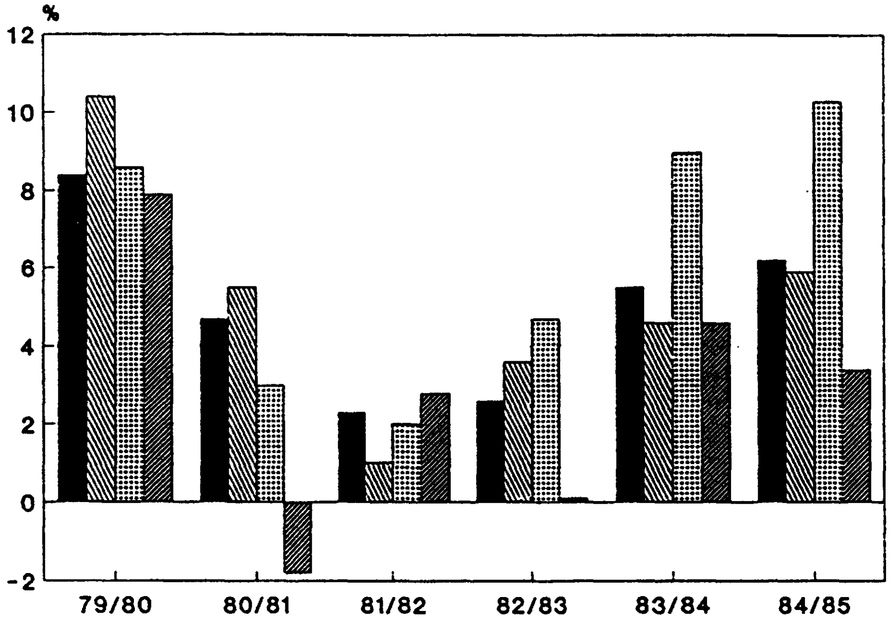
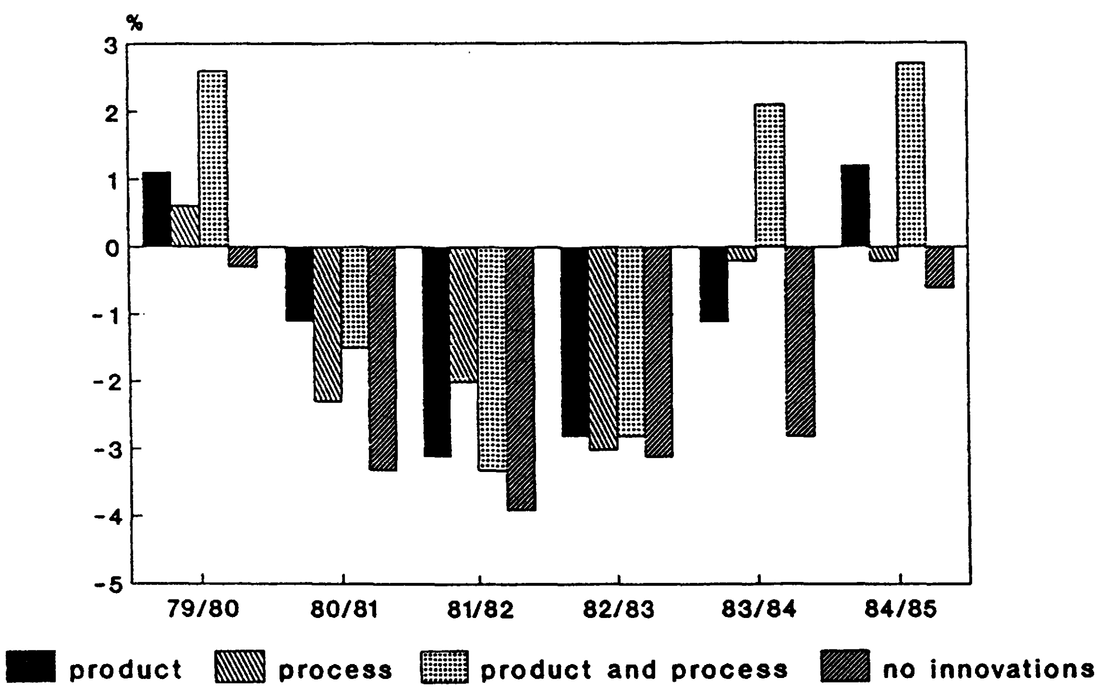


Figure 3. Growth of employment for types of innovators, 1979-1985



Source : ifo Innovation Survey.

linked to product, process and combined product/process innovations. As stated above these data should be used as quantitative input indicators for the structure and intensity of technical change.

Table 1 shows figures for output and employment growth from 1980 to 1986 for selected sectors of industries and their expenditures for product and process innovations as a percentage of output in 1980. In general one can say that at branch level the sectors characterized by high innovation expenditures exhibit more pronounced employment and turnover effects than the average, and have thus increased their share of output over this period of structural and sectoral change. One fact that it is not possible using this data base to achive clearer differences between innovative activity, growth and employment is due to time lag-effects, the analysis of which would require a longer time series. Another fact is that there are growth effects on the demand side which cannot be neglected, e.g. different levels of saturation. Therefore one has to differentiate between product innovations as an indication for stimulating the preferences of demand and process innovations influencing the productivity of production.

Table 1. Innovation Expenditures, Employment and Growth
- for selected sectors of industry, in % -

Sectors of industry	Expenditure on innovation as a % of output in 1980		Change 1980 to 1986	
	Direct	Cumulative[a)]	Employment	Output[b)]
Chemical products	12.1	17.4	-0.2	2.3
Crude oil products	0.6	3.0	-3.2	0.0
Plastic products	3.1	7.6	1.5	3.8
Iron and steel	1.3	3.0	-4.9	-2.2
Industrial machinery	4.1	6.5	-0.5	1.8
Office machinery	16.0	19.9	3.9	10.2
Road vehicles	8.7	12.4	0.1	2.5
Aerospace	22.2	28.4	2.0	4.3
Electrotechnical products	9.1	12.0	-0.2	3.4
Textiles	2.8	5.8	-4.6	0.0

a) Incl. intermediary, investment and imported goods.
b) In real terms for 1980.

Source: ifo Business Survey, ifo Innovation Survey, ifo Investment Survey, Federal Statistical Office, "Stifterverband für die Deutsche Wissenschaft"; calculations by the ifo Institute.

The ifo Innovation Survey measures the innovation expenditures in industry only. On the basis of the R&D statistics of the Stifterverband für die Deutsche

Wissenschaft the innovation expenditures of all other sectors were estimated for the years 1980 and 1986. That was hard work, but it had to be done despite the many dissatisfying implications from an empirical viewpoint. Furthermore, the direct measurement of innovation activities of firms or industrial sectors is only the first step in analysing the consequences of technical change for growth and employment. In an industrialized economy where specialization in production is very important for efficiency and competitiveness, one must also identify the intersectoral diffusion of innovation.

7. Direct and Indirect Effects of Innovation : the Innovation Flow Matrix

The input output instrument has been used already to compute the direct and indirect effects of selected technologies and R&D expenditures (Wittig, 1982; Leontief and Duchin, 1986; Kalmbach et al., 1989). With regard to process innovations, like industrial robots or numerically controlled machines, it is possible to evaluate their partial cost effects and their labor saving impact. In this type of analysis, process induced qualitative changes of products and other product innovations are neglected. Such an analysis corresponds to a pure process innovator's strategy and its impact on employment. This type of approach cannot answer the question of whether this innovation strategy is really dominant at the level of the firm, the industrial sectors or the overall economy and whether it characterizes a specific "technological epoch" of an economy. However, the results illustrate to what extent employment compensation effects are necessary to stabilize the number of employees, for example.

The use of total R&D expenditures could be used to analyse the potential flow of know how between the sectors. But they should differentiate between sector specific product and process oriented R&D activities and their impact on growth and employment. Furthermore, R&D activities should be understood as an indicator for the potential of inventions, only. However, with regard to the effects of technical progress, one needs an indicator for the propensity of diffusion of new products and processes, i.e. the innovation potential. That is why the innovation-flow matrix was developed using the data of the ifo Innovation Survey.

It is possible to analyse the technology transfer process for individual technologies identifying the intrasectoral and intersectoral trajectories. However, it was already stated above that there is no chance to aggregate the figures for the whole range of innovations in industry. But with regard to the sectoral sales structure of new products there could be a possibility to get the needed data. Therefore, in 1987 the participants of the ifo

Innovation Survey were asked for their sales structure of new products which they had introduced on the market within the last five years. About 800 enterprises answered this question. However, the analysis of the data base showed that it was only possible to aggregate the figures for a few samples of sectors of industries. For other sectors the representativity of data was too low. But there were indications for the hypothesis that the most probable trajectories are comparable with the input coefficients measured by an actual input output table. This hypothesis is based on the observation that the channels of diffusion of new technologies between producer and user of product innovations follow already existing contacts on the market. Therefore, the input output table was used to develop the innovation flow matrix.

The central equation for the input output analysis is:

$Z = B\,(I - A)^{-1} \cdot Y$; with
Y = final demand
A = matrix of input coefficients:

$$a(ij) = \frac{x(ij)}{x(j)}$$

a(ij)	is the direct input of good i which is needed to produce one unit of good j.
x(ij)	: deliveries from sector i to sector j
x(j)	: production value of sector j
I	= unit matrix
$(I-A)^{-1}$	= matrix of cumulative input coefficients (Leontief Inverse)
B	= vector of (sectoral) innovation expenditures
Z	= direct and indirect innovative contents of final demand.

For the calculation of the innovation flow matrix the input output table published by the Federal Statistical Office for 1980 was used. In order to be able to identify a potential change in the intersectoral structure of innovation activities it was necessary to have input output tables up to the year 1986. Therefore, a specific method for updating input output matrices was developed. This method is based on an input output model which takes into account the basic idea of "activity analysis". In the iteration process of input output modelling, all quadrants of the input output table are considered. The result of this iteration method, which includes six steps, is compatibility of production and imports in the input output table with the change in gross value added and final demand based on official statistical data. This method excludes an arbitrary change of input coefficients. (See Penzkofer et al., 1989, p. 16-22.)

There were several possibilities of using the innovation expenditures of the ifo Innovation Survey, e.g. total expenditures, expenditures for product or process innovations, or only parts of the innovation expenditures (R&D, constructional design, production preparation or market introduction). Which type of innovation flow matrix is the best depends on the particular question one has in mind.

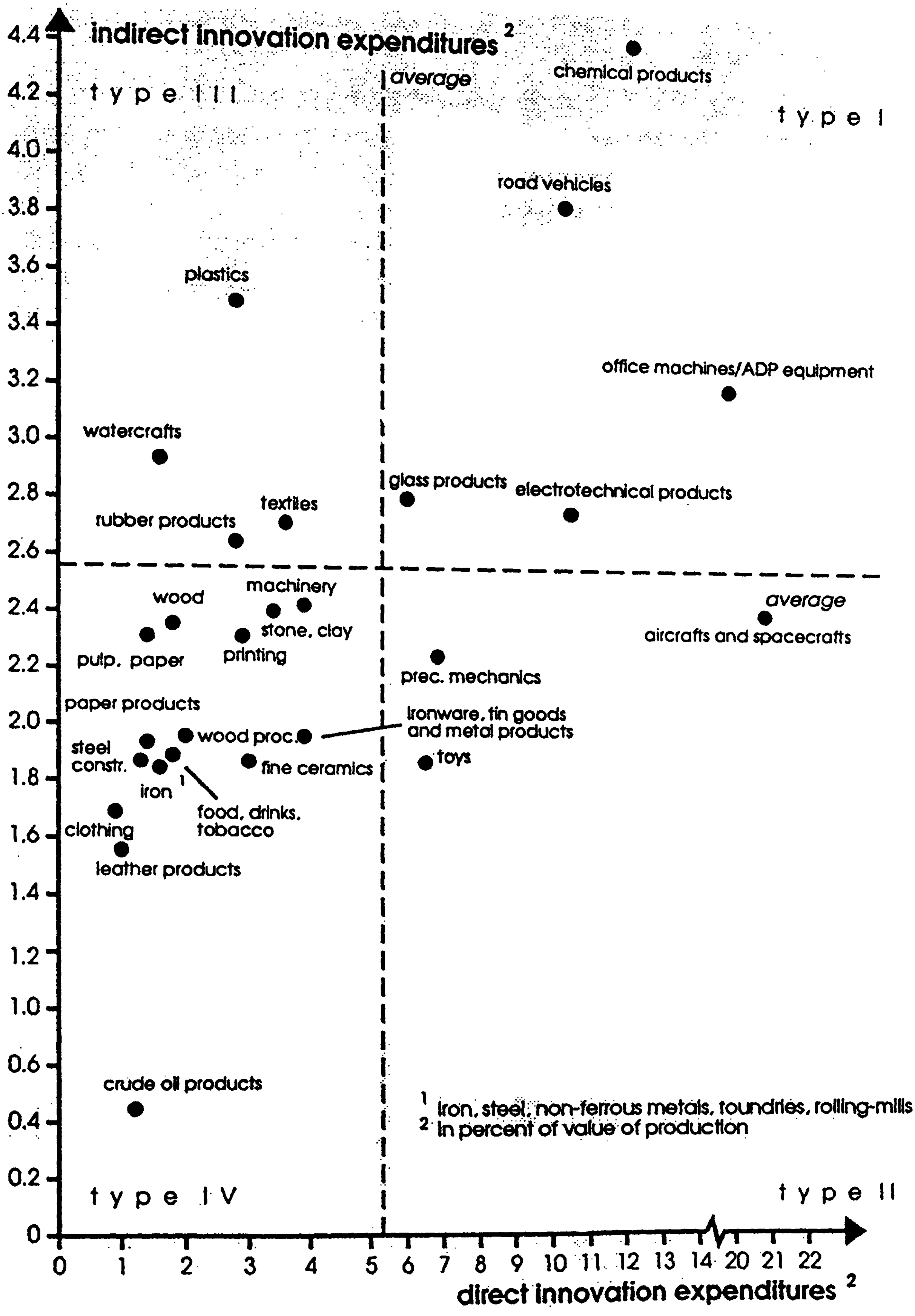
8. Direct and Indirect Effects of Innovation

The results of the innovation flow of total innovation expenditures showed that there is a broad scattering in industries with regard to direct and indirect innovation activities (see fig. 4). Industrial sectors which have relatively low direct innovation activities, like manufacturers of synthetic or textile products, benefit from relatively high indirect innovation effects from other branches of industry. On the other hand, there are sectors with high direct and indirect innovation activities like the chemical and automobile industry, data processing and electrotechnical products.

The position of industrial sectors in the so-called intersectoral innovation bundle portfolio of German industry was shown to have changed in some cases between 1980 and 1986. Initial results showed for the different innovation bundles of industries, that sectors with high direct and indirect innovation activities (type I) have had relatively low losses in employment in all years, while sectors with low direct and indirect innovation expenditures (type IV) lost employment above the average of all industries. (See Table 2.)

Several other approaches were used to analyse the innovation flow with regard to growth and employment. Regression analyses revealed for example, a good correlation between direct and indirect product innovation expenditures and market growth. The ifo investment matrix was used to calculate the direct and indirect effects of process innovation expenditures on labor productivity. Both approaches could be the elements for disaggregated macroeconomic models, using innovation activities as explanatory variables of production and demand (Krelle, 1986). In a macroeconomic model which was developed for another study (Scholz, 1980) that can be seen as a forerunner of the META research project, only the data from the ifo Investment Survey were available. Now having both investment and innovation data, the next step is to continue this kind of model development.

Figure 4. Intersectoral innovation-bundle of the German industry 1986



Source : Ifo Institute for Economic Research Munich.

Table 2. Changes in Employment and Gross Value-added in Different Types of Innovation Flow (1980-1986)

- in % -

Sector belonged in 1980 to type...[a)]	All branches E	All branches V	of which: manufacturing industry E	of which: manufacturing industry V
I	-0.4	16.6	-0.6	20.7
II	8.2	25.5	-9.4	-4.3
III	-3.8	5.1	-12.1	9.2
IV	-3.5	5.2	-12.1	-2.7
Total	-2.2	9.3	-8.1	5.6

a) See Figure 4.

Explanation: E = Change in Employment
V = Change in gross value-added at 1980 prices

Source: ifo Business Survey, ifo Innovation Survey, ifo Investment Survey, Federal Statistical Office, "Stifterverband für die Deutsche Wissenschaft"; calculations by the ifo Institute.

9. Innovation Flow and Final Demand

It was a central hypothesis of this specific part of META research that the rate and direction of innovation activities, which are necessary conditions for technical progress, change over time, lead to different "technological epochs" and influence economic and social change. With the data base of the ifo Innovation Survey and with the help of the innovation-flow matrices, it is now possible to describe and indicate the structure and direction of technological innovation activities more specifically.

The national budget of West-Germany for product innovation, i.e. excluding investment for rationalization and process innovation, has grown from about DM 32 bn. in 1980 to DM 39 bn. in 1986 in real terms. This corresponds to an average annual growth rate of 3.4 %. With regard to final demand, the innovation expenditures directed towards private consumption show a slight decline from 30 % (1980) to 29 % (1986). The innovation input for equipment investment shows a slowdown from more than 15 % to about 14 %. Export goods have tied up more than 38 % (1980) and up to 43% (1986) of the national innovation budget. Thus, there is a strong export orientation of the West German economy in its innovation strategy (Frühstück and Wagner, 1990), which is based to an extraordinary extent on the innovation activities of the investment goods industries, while the innovation input linked to construction investment and public households is relatively small. It is not clear whether this orientation of innovation is typical of highly industrialized countries, because there are no data for international comparisons available.

10. Conclusions

The research results for West Germany show that the innovation per unit of investment goods is more than twice that for consumer goods. About 50 % of the consumer oriented national innovation budget is directly and indirectly linked to automobiles and chemical products. Electrotechnical products and food together account for an additional 20 %. It seems that the innovativeness of private and public sectors should be stimulated far more in the future. Without an intensification of innovation activities on the supply side or a stimulation of innovation behaviour on the demand side, there will be a process investment dominated innovation strategy, which seems to be not sufficient to compensate the release effects of modern production techniques on the labor market. That research result should have a policy impact for future measures with regard to R&D and innovation policies. Yet there are already several political stimuli regarding technology based innovative compensation potentials, e.g. innovations in the field of environmental protection and infrastructure with complementary positive job effects for the service sector.

Perhaps the economy will be confronted with innovative consumer goods from other countries to a much greater extent in the coming years, too. In that case the question must be posed of whether it is really an adequate innovation strategy for a highly industrialized country to receive impulses for a higher quality of life from outside.

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(12)

Comment : *Luke Georghiou*

In commenting on Professor Scholz's paper I will confine my discussion to some general principles arising from this paper. To begin with I should like to comment on the innovation activity approach. It must surely be a strength of this concept that it includes not only R&D expenditure but spending arising from what Teece terms the "complementary assets" of the firm, that set of activities which encompass the transition from R&D to production. A strong message from recent case-study based evaluations is that it is in this phase that many problems of European industry lie. However, from the experience of empirical innovation studies I must question the basis of the data which underpins this and similar studies. The problem is that firms are frequently unable to disaggregate their costs in the required manner. For example, the same R&D may relate to a number of innovations and more importantly the downstream costs may extend to products other than innovations. Is the survey design predicated on a linear model ?

This takes me to a point of greater difficulty for the empirical student of innovation. We are told that more than half of the products are unchanged for at least 3 years after market introduction, in all sectors, implying that innovation and diffusion are discrete activities. However, my impression is that the author feels uncomfortable with this static view. An alternative view would characterise innovation as a continual process driven by competitive pressure.

Many of these problems arise from the use of a unit of input as a measure of output. Expenditure on innovation may not always be a suitable proxy for technical change. Differences in both the efficiency and the creativity of firms (and sectors) may result in widely different returns for the same investment at any stage of the process. Expenditure on design and marketing can be just as unproductive as R&D spend.

I move now to one of the strengths of this approach, the treatment of intersectoral flows. These remind us strongly that we cannot neglect the intersectoral benefits of innovation which in turn lead to the paper's conclusions regarding the dominance of investment-goods in unit innovation expenditure. Without international comparative data it is not clear the extent to which this reflects differences in the cost of innovation (based on factors such as the maturity of the technology and the state of competition in the market); or the behavioural inclinations of different sectors of German industry.

I shall conclude with a point which applies to much of the work we are considering today, that is the question of in which direction causality lies. Both theoretical development and quantitative studies benefit from interaction but it is hard to interpret measurements without a clear model which illuminates their significance.

Chapter 8 - Structural Change and Industrial Performance

Andrew Wyckoff

Soon to be published as an OECD document, the report examines changes in the industrial structure of seven OECD economies (Australia, Canada, France, Germany, Japan, the United Kingdom, and the United States), measured by changes in the output and employment shares accounted for by individual industries over the decade-and-a-half from the first oil crisis in 1973 to the mid 1980s. Its aim is to describe patterns of change and to characterise them in policy relevant terms by presenting an accurate picture of the current industrial composition of these economies and how they got to this state, thereby establishing a framework for analyzing their likely evolution in the future.

Although it does not examine the institutional factors behind the compositional changes such as changes in labour or financial markets, the report does identify which economic factors -- exports, domestic demand, imports and changes in the pattern of inter-industry linkages -- were associated with a shift in an industry's position within the economy. (For the decomposition of employment, labour productivity is an additional factor.) This decomposition of structural change into the factors associated with it represents an extension of standard compositional work and provides a complement to previous institutional analyses carried out in the OECD.

This report focuses on the factors of change that lie below the broad sectoral level. It makes use of a new industry-level OECD database, which includes internationally comparable, constant price input-output tables for the 7 countries in the study. The decomposition of changes in output and employment growth according to the various sources underlying them, made possible by these input-output tables, is carried out at the individual industry level (33 separate industries). Technology intensity and real growth rates in output are used to classify individual industries into different performance groups: high-, medium-, and low-technology as well as high-, medium-, and low-growth. These categories form the basic elements used to describe the key patterns of observed structural change and compare the experience of different countries.

Principal Findings

The Extent of Change

* *Countries in our sample have exhibited a significant shift in real output towards services and high-technology manufacturing.* Within services, wholesale & retail trade; finance & insurance; real estate & business services; and social & personal services have shown the most significant growth. Most of the high-technology manufacturing gain in share was due to the computer & office machinery and communication & semiconductor industries.

* *These output gains have been offset by reductions in low-technology manufacturing, construction, and in some countries, medium technology manufacturing industries.* In particular, the shipbuilding, ferrous metals, textiles, petroleum refining, and fabricated metal product industries experienced low-growth and declining shares of total output.

* *All seven of the countries experienced a shift in employment shares out of agriculture and manufacturing and into services.* Within the service sector most of the gains were concentrated in the financial services, community and social services, and the trade & hotels group. The largest employment share losses in manufacturing were in the low-technology manufacturing sector.

Factors Associated with Structural Change

* *Technological change played an important role in both expanding and declining sectors.* On average, industries made more intensive use of financial services such as real estate & business services as inputs into their own production processes, thereby stimulating their output. The same was true for high technology manufactures, although it was not the predominant factor in growth. *Technology was also the predominant cause of decline in low growth industries.* On average, industries throughout the economy made less intensive use of the outputs of these sectors. In general, this technological effect outweighed losses due to import penetration, contrary to popular perceptions.

* *International trade played an important role in both the expansion of high technology and the losses in medium technology manufacturing output shares (Table 1).* High technology growth was driven primarily by exports -- technical change and domestic

final demand expansion, though important, generally played a secondary role. The exception, for all countries other than Canada and Germany, was computers, where domestic final demand was the primary force.

Table 1. Sources of Change in Real Output Shares for Manufacturing

Country	ISIC Sector	Total Change in output share (percent per year)	Source of Change				
			Domestic final demand expansion	Export expansion	Imports of final goods	Imports of interm. goods	Technology (change in I/O coeff.)
Australia (1974-86)	Manufacturing	-4.20	-2.86	0.77	-2.30	-2.40	2.58
	High technology	-0.27	0.33	0.17	-0.46	-0.53	0.22
	Medium technology	-0.87	-0.92	0.53	-0.97	0.88	1.35
	Low technology	-3.06	-2.27	0.07	-0.87	-1.00	1.00
Canada (1981-86)	Manufacturing	-0.66	-1.63	3.11	-0.89	-0.89	-0.36
	High technology	0.31	-0.09	0.78	-0.25	-0.16	0.03
	Medium technology	1.17	-0.22	1.90	-0.27	-0.40	0.16
	Low technology	-2.14	-1.33	0.43	-0.37	-0.33	-0.54
France (1972-85)	Manufacturing	-3.98	-2.00	4.49	-2.34	-2.92	-1.21
	High technology	1.72	0.81	1.34	-0.29	-0.29	0.15
	Medium technology	-0.52	-0.46	1.63	-0.76	-0.95	0.02
	Low technology	-5.18	-2.35	1.52	-1.29	-1.68	-1.38
Germany (1978-86)	Manufacturing	-2.32	-1.34	3.52	-1.32	-2.11	-1.07
	High technology	0.87	0.31	0.94	-0.26	-0.25	0.13
	Medium technology	0.44	-0.34	1.84	-0.37	-0.86	0.18
	Low technology	-3.63	-1.31	0.74	-0.69	-0.99	-1.38
Japan (1970-85)	Manufacturing	1.36	-4.05	6.78	0.01	-0.36	-1.02
	High technology	7.25	2.58	3.41	0.11	0.04	1.11
	Medium technology	1.02	-2.29	3.00	0.01	-0.12	0.43
	Low technology	-6.92	-4.34	0.38	-0.11	-0.29	-2.55
UK (1968-84)	Manufacturing	-11.57	-2.76	1.70	-4.18	-5.33	-1.00
	High technology	0.49	0.52	1.49	-1.02	-0.72	0.21
	Medium technology	-4.09	-0.40	0.65	-1.84	-2.66	0.16
	Low technology	-7.97	-2.88	-0.44	-1.32	-1.96	-1.38
USA (1972-85)	Manufacturing	-3.08	0.86	1.56	-1.74	-1.68	-2.07
	High technology	2.40	1.87	0.80	-0.34	-0.24	0.31
	Medium technology	-1.52	0.05	0.34	-0.77	-0.66	-0.47
	Low technology	-3.95	-1.05	0.42	-0.63	-0.78	-1.91

* *Change in labour productivity growth rates was the single most important factor affecting the structure of employment.* For those industries experiencing the lowest growth in output across the five largest countries, the effect of productivity was the dominant factor associated with declining employment growth rates, exceeding the impact of imports or changes in "technology". *In general, the relatively high labour productivity growth rates in manufacturing compared to other sectors caused manufacturing em-*

ployment share losses to be greater than manufacturing output share losses. Despite its high output growth rate, the employment share of high-technology manufacturing was mostly stable or falling moderately.

The Direction of Change

* *Domestic demand for final products was on average the predominant factor behind industries experiencing high output growth rates.* This trend was particularly pronounced in the US where domestic final demand was the dominant factor driving every one of ten highest growing industries, significantly ahead of other factors.

* *All the countries had structural shifts in output towards the high-technology manufacturing sector*, but Japan's share gain and output growth rate were more than double that of the next closest country, the United States. The 7.2 annual output growth rate set from 1970 to 1985 was achieved predominantly through exports and to a lesser extent domestic demand and technological change. Although a relatively small factor, the Japanese high-technology manufacturing sector also benefited from the displacement of imported high-tech products by those produced domestically -- the only country of the seven countries to do so.

Cross Country Comparisons

* Broad comparisons of overall structural change reveal substantial differences between countries:

  - The rate of the structural change of output was significantly higher in Japan than in other countries and would generally be recognized as being favourable with substantial shifts into high-technology manufacturing and other high-growth industries. Because of these gains, Japan was the only country to register an increase in the output share of manufacturing.

  - Industries gaining output share in Canada, France and Germany were also mostly export driven. In Australia and the US, in contrast, domestic final demand was the most important factor. In the UK it was a mixture of both exports and domestic final demand.

- Imports had a negligible adverse impact on output growth in Japan but were significant in Australia, France, Germany, the UK and the US.

- Only two countries, Australia and the UK, had net gains in the share of output accounted for by the natural resource sector. This reflects Australia's agriculture and mining resources and UK North Sea oil.

- Canada and Germany were the only two countries to register a net increase in the share of employment in medium-technology manufacturing.

Chapter 9 - An Exploration of the Interrelationship of R&D Expenditure and Technical Progress in the major OECD Economies

Liam O'Sullivan and Weerer Röger

1. Introduction

Technical progress is regarded as a major source of growth in industrial economies. Policies to stimulate growth, both at firm and government level must therefore aim at increasing the rate of technical progress. R&D expenditures are widely seen as an important instrument in this regard. Due to the similarity of products and technologies in industrialized countries the hypothesis is that technical progress in one region can also be realized elsewhere through trade in goods or patents and by imitation. Besides direct R&D activity, diffusion of technical knowledge is likely to be a very important contributor to technical knowledge especially in those countries/sectors which are not technological leaders but which are endowed with the necessary technical skills to adopt new developments. This paper therefore tries to assess the relative importance of domestic and foreign knowledge (measured by the stock of R&D capital) in determining technical progress in the major European economies (Germany (DE), France (FR), Italy, (IT) and the United Kingdom (UK)), as well as the United States (US) and Japan (JA). The analysis is restricted to aggregate data, but an attempt is made to measure the contributions of high and medium-tech sectors separately. Finally - with the help of the Commission's macroeconometric model, Quest - the labour market implications of technical progress are assessed from a macroeconomic standpoint.

We first present the theoretical framework underlying the empirical analysis. Then we describe major trends in TFP and R&D in Europe, the US and Japan and discuss some measurement problems associated with these concepts. We present our empirical results in the following section. The concluding section of the paper addresses the question of the macroeconomic impact of technical progress, with particular emphasis on the operation of the labour market.

2. Methodology

In following the approach adopted by Griliches (1988), we specify a standard production function where R&D is treated as an additional type of capital.

$$y = \alpha c + (1-\alpha)l + \Theta k + a + \epsilon^{1} \qquad (1)$$

y = Rate of Growth of Value Added
c = Rate of Growth of Capital
l = Rate of Growth of Employment
k = Rate of Growth of R&D-Capital (Knowledge)
a = Autonomous Rate of Technical Progress
ϵ = Stochastic Innovation.

The parameter Θ is the output elasticity of R&D capital $(\delta Y/\delta K)(K/Y)$.

Since $k = (\delta K/K)$
we get $\Theta k = (\delta Y/\delta K)(K/Y)(\delta K/K)$.

The marginal product of R&D capital is treated as a constant and is given by

$$m = (\delta Y/\delta K)$$

If it is further assumed that R&D does not depreciate[2] we can write

$$R\&D = \delta K$$

and equation (1) can also be written as

$$y = \alpha c + (1-\alpha)l + m((R\&D)/Y) + const + \epsilon \qquad (1a)$$

In order to examine the international diffusion of knowledge we postulate a (Cobb-Douglas) production function for knowledge with domestic and foreign knowledge-capital as inputs

$$K = K(K_D, K_F) = K_D{}^{d} \cdot K_F{}^{f} \qquad (2)$$

K_D = Domestic Knowledge Input
K_F = Foreign Knowledge Input
d, f = Knowledge Elasticities

1 Regarding notation, the following convention is used : x denotes the growth rate of the variable X.
2 The assumptions regarding depreciation are discussed more fully in Griliches(1988).

The rate of growth of knowledge can then be written as

$$k = dk_D + fk_F \tag{2a}$$

with d and f representing the weights with which domestic and foreign factors contribute to the growth of knowledge in one country.

The domestic factor which contributes to the growth of knowledge is again measured as R&D expenditure. The foreign factor could either be measured as foreign R&D expenditure or more directly as the increase in foreign (total-factor) productivity. Foreign actual innovations seem to be a more reasonable measure since it is likely that domestic firms get access to foreign knowledge after it has materialized in new technologies and not at the stage when innovations are developed[1]. Therefore domestic knowledge input is represented by domestic R&D capital, while foreign knowledge is generally represented by (a linear transformation of) foreign total factor productivity. With this new representation of knowledge as in equation (2), equation (1) can be written as

$$y = \alpha c + (1-\alpha)l + m_D(R\&D/Y) + m_F tfp_F + a + \epsilon \tag{3}$$

The coefficient m_D can be interpreted as above, as the marginal product of R&D-capital. The coefficient m_F must be interpreted as an elasticity of output with respect to foreign technical progress.

3. Trends in R&D and TFP

3.1. TFP

Total factor productivity is usually measured in one of two different ways. Either a production function is postulated and the residual is regarded as a measure of disembodied technical progress or the residual is calculated directly via Solow's method[2]. In this paper the second method is adopted. It has two major advantages over the production function approach, it is a non-parametric method, i.e. no specific form for the production

1 In our empirical estimates we test both measures. Except for Japan (and the UK as a borderline case), TFP seems to be the better measure.

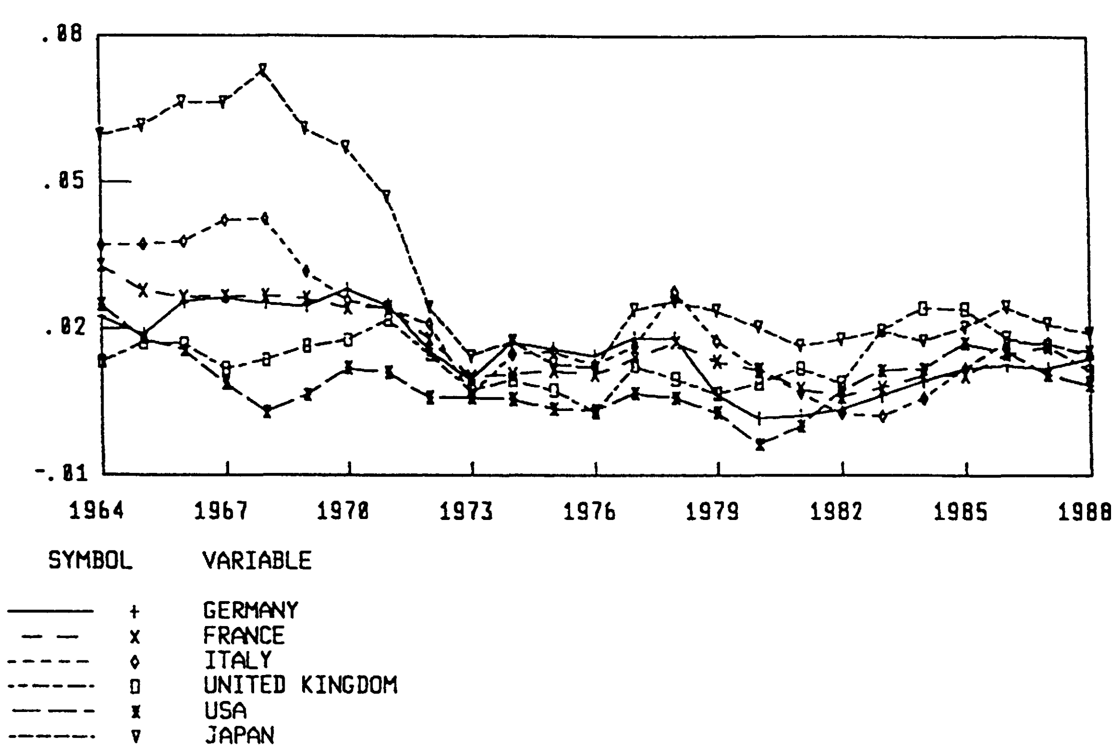
2 The Solow Residual (SR) is defined as

$$SR = y - al - (1-a)c$$

where a is the labour share in value added.

function need be postulated and it is easy to calculate. The drawbacks of this method are the assumptions on market structure - namely the assumption of perfect competition - which must be made in order to determine the factor shares (see e.g. Hall 1988). However, calculations of the Solow Residual with adjustments to correct for positive markups do not change the dynamics of TFP in any essential way. Therefore, for the present purposes this weakness of Solow's method does not seem to be crucial. A criticism which applies to both methods of calculating changes in TFP concerns spurious cyclical effects due to labour hoarding over the business cycle. This problem is effectively dealt with in this study by filtering the data with a 5-year-moving average filter in order to remove business cycle effects[1]. One advantage of filtering the data is the better visibility of trend developments in TFP. As can be seen from Figure 1, total factor productivity can roughly be divided into two periods within our sample (1964-1988). The first period ending at the end of the 1970's can best be characterized by a declining trend in the growth rate of TFP. This trend is especially pronounced for Japan. Throughout the 1980's a reversal of this downward trend can be observed for all countries in our sample. It is also interesting to notice that US-TFP growth forms the floor for nearly all periods in our data set.

Figure 1 : TFP Growth Rates



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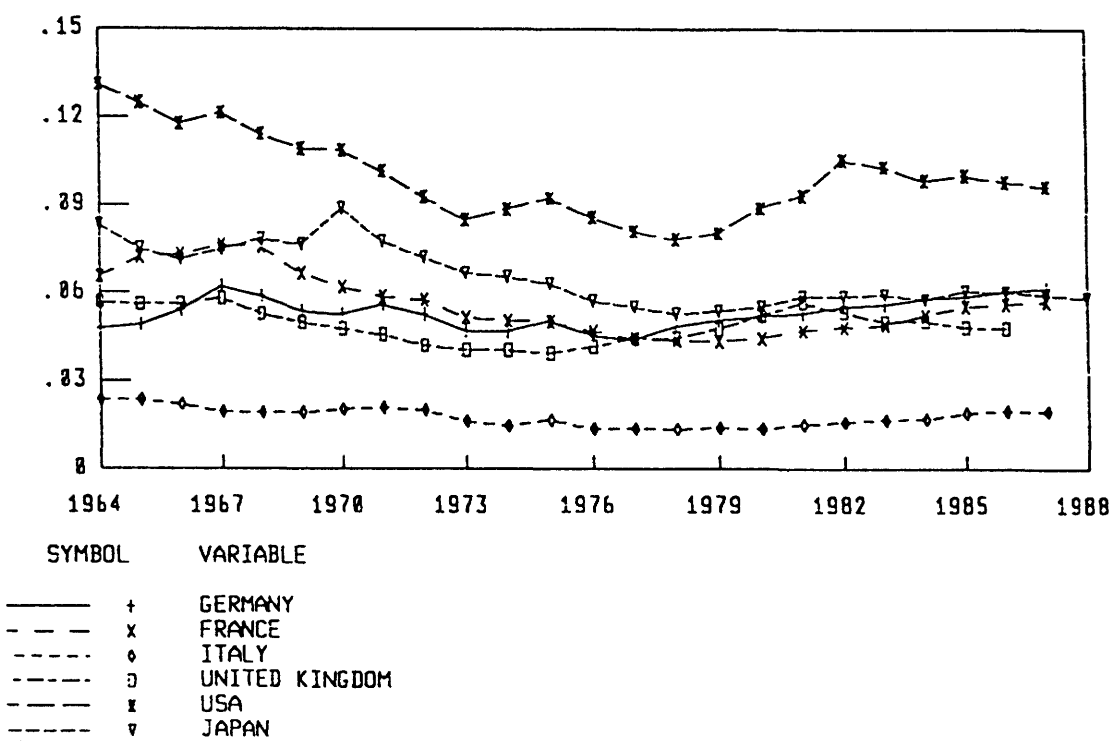
1 The data used to calculate TFP are total economy aggregates and are taken from the Commission's Eurostat databank.

3.2. R&D

As outlined in Section II a commonly used measure for R&D input is the share of R&D in value added (R&D/Y)[1]. The important question, however, remains whether real or nominal shares should be calculated. Since R&D figures are usually published in nominal terms a proper deflator for R&D is normally not available, so the value added deflator is used implicitly in many studies. In contrast to this common practice we consider the wage rate a more appropriate deflator, in order to stress the human-capital content of R&D expenditures. Our choice of deflator was also dictated on the basis of regression results for Europe and Japan using both deflators. With the value added deflator the share of R&D shows a strong positive trend for both regions resulting in a negative contribution of R&D to TFP growth. Reasonable regression results could only be achieved with the wage rate as a deflator[2] (see Figures 2 and 3). A by-product of this analysis certainly is that many indicators on R&D-developments in Europe and Japan may convey an excessively optimistic impression about development of real R&D shares in these countries if they are based on the value-added deflator (and in contrast an overly pessimistic view on R&D contributions to technical progress in Europe and Japan).

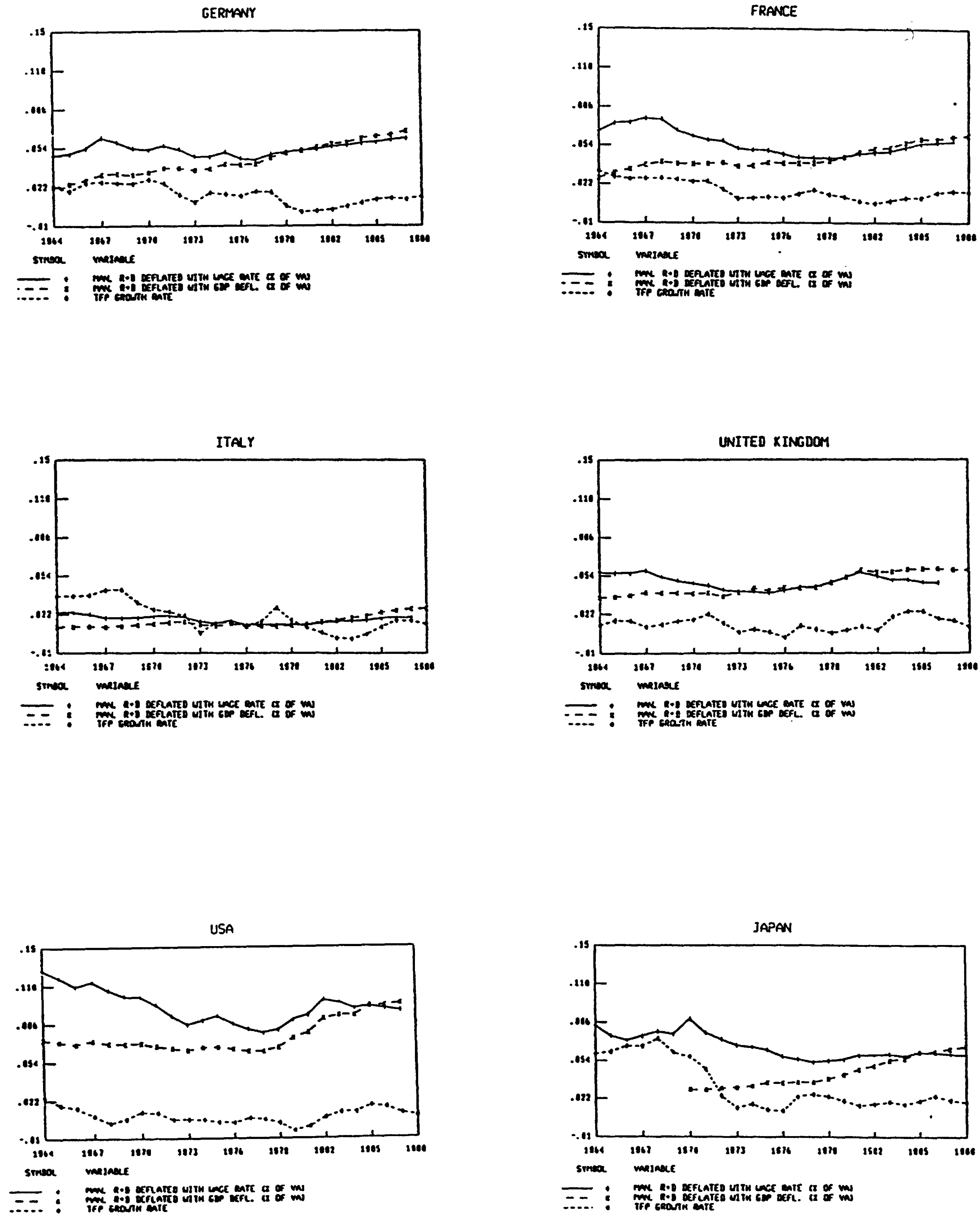
Figure 2 : Manufacturing-R+D (% of value added)



1 For our empirical analysis we use the share of manufacturing R&D in manufacturing added. The data on R&D are taken from OECD's BERD databank.

2 For the US, it does not seem to matter whether the value added deflator or the wage rate is used to deflate the series for R&D expenditure.

Figure 3 : R&D Indicators and Technical Progress



Given these adjustments to the data it is interesting to observe that the R&D share in value added shows a similar pattern to TFP growth. Prior to the 1980's a decline in R&D expenditure can be observed in nearly all countries and especially for the US. Starting again at the end of the seventies the share of R&D in value added begins to recover.

- A comparison between both developments (TFP + R&D) suggests that there is a relationship running from R&D to TFP on a purely country by country basis.
- However, these figures are somewhat puzzling when comparing their relationship across countries. This is especially true in comparing the US to the other countries. In terms of TFP growth the US performance is generally the weakest of the countries in our sample while simultaneously its R&D share is by far the highest for all countries.
- On the other hand TFP growth declines more strongly (on average) in the non-US world while R&D in these countries declines less markedly than in the US (see Griliches) or even stays constant.

In order to reconcile this cross-country pattern in the data with R&D expenditure the hypothesis can be put forward that knowledge flows from the US to the rest of the world but not vice versa or to a much lesser extent (another explanation could of course be that the return to R&D in the US is much lower than in the other regions. Some empirical evidence on this issue will be presented in the next section.

4. Empirical Results

4.1. The Effect of R&D on TFP and its International Diffusion

In our empirical analysis we examine the impact of R&D on technical progress on a macroeconomic level. The main results from our regressions are contained in Table 1. Only a broad outline of the results is given here - a more detailed discussion of the full macroeconomic consequences of R&D follows in the next section.

US

- Our results for the US are in the range of previous studies. Technical progress lags R&D expenditure by at least two years.

- Spillovers from other industrialized nations to the US are rather limited. The hypothesis of zero spillovers from other regions cannot be rejected at high levels of significance.

Table 1. Effects of Domestic and Foreign Knowledge on Technical Progress*

	Lagged	Domestic	Foreign(US)**	R^2
DE	0.68 (7.72)	0.25 (1.95)	0.32 (3.20)	0.73
FR	0.63 (5.91)	0.14 (2.09)	0.20 (2.45)	0.87
IT	0.25 (7.95)	0.40 (1.08)	0.43 (2.43)	0.78
UK	-	0.41 (2.72)	0.36 (2.21)	0.40
US	0.47 (2.97)	0.15 (2.02)	-	0.58
JA	-	0.49 (1.40)	0.43 (1.51)	0.22

* Estimation Period is 1966-1988.

** For the European countries, the explanatory variable is US TFP while for Japan it is US high-tech R&D, introduced with a one-year lag.

Europe (Germany, France, Italy, and the United Kingdom)

- R&D effects are in general somewhat stronger for Europe than for the US. Italy is an exception with an insignificant effect of R&D on TFP (see also section IV.2). The impact of R&D expenditures on technical progress has a minimum lag of two years.

- Spillovers from the US to Europe are quite marked, especially in the case of Italy, followed by the UK with less pronounced effects in France and Germany.

- Spillovers from Japan to Europe could not be detected.

Japan

The results for Japan are more difficult to interpret than for the other regions, using the same data transformation (growth rates of TFP). From Figure 1 it is obvious that a major shift in the growth rate of TFP occurred between 1969 and 1973 which can neither be adequately explained by movements in our R&D indicators for Japan nor by US R&D imports. Since we do not want to impose too many a priori restrictions on this process and since we also want to keep the analysis simple we formulate the slightly more general model for Japan with a stochastic intercept.

$$tfp_t = \alpha_t + m_D(R\&D/Y)_t + m_F(HTUS/YUS)_{t-1} + \epsilon_t \qquad (3a)$$

where the explanatory variables are the domestic rate of expenditure on R&D and the US rate of expenditure on R&D in the high technology sectors and α evolves according to

$$\alpha_t = \alpha_0 + \alpha_{t-1} + u_t \qquad (4)$$

We estimate (3) in first differences to eliminate the stochastic intercept. Given these transformations we obtain estimates for β with the expected sign.

The result is as follows

- The domestic R&D-effect is relatively strong and has a much more immediate impact given the absence of lags.
- There is also a strong US-effect. However, unlike the European countries a significant US effect can only be found for US High-Tech R&D, while the change in US TFP has no significant influence on Japanese productivity.
- No spillovers from Europe could be detected.

In summing up this section, we wish to emphasise the following features of our results.

The estimates indicate that the US was a major source of technological growth in Europe and Japan within our sample period but has itself not benefited from technical progress in the other regions. From our statistical analysis, it is difficult to decide whether this is the result of US technical leadership or merely an indication of a US inability to adopt foreign inventions to a marked extent. The fact that Japan and the European countries have not benefited from each other to a significant degree points, however, to the first interpretation.

The impact of domestic R&D on technical progress varies slightly from country to country, being relatively strong for Germany, the UK and Japan. Interestingly, the transmission from R&D to technical progress seems to occur much faster for Japan than for Europe and the US. This is true for both the domestic and foreign knowledge components.

4.2. The Relative Importance of High-Tech-R&D

Since we measure the effect of R&D on technical progress on an aggregate level it is very likely that we are overlooking the possibility of alternative types of R&D or R&D in different sectors contributing differently to overall economic progress. This is due to varying sectoral marginal products of knowledge and also to different rates of spillover of sectoral innovations throughout the economy. Constructing a simple aggregate for R&D which weights the R&D expenditure of each sector equally may therefore lead to a severe aggregation bias. Not only are we unable to measure the relative importance of certain types of R&D this way but due to possible errors of measurement we may also underestimate the marginal product of R&D. Therefore we separate High-Tech R&D[1] from the rest and estimate its contribution separately.

The results can be briefly summarised as follows:

- US, JA: High-Tech sectors do not contribute any differently to TFP-growth than the other manufacturing sectors.
- DE, FR, UK: High-Tech sectors contribute more strongly to TFP growth (albeit insignificantly) than other sectors.
- IT: High-Tech sectors contributes less to TFP growth than other sectors. It is noteworthy also that it is only when the disaggregated data is used that the domestic R&D effect becomes significant, with marginal productivity of Medium and Low-Tech sectors equal to 0.43 in the short term.

[1] This includes the Electronic Engineering, Chemicals and Aerospace sectors.

5. The Macroeconomic Impact of Technical Progress

In this section we present the results of simulations carried out using an adapted version of the Quest macroeconomic model[1] where the rate of technical progress is slowed down to levels consistent with the rate of R&D expenditure in 1980. The impact of the slowdown is assessed on the basis of the regression results presented in the earlier sections scaled by the change in the ratio of real R&D expenditure to output on average in the 1980s.

5.1. The Macroeconomic Issue

In terms of macroeconomic impact, the rate of technical progress directly affects labour productivity. In a supply-side model, the effect of a supply-side shock such as a slowdown in the rate of technical progress operates directly on the labour market via reduced output. A suitable focus of attention in that case is the extent to which real wages and employment adjust to new conditions and particularly, whether labour market clearing mechanisms operate in each country.

In carrying out simulations we have assumed throughout that the level of inflation of value-added prices is fixed relative to the historical baseline. This assumption is useful insofar as it enables us to focus on the response of the real economy to the shock. The model used to carry out the simulations employs a standard CES production function where technical progress is assumed to be exogenous and derived factor demands which are summarised in the following equations[2]. For each country the growth rate of wages is determined by inflation, the growth rate of labour productivity, the unemployment rate and changes thereof.

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[1] The Quest macroeconomic model has been developed in the Econometric Modelling Division of the Directorate-General for Economic and Financial Affairs. A detailed description of the model is included in European Economy, No. 47, March, 1991. The simulations described here only involve the supply mechanisms as well as the wage determination process in the model.

[2] As regards the capital stock, the steady state growth rate is assumed along with constant real interest rates.

$$Y = a_0(\alpha_1 K^{-\beta} + (1-\alpha_1)(Le^{\mu t})^{-\beta})^{-1/\beta} \quad (5a)$$

$$L = b_0 Y e^{-\mu\beta\sigma t} (W/P)^{-\sigma} \quad (5b)$$

$$K = c_0 e^{\mu t} \quad (5c)$$

$$w = a_1 p + a_2(y-l) + a_3 ur + a_4 \delta ur \quad (5d)$$

where Y = volume of output
K = capital stock
L = labour inputs
W = nominal wage rate
P = price level
t = time
ur = unemployment rate
μ = labour-augmenting technical progress
α,β = production function parameters
σ = elasticity of substitution.

The following table summarizes the major model parameters underlying our simulations.

Table 2. Key Model Parameters

	a_1	a_2	a_3	a_4*	σ
Germany	1.	.90	-.09	-.84	.61
France	1.	.30	-.13	-.41	.15
Italy	1.	.37	-.22	-.63	.24
UK	1.	.31	-.11	-1.36	.59
USA	1.	.50	-.22	-.13	.77
Japan	1.	.80	-1.17	-1.27	.16

* Values in the Table refer to long run elasticities.

In our simulations, we use the estimation results given in Table 1 to derive the necessary adjustments[1].

5.2. *R&D Expenditure in the Major OECD Economies*

The effect of fixing real R&D expenditure at 1980 levels is quite substantial for the US economy, amounting to an average expenditure reduction of 1.8 percentage points of output. For the Japanese, German, French and UK economies the typical reduction in expenditure is just over a half of a percent of output while in the case of Italy, the reduction is half that again. However, in terms of the impact on technical progress in countries other than the US the influence of the change in the rate of technical progress in the US is also taken into account. Table 3 details the calculation of the effects for each country.

The input to the simulation can be decomposed therefore into domestic and external elements.

The domestic component relates to the effect on technical progress of the change in expenditure on R&D in each country over the period 1980-87 while the external effect comes from the change in the rate of technical progress in the US over the same period. The individual effects in each country are scaled by the coefficients given earlier in the estimation results. The US has the strongest domestic effect to take account of because of the relatively pronounced change in its rate of expenditure on R&D in the course of the 1980's.

On the other hand, the US, by our definition, does not encounter an external element to the change in technical progress which in the case of the other countries is generally of the same order of magnitude as the domestic effect except for Japan where the influence of the (rapidly-changing) rate of R&D expenditure in the US high-technology sectors is particularly strong. The total effect of the technology shock, given by the sum of the domestic and foreign components, reduces the rate of technical progress by close to 1% a year in Japan (by far the strongest impact), while for the other countries the full effect ranges between a quarter and a half of one percent.

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[1] For the reasons given in Section 3, we preferred to calculate the measure of total factor productivity in terms of the Solow Residual instead of the estimated production function. However, the Solow Residual incorporates the CES specification as a special case.

Thus the consequences of freezing expenditure at 1980 levels are particularly serious for the Japanese economy. This may be interpreted as giving support to the view expressed in the literature regarding the dissemination of technology at global level. In particular, it may lend support to theories which stress differences in the quality of R&D expenditure across countries[1].

Table 3 : Reduction in technical progress implicit in fixing R&D expenditure at 1980 real levels (% points)

	DE	FR	IT	UK	US	JA
1. Mean Rate of R&D Expenditure (1979-1987)	.056	.050	.006*	.051	.096	.058
2. Baseline Rate (1978)	.049	.044	.006	.045	.078	.052
3. Change in Rate (1)-(2)	.007	.006	.000	.006	.018	.006
4. Mean Rate of Tech. Progress (1979-1987)	.0082	.0113	.0101	.0160	.0088	.0197
5. Medium-Term R&D Coefficient	.375	.210	.645	.410	.225	.490
6. Domestic Effect of Reduced R&D (5)x(3)	.0026	.0013	.000	.0025	.0039	.0029
7. Medium Term R&D ("foreign") Coefficient	.480	.300	.645	.360	-	.430
8. Foreign Effect	.0019	.0012	.0025	.0014	-	.0065**
9. Total Effect (6)+(8)	.0045	.0025	.0025	.0039	.0039	.0094
10. Adjusted Rate of Tech. Progress (4)-(9)	.0037	.0088	.0076	.0121	.0049	.0103
11. Scaling Factor (10)/(4)	.45	.78	.75	.76	.56	.52

Notes: * The table includes only a "low-tech" rate of R&D expenditure in the case of Italy. For this reason, it is somewhat out of line with the pattern in other countries.

** In the case of Japan, the US rate of high-tech R&D expenditure is substituted for the growth rate in technical progress to give the "foreign" effect. There are, of course, no lagged effects in the equations estimated for Japan and the UK.

1 Many studies posit that Japanese R&D expenditure stresses development of processes whilst the typical US project tends to represent a new departure.

5.3. Macroeconomic Results

The results of the simulation exercise are presented in graphical form underneath for the core macroeconomic variables, GDP, employment and wage rate growth. The first point to stress is the difference in cross-country effects. This, however, is not too surprising as it broadly corresponds to the size of the shock given in each case.

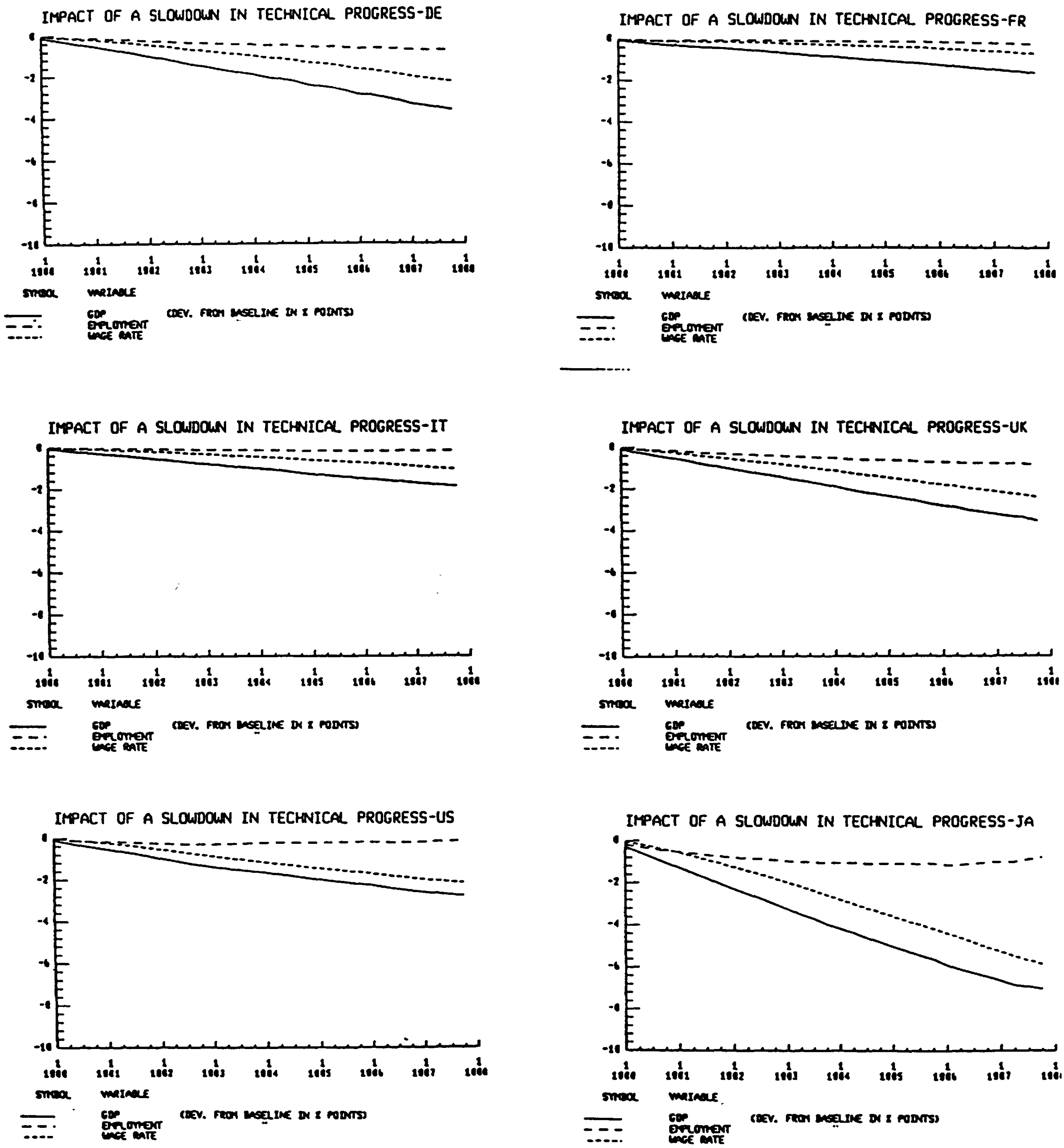
What is probably of greater interest is the adjustment mechanism in the labour market which apportions the change in output between real wages and employment. Although it cannot be said that technical change is employment neutral, there is nonetheless a strong degree of real wage adjustment in each case. What is at issue here is whether the wage-price block confirms the approach adopted in specifying the supply block. Insofar as the results across the different models demonstrate a strong degree of convergence in apportioning much of the adjustment to the technology shock to changes in real wage levels, it could be argued that this is indeed the case. In terms of the experience of the 1980's, this argument can be inverted, implying that while technological growth contributes in a small way to employment growth, the principal determinant of employment performance is the behaviour of labour market agents.

The share of adjustment to the change in the rate of technical progress borne by the real wage rate and the level of employment is determined by three important parameters, the elasticity of substitution in the labour demand equation alongside the labour productivity and the Phillips Curve effects in the wage rate equation.

The higher the elasticity of substitution, the stronger is the autonomous shift in labour demand for a given change in technical progress. Other things being equal, countries with a low elasticity of substitution (like Japan and France) should experience smaller employment effects. On the other hand, the closer the elasticity of wages with respect to labour productivity is to unity, the more employment neutral the shift in technology. This employment neutrality characteristic is reinforced in proportion to the strength of the Phillips Curve effect.

It is clear from Figure 4 that most of the adjustment in the labour market is borne by wages, particularly reflecting the strength of the productivity effect in the wage equations. It is also evident from the figure that the US and Japanese unemployment rates have a more pronounced tendancy to revert to historical levels in the aftermath of the shock.

Figure 4 : Simulation Results Using QUEST



6. Conclusions

The approach adopted in this paper represents a first step in the analysis of cross country diffusion of R&D (or its upshot) at a very high level of aggregation. At this stage, we only want to outline briefly some issues that should be dealt with in extending this line of research.

- An important problem seems to be measurement of real R&D which can perhaps be incorporated within the theoretical specification of a production function for knowledge which takes proper account of human capital and material inputs.

- It should be noted that in our analysis we take R&D expenditure as exogenously given and derive its effects on technical progress. In regarding R&D as an economic phenomenon, namely as an input into the production of knowledge, it would certainly be necessary to specify the demand for R&D. In this respect, the international economic environment seems especially important since firms might find it relatively easy to relocate R&D expenditures across countries in reaction to either macroeconomic events such as changes in labour costs or structural changes (e.g. in education or research policies).

- Given the impact R&D expenditures have on TFP and therefore on growth, it also seems to be a very much neglected phenomenon in macroeconomic models and it would certainly be useful to improve the supply side of these models by specifying more clearly the process of innovation adopted by firms and governments.

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Comment : *Martin Brown*

I am a staff-member of OECD. My remarks are very much based on research sponsored by OECD in the context of its Technology and Economy Programme (TEP). However, they do not, in any sense, represent the views of the OECD. TEP has several published outputs, but principally "Technology and the Economy : The Key Relationships" (OECD, 1992) and "Technology and Productivity : The Challenge for Economic Policy" (OECD, 1991).

I very much welcome this paper for two reasons. First, this meeting is supposed to be about the evaluation of *government* R & D programmes, and this paper is the only in-house contribution. Second, the paper pursues, very tentatively, an important route in identifying the impacts of government S & T efforts on economic performance.

I wish to stress the first criterion. There is an intractable problem about the evaluation of government R & D programmes. I had supposed that this meeting was about that problem, even though it was also about quantitative evaluation in general of the results of R & D programmes. I do not think that this meeting, although extremely interesting, has so far greatly advanced the discussion. Nor do I think that this paper takes us very far in the evaluation of government R & D programmes, although, at least, it suggests that within the European Commission we are thinking about the links between official R & D programmes and their macroeconomic impacts.

This initiative must be welcomed. Government R & D programmes are necessarily a rather small part of the overall R & D effort. It is most important that there should be in-house evaluation of these programmes.

I have no problems with the methodology employed in this paper, given that it seeks to bring together the EC's econometric modelling capabilities with its activities in promoting R & D.

However, I have some big problems with the concepts involved and with the provisional conclusions of the research. My remarks are intended to be positive, because I judge that this work should continue, particularly in-house. However, I focus on the points where I am in doubt.

My central problem concerns the overall interpretation of the relationship between R & D (taken as a proxy for technological effort) and Total Factor Productivity (TFP) (taken as a proxy for technological output). This report finds a close relationship between national expenditures on R & D and the growth of TFP. The message coming from OECD's TEP is that this relationship does not exist.

More important, there is a "productivity paradox". There is no doubt that TFP growth decelerated sharply in the 1970's, but this was after exceptional growth rates in the 1950's and 1960's. TFP growth has, contrary to the paper's claims (Figure 2), not really picked up since. However, there is a strong perception in OECD countries that technology innovation has accelerated, as evidenced by aggregate R & D expenditures. So, the conclusion is that there is a productivity paradox.

This issue is analysed in depth in the TEP publication "Technology and Productivity : The Challenge for Economic Policy".

There is a major problem about what proxy to take for "technical progress". The paper takes "R & D" as a per cent of GDP. However, this is certainly not aggregate R & D ("GERD" in the OECD terminology) : it is probably "*enterprise expenditures on R & D*". Aggregate R & D statistics could give quite different conclusions. The more important question is : what is the relevant R & D statistic ?

There is considerable evidence that aggregate R & D expenditures are not a good proxy for technical progress (see OECD, "Technology and the Economy"). To the extent that the focus of the analysis is on government R & D programmes, the proxy should be about government funding of specific R & D programmes. Unfortunately, there is no good data on this. The paper's R & D notion seems to be about enterprise R & D, and one may wonder what this has to do with government sponsored R & D programmes.

The paper discusses the relevance of R & D in "high-tech" sectors to TFP. The apparent definition of "high-tech" sectors could be considered further : it concludes "chemicals", which on OECDs classification is, at best "medium-tech". However, the overall conclusions are surprising : high-tech sectors do not contribute more significantly to TFP-growth than other sectors.

The paper introduces the notion of "international diffusion of technology", defined as the (partial) correlation between TFP in one country and R & D expenditures or TFP developments in another country. It would be surprising if this was a meaningful correlation, even if statistically significant. The paper finds negligible technology transfers from other OECD countries to the US and between Japan and the European Community countries. In any normal discussion of technology diffusion, these conclusions would be counterintuitive. Probably, much more work should be done on this "international diffusion" concept, or it should be abandonned. It certainly does not relate to any normal microeconomic analysis of "technology diffusion".

Chapter 10 - Drawing Lessons from an Experiment in Large-Scale Modelling of the Impact of Technical Progress

Stanislas Standaert

1. Introduction[1]

This paper reports on simulation exercises performed with some linked multi-sectoral models on the effects of an acceleration of technical progress between 1991 and 2005. This shock is interpreted as the result of the diffusion of new information technologies up to 2005[2]. After a review of the procedure followed and of the results (sections 2 and 3), we attempt at identifying some limitations of the work, and some ways of overcoming them (section 4).

Models are always never conceived for the use to which they are eventually put, and the Hermes system we used is no exception to the rule - this may make for more unprejudiced results. The Hermes models have been constructed on the implicit view that potential productivity growth is constant, and in the perspective of a use for medium term forecasting. The exercise undertaken here is based on the view that potential productivity growth is variable, and considers longer term effects of productivity variations.

Both modellers and model users have an interest in viewing models as black boxes. In our view, the function of models is to facilitate dialogue, by offering a framework in which questions can be better formulated, and by indicating hidden implications of statements - but this is perhaps more difficult than modelling proper. A peculiarity of the model used is that the entry costs for a dialogue are high. Once they are overcome, though, it can become very rewarding thanks to the very complexity of the instrument used. Some conditions for the success of such a process will be discussed in the last section.

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1 Modelling is a collective work. This one would not have been possible without the support of Pierre Valette and Eric Donni (CEC), who gave us access to the models and helped us in using them. I owe a particular debt to Roberto Golinelli, the co-author of the reference simulation, Francis Bossier, who supervised the Hermes-Club forecast, Paul Zagamé, Eric Van Halewijn, Vincent Detemmerman, Peter Bandilla and the staff of DG XII/E/5 were directly or indirectly of invaluable help.

2 The simulations are reported in full in Standaert (1991), which is part of a more comprehensive report to the EC directed by Luc Soete and Chris Freeman (Merit, Maastricht). They rely on a reference projection prepared on this occasion in collaboration with Roberto Golinelli (Prometeia, Bologna).

Before proceeding, some general information on the tool used is in order. The Hermes models are multi-sectoral models developed at the initiative of the CEC (DG XII) for most EC-countries. They are basically of neo-Keynesian ascent, but feature a well-developed supply side, a feature which turned out to be very helpful in this exercise. They are in fact eclectic enough to accomodate many types of shocks. They have been developed by national teams, allowing to introduce more country-specific information, and forcing even the reluctant user to adapt to the idiosyncrasies of each country (or modeller). Introductions are provided by D'Alcantara and Italianer (1982) and Italianer (1986). A book edited by Donni, Valette and Zagamé is forthcoming.

The models can be assembled in many constellations. In this case, given the lenght of the horizon considered, it was decided to use the Hermes models for Germany[3], France, Italy and the UK, as well as the linkage modules for the five branches for which bilateral trade are represented. Taken together, this represents a set of about 10000 equations. It would be incorrect to conclude that the rest of the world is completely exogenous. The sectoral trade modules use as exogenous variables the import volumes and the export prices of more than twenty (groups of) countries, but determine endogenously via income and price effects the import and export shares, and hence the exports and import prices.

All models have strengths and weaknesses. The treatment of monetary variables, and of international financial flows, feature among the weaknesses of the Hermes models. Fortunately given the nature of the issues studied Hermes's comparative advantage clearly lies in the analysis of structural developments in the longer term - in which monetary forecasts are anyway risky. Hermes's explicit treatment of capital accumulation is an obvious asset in this respect, as is its detailed representation of the supply side of the manufacturing branches. Its almost homogenous treatment of labour is in turn a disadvantage. These remarks should not let us forget the unique property of the system: its ability to seize simultaneously the interaction of many segments of the European economy distinguished according to country and industry (36 in this case, if government is treated as an industry).

Section 2 below describes the inputs of the alternative scenario we have developed, considering in turn the theoretical mechanisms involved and the shocks proper. Section 3 summarises the macro-economic and the sectoral results of this scenarios, and

3 By Germany, we mean western Germany throughout. This implies that certain concepts must be interpreted with care, especially balance variables such as the trade balabce and the net lending of the government.

briefly reports on some sensitivity analyses. Section 4 discusses both the achievements and the limitations of the exercise.

2. A Scenario of Accelerated Diffusion

While it may be optimistic in certain respects, the baseline projection, which is documented in Standaert (1991), and relies partly on the 'Club Hermes' 1990 forecast, is definitely conservative regarding technical progress, since it relies exclusively on the continuation of the past trends, as estimated over the period 1965-1987 (on average). The combination of those trends, as structural features of the production functions, with the functioning of the macro-economy, actually turns out to make for slightly decreasing rates of actual productivity growth, because of the slow-down of investment.

We have developed an alternative scenario relaxing that assumption, and allowing for an acceleration of technical progress at rates which can vary across countries and across industries. The exercise should help to identify the conditions making it possible to reap the full benefits of such an acceleration. To assess how important the various components of the scenario are, we have also run a number of variants of this 'central' alternative scenario. These variants can be seen as 'technical' exercises pertaining to the role of a single factor. Taken together, they provide the 'central' alternative with an additional dimension, ie, a feeling for the fragility or solidity of the jigsaw which has been assembled.

Two related studies based on Hermes and considering respectively linked and unlinked simulations are Golinelli (1990) and Van Zon (1991). Other comparable studies have already been performed in the past for European countries. Useful surveys are provided by De Villé and Germain (1988) and De Wit (1990). However, to the best of our knowledge, these studies deal with a single country, so that the assumptions on the behaviour of the rest of the world play a more critical role than is the case here. More often than not, they also consider a shorter time horizon. Good examples are provided by the work of Whitley and Wilson (1982) on Britain, and of Meunier and Volle (1984, 1985) for France. Of even more direct relevance to this study is the work of Bossier (1986) and Assouline et al. (1986) using respectively the Belgian and the French Hermes models to explore "modernisation" variants involving an acceleration of technical progress and a "voluntaristic" investment boom.

In this section we provide a detailed description of the shock and of the auxiliary assumptions introduced. But before examining these, it is useful to mentally review the major effects involved by a productivity shock, which are fairly straightforward, given the familiar neo-Keynesian character of the models.

2.1. The Logic of the Shock : A Preview

We shall distinguish between direct effects, which are rather micro-economic, and induced effects, which are more macro-economic. We rely here exclusively on the mechanisms present in the Hermes models, and stick to the assumption of a passive government, i.e., a goverment whose behaviour is described by fixed real expenditure on goods and services, and by unchanged taxation and transfer policies, as reflected by various rates. We won't review the literature; a useful introduction is provided by Sinclair (1981).

We should like to emphasise from the outset that a number of net effects are a priori uncertain. Since small positive or negative net effects may have cumulative consequences, one becomes extremely dependent upon the robustness of the estimates one uses. This can be remedied by more reliable estimates only within limits. A case in point refers to the net trade effects. In other words, some results may have the character of "razor's edge" results.

A first direct effect is the decrease of prices. This is not immediate, because of the long lags sometimes involved in translating cost decreases into price increases. This induces substitution effects between the components of domestic demand, because the rates of productivity increases and/or price decreases are not uniform. (The welfare effects are immediate).

Even more importantly, it induces direct trade effects which boil down to substitution effects. The latter effects act both via imports and exports. As far as exports are concerned, it is important to realise that the particular constellation of models we have used implies that, except for the invisible hand of the modeller, two mechanisms can be involved. Exports to those countries not fully endogenous can increase via an increase in the import share, which remains endogenous. For the four countries which are fully endogenised, both the level and the composition of imports can change.

Somewhat anticipating, we would like to point out that the strong disaggregation of the model allows better than conventional macro-models these substitution effects to cumulate. Indeed, the original shock fosters output and therefore investment. Since the diffusion of new technologies is intimately related to investment, technical progress is further accelerated.

A second direct effect is the decrease of employment - ceteris paribus -. Indirectly, this makes for a decrease of wages via the familiar Phillips effect. The effects set out so far would make for a cumulative deflation unless checked by other mechanisms.

A third direct effect is the reflection of productivity increases in wages, which counteracts the effect of unemployment. Even before examining the results, we can anticipate that much will depend on the balance between the two mechanisms just mentioned. The results to be presented are consistent with the view that if unemployment increases, real wages will increase less than productivity. When the productivity increase is large, this leaves open a fairly large margin of uncertainty.

The next step is to turn to wage income. In the meantime, we have left the direct effects and venture into the uncertain world of the indirect repercussions. Whether the purchasing power of wages will increase depends on more than the combination of the two direct effects just mentioned. In fact, the decrease of employment will be reinforced by an increase of real wages, but this may be overcompensated by favourable developments on the demand side. The net effect is therefore uncertain.

A crucial link in the diffusion of the effects is constituted by investment. Although there are variations across countries and industries, they include as two major determinants the development of demand and profitability considerations. Innovations do not as such boost investment - which is perhaps reasonable at a fairly aggregate level: technical progress is a process of creative destruction, and innovations may simultaneously stimulate certain investors, and hamper investment by non-innovators.

Clearly, there is scope for benefiting from the cumulative effects of a demand shock provided the net trade effects are positive, and investment reacts fast enough to the opportunities provided. The role of the net trade effects is quite crucial in a multinational scenario where several countries are affected by similar shocks, since it it possible in theory for a country experiencing a productivity increase to be a net loser : if its relative competitiveness decreases, it may be badly hit by the ensuing cumulative effects.

2.2. Description of the Shocks

We now turn to a detailed description of the shock. It is basically an increase in the rate in technical progress interpreted as the result of the further diffusion of new information technologies. The following features of the shock should be kept in mind:

- the shock primarily affects the potential for productivity increases (the production function) rather than actual productivity. The extent to which the increased potential results in actual increases depends on many factors, including for example the rate of investment.

- the shock affects the industries separately, and can be differentiated across industries.

- the shock is variable over time and over countries, in order to take into account the variable levels of diffusion of the techniques in question.

- last but not least, the shock also affects outside (including non-EC) countries.

Regarding the differences across industries, we distinguish between *three treatments of technical progress*.

* In the three manufacturing industries the models distinguish, a fairly sophisticated treatment of the shock is possible, because the production functions are of the putty-clay type. This allows to distinguish between two types of technical progress : embodied, i.e., tied up in new equipment, and disembodied, i.e., affecting possibly all "generations" of factors. Along another dimension, a distinction is possible between changes affecting all factors in the same way, and changes affecting specifically some factor, in which case a bias is introduced. Those different possibilities have been exploited. In the central scenario, the bulk of the shock is an acceleration of embodied technical progress, affecting incremental capacity and the corresponding factor utilisation. This form of technical progress is in principle unbiased (although this will have to be qualified in respect of the factor capital in three countries : see below).

(In certain variants, we have assumed in addition that the diffusion of information technologies allowed to increase the efficiency of the labour corresponding to the capacity already installed in 1990. This form of technical progress is disembodied and biased. Unlike 'traditional' disembodied technical progress, it does not benefit incremental capacity. More informally, we could say that some 'retrofitting' increases the productivity of the 'existing' labour force, besides embodied technical progress affecting all new factors.)

* The above distinction between embodied and disembodied progress cannot be made in the two services branches : Transport & Communication, and Other Market Services, because of a different treatment of technology. This is natural to the extent that the association between technology and capital equipment is less immediate in the services. Important cases of close association exist, however, notably in the area of Telecommunications. The shock introduced here affects the entire capacity and labour force, and is labour saving. This implies that a shock equal in size to the manufacturing industries would have much stronger effects, except for the fact that the use of other factors (energy, other intermediates ...) is not directly affected.

* Three other market branches are distinguished in Hermes : Agriculture, Construction and Energy. No separate productivity shock was introduced in these sectors because the potential for information-technology induced productivity growth was thought to be more limited, and because even strong local effects would result in a limited macro-economic impact. However, they can benefit indirectly from the shock affecting the other branches.

Regarding the *timing of the shock*, we started from the view that the diffusion of technical progress follows a S-shaped pattern as represented, for example, by a logistic curve. On one interpretation, this view implies that the proportion of firms having adopted a particular innovation follows a S-shape. As a simplification, we may view the productivity increases made possible by the information technologies as one single innnovation. The increase of productivity in any period depends then on the increase of the number of adopters, as a proportion of the total population. In practice, we have assumed that the time path of incremental productivity changes is determined by two parameters of a linear relation which writes :

$$pr(t) = k\,(1 - (t/E))$$

where :

pr : increase in the growth rate of productivity
t : time, equal to 0 in the base year (1990), and to 15 in 2005
k : a parameter reflecting the maximal (incremental) growth rate of productivity (in 1991)
E : a parameter interpretable as the 'end-year' of the productivity increase.

It is easily seen that choosing a low value of E (still larger than 15) makes for rapidly decreasing productivity growth, corresponding to the exhaustion of the potential for productivity growth. Choosing a low value of K implies that the total potential for additional productivity growth after 1990 is limited. This simple framework makes is possible to approximate very different situations, which can be typified by the following archetypes :

The catcher-up : both K and E are large. For example, if K=0.02 and E=100, pr(15), ie the growth rate of productivity in 2005 will be equal to 1.7 %.

The exhausted innovator : both K and E are small. If K=0.005 and E equals 20, pr(15) equals 0.125 %.

In the central scenario, E has been set equal to 50, suggesting on a litteral interpretation that the productivity potential of IT will be exhausted by 2040. The value of K depends on the industry considered. In the manufacturing industries, K has in principle been set to 1%. Remember that this effect touches only marginal capacity. It capacity was stationary, and if 10% of capacity is renewed each year, it would take 10 years to increase productivity by 1%. In the services, K has been set equal to 0.5% or slightly less.

We have already suggested that the role of investment was crucial in the propagation of the shock. We turn to reviewing issues surrounding *investment behaviour*. They can be summarised by the following questions, followed by the approach taken:

(1) Does the technology shock require additional investment, over and above what would normally take place given the time path of capacity ?

Given the aggregation level of the model, we reckon as a first approximation that the accelerated diffusion will result in a change in the composition of the Equipment goods (in the specific sense of the Hermes model) without change in the share of these goods in investment. (These shares are exogenous; given the aggregation level of the model, investment essentially comprises construction and equipment goods).

(2) Does the shock entail additional scrapping, given, say a time path of output ?

The answer is definitely yes. It is however difficult to evaluate its size. We should recall that disembodied technical progress also increases the efficiency of older machinery. The central alternative assumes that the rate of scrapping, whenever relevant, ie, usually for the manufacturing industries, increases by 2% throughout, ie, by 0.2 percentage points. A more pessimistic assumption will be considered separately.

(3) Do the innovations associated with the shock stimulate investment, over and above other effects ?

We have already mentioned earlier that we reckoned that this effect can be neglected in a first approximation. It can however become an ingredient of an optimistic scenario.

(4) Is the induced (or macro-economic) effect of the shock on investment modelled adequately ? - this question boils down to the question whether the investment functions are satisfactory.

This key issue will now be discussed in some detail both from the point of view of actual economic behaviour and from the point of view of its incorporation in the model.

From a modelling point of view, one must realise that two different views of investment behaviour are present in the Hermes models, whose implications for the effects of new technologies are completely at variance. A first view, present notably in the British model, takes investment to be independent of the productivity of capital. Investment is essentially determined by an accelerator effect, besides profitability considerations. Admittedly, productivity affects profitability, but this (roundabout) effect is of secondary importance in that model. This implies that the direct effect of a productivity shock on investment is almost nil; in contrast, there is an immediate impact on capacity, since incremental capacity equals investment times the productivity of capital at the margin, which is directly affected by the shock.

The alternative approach relates investment to desired changes in capacity, taking into account the productivity of capital. As in the previous case, the desired changes in capacity are linked to the recent changes in output, but via the productivity of capital. A ceteris paribus increase in the productivity of capital results then almost immediately in a decrease of investment. Another effect incorporated in the specification relates to the substitution effects between factors. These substitution effects could make for an increase of investment, ceteris paribus, provided capital becomes relatively cheaper than the other factors, but this is not implied automatically by the scenario considered.

Obviously, the specifications have not been chosen in the perspective of the modelling of the effects of innovations on investment. We have tried to neutralise the heterogeneity of the specifications, while exploiting to the maximal possible extent the information contained in the equations. In practice, this means that we have imposed in a first step that investment be not directly influenced by productivity, allowing only for the second round effects. Concretely, we haven't shocked the productivity trends incorporated in the French and German investment equations, which results in fairly similar simulation properties across countries. Notice that this differs from the approach taken by Assouline et al. (1986) in an earlier study limited to the French economy; a major advantage of our approach is that it avoids the need for possibly arbitrary assumptions on an exogenous increase of investment to compensate for the depressing effects of the productivity increase. In Italy, we have replaced the variable marginal productivity of capital present in the investment functions by their baseline value, while leaving it endogenous, and affected by the shock in its other occurences.

No other changes have been brought to investment behaviour, except in Britain where the accelerator effect turned out to be unrealistically sluggish, a feature which has also been identified in other exercises. British investment has therefore been boosted, but based on considerations of macro-economic plausibility rather than on account of a special "innovation" effect of the accelerated diffusion of new technologies. Summarising, we can note that investment behaviour has been changed in all countries, at least in the manufacturing industries, and that the changes were always in favour of stronger investment effects. It is therefore possible to interpret the results as being due in part to the effect of innovation as such on investment, besides the considerations which we have emphasised above.

Turning to *trade*, and in contrast with certain measures of economic policy, it is not sensible to assume that Europe would be the single beneficiary of the productivity boon, unless one thinks that the assumptions underlying the reference projection are unbalanced 'in favour' of third industrialised countries. Hence we assumed that a similar shock was affecting the industrialised (OECD) trading partners of the countries studied, including especially the United States and Japan, resulting in a decrease of the growth rate of export prices of manufacturing goods by those countries by 20% . To fix ideas, this represents a 1 percentage point decrease if the baseline growth rate was 5%.

Notice finally that we have fixed labour time at its baseline value, in order not to make the results dependent upon the variety of approaches taken in the different models. The behavioural functions used do not always have firm theoretical foundations, and we prefer to treat labour time as a policy instrument. This issue has been studied with Hermes by Catinat et al. (1989).

In conclusion, we should point out that it is almost impossible to ensure that the ex ante shocks are identical over countries - we have already mentioned that this was not the case over branches. The reason is the heterogeneity of the specifications in spite of the common frame of reference, particularly in the services. For example, while some models relate actual labour demand to an explicit "optimal" level, the latter concept is absent from other models. Part of the ex post differences across countries are therefore due to small differences in the a priori shock, although we have attempted to reduce them to a minimum.

3. Review of the Results and Sensitivity Analysis

We first review the macro-economic and the sectoral results of the 'central' alternative scenario; we then turn to the sensitivity analyses.

3.1. Major Macro-economic Results

Macro-economic results for 2005 are summarised in the Tables 1 to 4. Since the time path of the changes is quite steady, we shall disregard it here - although the precise dynamics may go a long way to explain differences across countries. The tables make it clear that ex post, productivity increases by between 5 and 6% of the baseline level. The change in labour productivity can be allocated in many ways between output and employment. One observes that most of the increase is absorbed by output, although noticeable differences remain between, say, Italy and the UK. Of course, the different changes are not independent of each other, nor are they independent from the reference projection. Both a high 'baseline' growth rate and a large variation of production as a result of the shock boost investment and reinforce thereby the diffusion of technical progress. These effects may contribute to differentiate Italy and Germany from France and the UK.

A closer examination of the transmission mechanism of the shock is certainly in order. We shall especially emphasise wage and employment effects, investment effects, and trade effects.

Among the direct effects, the decrease of prices and the decrease of employment stand out. The decrease of prices made possible by the shock makes for substitution effects which are fairly well represented by Hermes thanks to its multisectoral structure. They affect both domestic demand and trade. We shall return to the trade effects below.

A crucial issue for the further transmission of the shock is how wages react. While an increase of unemployment makes for lower wages, the increase of productivity has a positive effect on real wages. Eventually, real wages increase by less than the productivity increase in all the countries considered because of a slight increase of unemployment. In 2005, the increases above the baseline range from almost 3% to almost 5%. We should emphasise that these results are affected by considerable uncertainty, because the precise magnitude of the elasticities involved is controversial, and because of the lenght of time over which the models have been simulated.

Closing the macro-economic circle, the wage bill is a major determinant of consumption demand. The simulations suggest that consumption increases less than the other components of demand. In fact, the share of wages in national income tends to decrease.

Investment is primarily boosted by the increased profitability, and by the induced effects of the shock on demand. The net effects we observe are very much a reflection of the indirect repercussions of the shock. Investment is also a behaviour which is notoriously difficult to model. Our results suggest that investment will be the most buoyant component of demand.

The trade effects are perhaps the most complex to analyse. The results of the multinational simulations bring together four different mechanisms. First, a country benefiting from a higher rate of technical progress enjoys substitution effects. The fact that the shock affects several countries simultaneously can however erase the resulting relative advantage. Since only part of the world benefits from an increase of productivity, we expect however that, on average, an increase of productivity will be favourable on account of these effects. Third, the productivity shock results in an income effect on trade. For example, and with the exception of Italy, all the countries studied see an increase of imports although their trade balance improves because of the increased domestic absorption. This contributes to feed export demand abroad. The last effect is a terms of trade effect, which can benefit a country even if it is not directly affected by a productivity shock.

Concluding, although the trade effects turn out to be favourable in each individual country, we should point out that they are surrounded by a sizeable margin of uncertainty. In fact, and quite predictably, the assumptions made on the behaviour of the rest of the world turn out to be crucial. Worse, the direction in which a change of assumption will affect the results is uncertain, since the terms of trade effect, which certain variants not reported here have clearly brought out, can lead to 'counter-intuitive' results.

Table 1. Accelerated diffusion : Germany

(% Difference from Reference Projection)

	1995	2000	2005
DEMAND AND OUTPUT:			
Private Consumption	0.4	2.4	2.8
Gross Fixed Cap.Formation	1.5	3.8	4.5
Investment by Firms	2.2	5.2	5.9
Exports of Goods and Services	1.4	3.4	5.3
Imports of Goods and Services	1.3	1.2	0.4
GDP	0.7	3.4	5
GDP Growth rate (Diff.)	0.4	0.4	0.3
PRICES:			
Private Consumption Prices	-0.7	-1.4	0.2
Export Prices	-1.6	-4.1	-3.7
Import Prices	-2.1	-4.7	-4.4
GDP Deflator	-0.6	-1.6	-0.1
LABOUR MARKET:			
Employment	-0.4	-0.2	-1
Unemployment rate (Diff.)	0.4	0.2	0.9
Nominal Wage	-0.2	1.7	5.1
Real Wage	0.5	3.1	4.9
Labour productivity per head	1.1	3.6	6
OTHER INDICATORS:			
Trade Bal.(Diff.,% of GDP)	0.2	0.9	2.2
Gvt.Bal.(Diff.,% of GDP)	-0.1	0.3	0.5
Wage share (% GDP)	-0.8	-0.4	-1.1
Profits share (% GDP)	0.8	-0.2	2.3

Table 2. Accelerated diffusion : France

(% Difference from Reference)

	1995	2000	2005
DEMAND AND OUTPUT:			
Private Consumption	1.1	2.6	3.1
Gross Fixed Cap.Formation	1.5	2.4	3.1
Investment by Firms	2	3	3.9
Exports of Goods and Services	2.9	5.3	7.3
Imports of Goods and Services	2.6	4.6	5
GDP	1.2	2.6	3.9
GDP Growth rate (Diff.)	0.2	0.3	0.2
PRICES:			
Private Consumption Prices	-1.3	-2.1	-1.8
Export Prices	-0.8	-1.9	-1.8
Import Prices	-1.9	-2.9	-1.8
GDP Deflator	-0.9	-1.4	-1
LABOUR MARKET:			
Employment	-1.8	-1.2	-0.8
Unemployment rate (Diff.)	0.6	0.4	0.2
Nominal Wage	0.4	1.2	2.7
Real Wage	1.7	3.4	4.5
Labour productivity per head	2.7	3.7	4.6
OTHER INDICATORS:			
Trade Bal.(Diff.,% of GDP)	0.4	0.6	0.9
Gvt.Bal.(Diff.,% of GDP)	-1	-0.1	1
Wage share (% GDP)	-1.7	-1.3	-0.9
Profits share (% GDP)	2.9	2.4	2.1

Table 3. Accelerated diffusion : Italy

(% Difference from Reference)

	1995	2000	2005
DEMAND AND OUTPUT:			
Private Consumption	1.5	3.1	4.6
Gross Fixed Cap.Formation	1.4	1.9	2.8
Investment by Firms	2	2.1	2.8
Exports of Goods and Services	0.8	1.5	1.7
Imports of Goods and Services	-0.2	-1.7	-4.2
GDP	1.6	3.7	6.1
GDP Growth rate (Diff.)	0.4	0.4	0.5
PRICES:			
Private Consumption Prices	-1.2	-3.7	-5.5
Export Prices	-2	-4.7	-5.2
Import Prices	-1.5	-2.7	-1.4
GDP Deflator	-1.4	-4.4	-6.7
LABOUR MARKET:			
Employment	-0.2	-0.1	0
Unemployment rate (Diff.)	0	0	0
Nominal Wage	-0.1	-1	-1.5
Real Wage	1.1	2.8	4.3
Labour productivity per head	1.8	3.8	6.1
OTHER INDICATORS:			
Trade Bal.(Diff.,% of GDP)	0.1	0.3	0.6
Gvt.Bal.(Diff.,% of GDP)	0.2	0.4	0.7
Wage share (% GDP)	-0.4	-0.3	-0.5
Profits share (% GDP)	0.8	0.9	1.4

Table 4. Accelerated diffusion : United Kingdom

(% Difference from Reference)

	1995	2000	2005
DEMAND AND OUTPUT:			
Private Consumption	0.6	1.7	2
Gross Fixed Cap.Formation	0.6	3.2	2.2
Investment by Firms	0.7	3.9	2.5
Exports of Goods and Services	0.4	1.5	2.5
Imports of Goods and Services	0.2	1	0.2
GDP	0.6	1.9	2.9
GDP Growth rate (Diff.)	0.2	0.2	0.2
PRICES:			
Private Consumption Prices	-0.7	-0.8	-2.2
Export Prices	-1.3	-2.8	-4.1
Import Prices	-1.3	-1.8	-1.7
GDP Deflator	-0.7	-1.2	-3.3
LABOUR MARKET:			
Employment	-0.8	-1.4	-1.9
Unemployment rate (Diff.)	0.5	0	1.2
Nominal Wage	0.6	1.9	0.5
Real Wage	1.2	2.7	2.7
Labour productivity per head	1.4	3.4	4.9
OTHER INDICATORS:			
Trade Bal.(Diff.,% of GDP)	0	-0.3	-0.2
Gvt.Bal.(Diff.,% of GDP)	-0.3	-0.6	-0.8
Wage share (% GDP)	-0.4	-0.7	-1.5
Profits share (% GDP)	0.4	0.5	1.5

The most worrying feature of the simulations lies probably in increase of unemployment. This result ought to be interpreted with care, since it is obtained with a model which treats labour as homogenous, and where the endogeneity of hours, if any, has been suppressed. It is consistent with a scenario where one category of workers would benefit from the increase of productivity, while another one would suffer both from unemployment and the effect of unemployment on wages. Moreover, we have not explored the full array of corrective policy measures, but we should notice that some room of manoeuvre is created for costly goverment policies (ranging from training programmes to tax reductions).

A message of this exercise is that much is to be gained by an acceleration of the diffusion of new technologies in Europe (as we have calibrated it), but that the full appropriation of it is not warranted. A number of conditions for favourable effects have been identified; at the same time the potential for alleviation the potentially adverse effects of the phenomenon has been indicated.

3.2. Major Sectorial Results

In this short discussion, we shall focus on five industries comprising most of total employment. The major ex post effects of the shock on productivity are provided by the Tables 5 to 8, which enable the reader to see how the productivity gains are allocated over employment and output, inter alia. Information is provided as well on the sectorial trade effects (which can differ from the macro-economic ones) and on investment. All figures pertain to percentage differences from the reference projection, except for "Productivity Growth", where we computed the difference between the growth rates of productivity in the scenario and in the reference, in order to put certain figures on percentage differences into perspective. In particular, it can be verified that some decreases of the incremental growth of productivity occur over time, a feature related to the slight decrease of the ex ante shock over time.

Not all results have the same degree of reliability. The time path of the productivity effects in the French services features an anomaly related with the particular structure of the equations, and the same holds true for the Italian services, where the effects are too small rather than too large. This require further examination. The UK and even more West-Germany are representative of the type of sectoral differentiation one observes (this statement is based upon extensive experimentation with variants). The phenomenon that

Table 5. Accelerated diffusion : Sectorial results for Germany

(% Difference from base)

	1995	2000	2005
CONSUMPTION GOODS :			
Output	0.7	4.4	7.1
Investment	2.3	8.1	12.4
Employment	-0.5	-0.1	-0.1
Exports	2	5.3	8.3
Imports	1.8	2.3	0.8
Productivity	1.3	4.5	7.2
Productivity Gr. (Diff.)	0.4	0.6	0.5
EQUIPMENT GOODS :			
Output	1.6	6.1	8.7
Investment	2.4	5.9	6.4
Employment	-0.8	-1.1	-3.6
Exports	1.9	4.2	6
Imports	2	-0.3	-3.7
Productivity	2.5	7.3	12.7
Productivity Gr. (Diff.)	0.8	0.7	1.3
INTERMEDIATE GOODS :			
Output	0.9	4.7	7.5
Investment	2.5	6.5	7.1
Employment	-0.9	-1.2	-4
Exports	1.3	3.3	5.7
Imports	1.8	1.8	1.4
Productivity	1.8	6	12
Productivity Gr. (Diff.)	0.6	0.8	1.3
TRANSPORT AND COMMUNICATION SERVICES :			
Output	0.5	2.9	4.2
Investment	1.8	2.9	3.5
Employment	-0.1	1.1	0.1
Productivity	0.6	1.8	4.1
Productivity Gr. (Diff.)	0.1	0.3	0.4
OTHER MARKET SERVICES :			
Output	0.6	2.7	3.4
Investment	3.2	6.4	6.3
Employment	-0.5	0.4	0.5
Productivity	1.2	2.3	2.9
Productivity Gr. (Diff.)	0.1	0.2	0.1

Table 6. Accelerated diffusion : Sectorial results for France

(% Difference from base)

	1995	2000	2005
CONSUMPTION GOODS :			
Output	1.6	3.7	5.4
Investment	3.8	4.4	5
Employment	-0.2	0	0.3
Exports	3.8	7.3	9.4
Imports	2	4.7	5.7
Productivity	1.8	3.7	5
Productivity Gr. (Diff.)	0.4	0.4	0.2
EQUIPMENT GOODS :			
Output	2	4.5	8.1
Investment	2.1	3.7	6.5
Employment	0.7	2.3	4.8
Exports	3.9	7.1	9.5
Imports	3	4.8	4.7
Productivity	1.3	2.2	3.2
Productivity Gr. (Diff.)	2	0.2	0.2
INTERMEDIATE GOODS :			
Output	1.8	4	7.2
Investment	2.8	4.5	5
Employment	-0.3	-0.4	-0.1
Exports	3	5.1	7.2
Imports	2.6	4.3	4.1
Productivity	2.2	4.3	7.2
Productivity Gr. (Diff.)	0.2	0.6	0.6
TRANSPORT AND COMMUNICATION SERVICES :			
Output	0.9	1.8	2.4
Investment	0	0	0
Employment	-3.2	-3	-2.8
Productivity	4.3	5	5.3
Productivity Gr. (Diff.)	0.3	0.1	0.1
OTHER MARKET SERVICES :			
Output	1.1	2.6	3.5
Investment	2.9	4.7	4.4
Employment	-3.4	-2.7	-2.2
Productivity	4.7	5.5	5.9
Productivity Gr. (Diff.)	0.3	0.1	0.1

Table 7. Accelerated diffusion : Sectorial results for Italy

(% Difference from base)

	1995	2000	2005
CONSUMPTION GOODS :			
Output	1	2.2	3.4
Investment	1.5	1.9	2.3
Employment	-0.2	-0.9	-1.8
Exports	0.8	2.1	2.8
Imports	1.6	2.2	1.4
Productivity	1.1	2.7	5.3
Productivity Gr. (Diff.)	0.3	0.4	0.5
EQUIPMENT GOODS :			
Output	0.9	2.2	4.2
Investment	1.2	2.3	4
Employment	-0.4	-1.9	-3.1
Exports	0.8	1	0.4
Imports	1.1	-0.8	-4
Productivity	1.3	4.2	7.5
Productivity Gr. (Diff.)	0.3	0.7	0.7
INTERMEDIATE GOODS :			
Output	2.6	6.4	11.9
Investment	5.2	9.4	16.3
Employment	-0.5	-1	0.1
Exports	0.8	1.8	2.8
Imports	-4.3	-9.1	-14.7
Productivity	3.1	7.4	11.8
Productivity Gr. (Diff.)	0.5	0.9	0.8
TRANSPORT AND COMMUNICATION SERVICES :			
Output	0.4	0.6	0.8
Investment	0.3	0.5	0.7
Employment	-0.8	-0.6	-0.5
Productivity	1.2	1.3	1.3
Productivity Gr. (Diff.)	0.5	0	0
OTHER MARKET SERVICES :			
Output	0.9	1.7	2.6
Investment	2	2.1	2.8
Employment	-0.4	0	0.4
Productivity	1.3	1.7	2.2
Productivity Gr. (Diff.)	0.1	0.1	0.1

Table 8. Accelerated diffusion : Sectorial results for The United Kingdom

(% Difference from base)

	1995	2000	2005
CONSUMPTION GOODS :			
Output	0.4	1.9	2.4
Investment	2.2	4.8	7.3
Employment	-0.6	-0.9	2.3
Exports	0.6	0	0
Imports	0.2	0.4	0.1
Productivity	1	2.8	4.9
Productivity Gr. (Diff.)	0.4	0.3	0.4
EQUIPMENT GOODS :			
Output	0.4	1.8	3.6
Investment	2.3	4.5	8
Employment	-2.2	-3.9	-4.2
Exports	0.5	0	0
Imports	0.6	2.5	0.5
Productivity	2.7	6	8.2
Productivity Gr. (Diff.)	0.5	0.6	0.4
INTERMEDIATE GOODS :			
Output	-0.3	0.3	2.2
Investment	2.4	4	7.5
Employment	-0.9	-2.6	-2.8
Exports	0.3	0.8	0
Imports	0.1	0.6	0.1
Productivity	0.6	3	5.2
Productivity Gr. (Diff.)	0.2	0.5	0
TRANSPORT AND COMMUNICATION SERVICES :			
Output	0.7	1.8	2.6
Investment	0.8	5.3	2.7
Employment	-0.7	-2	-2.1
Productivity	1.4	3.9	4.8
Productivity Gr. (Diff.)	0.4	0.3	0.2
OTHER MARKET SERVICES :			
Output	0.5	1.4	1.8
Investment	0.2	5.2	1.5
Employment	-1.1	-1.9	-2.9
Productivity	1.6	3.4	4.8
Productivity Gr. (Diff.)	0.4	0.3	0.3

the productivity effects tend to be larger in the manufacturing industries in spite of the fact that the original shock was not, except for its unbiasedness, is due to to various features, some of which were already mentioned earlier. Sustained investment in the baseline reinforces the diffusion of productivity shocks, the additional push given to investment due to the shock reinforces it further. In turn, relative price decreases induce substitution effects in favour of the branches affected, which boost investment even more. This process is particularly visible in the branch of Equipment goods, which also benefits from the investment demand of the remainder of the economy. Productivity is stimulated as well by short term utilisation effects. Last but not least, the greater exposure of manufacturing to trade also contributes to strenghten the effects. In conclusion, the intersectoral differences are due primarily to international trade effects, and to the investment-productivity nexus.

3.3. Some Sensitivity Analyses

The central alternative we have just presented consists of a number of building blocks we have attempted to assemble into a coherent picture. In the process of constructing it, we have obviously experimented with various shocks, both in single-country and linked simulations. The final ingredients have been primarily chosen so as to reflect the external changes whose influence throughout the economy we wanted to trace, but also - secondarily -, so as to remedy what we perceived as deficiencies of the tool used. These deficiencies are probably unavoidable given the nature of the exercise. They differ across the country models. Paradoxically, the most awkward relations turned out to be quite unrelated with technology proper, such as wage or export equations.

We now turn to simulations where we have more mechanically introduced some shock, without much concern about the plausibility of the move taken in isolation. Hence the results reflect more immediately the properties of the model. We shall in turn review four such variants, pertaining respectively to an additional wage increase, a deterioration of the external competitiveness, an increased scrapping of the capital equipment, and a more differentiated diffusion pattern of technical progress. After describing the shock proper and its interpretation, we shall briefly examine some illustrative results, usually for 2005. Remark that Hermes features no marked cyclical behaviour, as presumably fits our purpose, so that the adjustment path between 1991 and 2005 is usually very smooth.

A tighter labour market

We have already suggested that uncertainty clouds our estimates of the evolution of labour supply, and of wage behaviour. In particular, it might be argued that our labour supply estimates are too bullish, or that the wage equations used do not properly reflect the future scarcity of skilled labour. It is then natural to experiment with a higher wage level. We have exogenised nominal wages and assumed that they gradually rose above the central alternative path, up to 2% more in 2005 (the increase is linear, and actually negligible in the first few years). The real increase is obviously smaller, and - surprisingly little - variable across countries.

Except in Italy, where consumption is extremely sensitive to profit income (a property also exhibited by other simulations) the shock has a positive effect on both productivity and GDP, although these are much smaller in order of magnitude. In France, for example, part of the nominal wage increase is eroded by inflation, so that the real wage eventually increases by 1.3%. This negatively affects the trade balance. However, domestic demand is boosted by wage income, which in turn stimulates investment. Employment is virtually stationary (it slightly decreases in Germany and Italy). The message is definitely not that labour shortages cum wage increases are harmless: the deterioration of the foreign balance must be kept in mind. Also, shortages are likely to be local, so that the decrease of competitiveness would actually hit some countries more than others.

More international competition

Hermes offers two instruments to reflect external demand and competitiveness: real imports by country and by branch (excluding services), and export prices of the rest of the world by country and branch. In this variant, we have considered gradually lower export prices for the manufacturing goods of the industrialised trading partners of the four countries we focus on. Remember that our central alternative already considered a decrease of the export prices of some countries as compared with the baseline. Here, we imagine that the diffusion of new technologies (or other phenomena) makes for a gradual deceleration of export prices of all trading partners except the developing and/or formerly 'socialist' countries up to minus 3% of the level of the central alternative in 2005. Remember that we deal here with nominal prices expressed in US dollars. All this implies that the macro-economic import prices will decrease by less, because manufacturing goods comprise only part of the imports, and because of the projected appreciation of the ecu vs. the dollar.

An interesting issue is whether this shock should be combined with an increase of imports of those trading partners. As the central alternative scenario has suggested, two opposed effects are involved: an income and a substitution effect. For the sake of simplicity, we have kept the level of real imports of the trading partners constant. This obviously allows for decreases of imports by the four countries we consider, since the bilateral flows are still endogenous.

We have mentioned as well that such a shock led ex ante to both a terms-of-trade improvement and a decrease of competitiveness, so that the eventual effects could be quite mixed. When the shock is partial, in the sense that it affects only some of the trading partners, the scope for net positive effects is larger. Here, the effects on GDP are negative, except in Germany where they are almost nil. One typically observes in increase of domestic demand led by consumption, and a deterioration of the trade position.

Variable diffusion patterns

We have also introduced some differentiation across countries of the acceleration of technical progress. We have allowed for some 'catching-up' of the less productive countries, and for a lesser acceleration in the more productive ones. We have used productivity, as measured by GDP per capita in 1989 as a simple criterion. It turns out that France is very close to the EC-4 average, while Germany and the UK are about respectively about 15% higher and lower. Italy is about 4% lower. We used this information to modify the parameters E and K mentioned earlier. E, ie, the maximal additional growth rate of productivity, was assumed to be 20% lower and higher in Germany and the UK, respectively. It was assumed to be 5% higher in Italy, and unchanged in France. We only modified the parameter E in Germany, where it was halved, since it was already quite high in the central alternative.

Ex post, and in 2005, productivity is 0.2% higher in Italy and 0.6% higher in the UK. It is 1.1% lower in Germany and virtually unchanged in France - in line with our expectations. Other results may be more surprising. In particular, the association between GDP growth and productivity growth is weak, since GDP increases in Italy, the UK and Germany. They are very much in line with our central alternative, an increase of productivity resulting in an increase of both GDP and unemployment through the same mechanisms. In Germany, the real (and nominal) wage decreases together with productivity, inducing a deflationary price spiral which enhances competitiveness in spite of the decrease of productivity. The net effect is an increase of output and employment. Wage determination clearly plays a key role here, and it would be dangerous to draw too far-reaching conclusions from these findings.

Accelerated scrapping

The Hermes models rely on the assumption of a constant rate of scrapping, which is particularly important in the manufacturing industries, where the link between capital stock and sectoral behaviour is modelled to be more direct than elsewhere. We have in the central alternative assumed a quite moderate increase of the rate of scrapping. An optimistic (from a particular point of view) perception of the effects of an accelerated diffusion of information technologies would suggest that more scrapping would take place. We have explored the implications of the incremental rate of scrapping in the manufacturing industries increasing from 0.2% to 1%. In practice this means that instead of scrapping, say, 10% of capacity each year in the reference projection, and 10.2% in the central alternative, one would scrap 11%. In contrast with the other variants we have considered here for the sake of simplicity a constant shock over time. This shock results typically in a GDP decrease of slightly less than 1% in 2005, with accompanying decreases of employment (generally smaller, though) and of real wages.

4. Drawing Lessons from the Exercise

It should be remembered that the whole exercise was intended to shed light on the effects of an acceleration of the diffusion of new information technologies. In practice we have dealt with an acceleration of technical progress with some inter-industry differentiation of the primary shock. We will first discuss some mainly macro-economic conclusions which emerge given this reformulation of the problem. We will then explain why the reformulation was performed, and how more useful scenarios can be explored.

'Blasé' economists might argue that the macro-economic conclusions could be readily anticipated from the Keynesian roots of the model. In this context, the gains made possible by a supply side shock do not materialise automatically, and require the mediation of demand. The extent to which this demand will be activated is then perceived as a major issue, especially if expectations adjust slowly; at the same time, provided this demand materialises, the message of the theory tends to be optimistic if demand shocks have strong real effects.

This line of argument is only partly convincing. For one thing, Hermes features a well-developed supply side. The fact that the model has been run over an exceptionally long period also suggests that many short term price rigidities have been overcome, and that the solution has more the character of a long term equilibrium[4], albeit one with some remaining imbalances, to which we shall return.

The exercise has sketched a possible future whereby the acceleration of productivity growth had globally positive effects on welfare in Europe. Recall that this would happen against the background of a baseline projection characterised by decelerating productivity growth, and that the shock itself was assumed to decrease in magnitude over time. A mechanism important for the success of the scenario is the investment-productivity-price nexus, whose role was especially brought out by the results for the manufacturing industry. The link between investment and productivity is made possible by the putty-clay nature of the production function. The explicit manifestation of the substitutions induced by the price decreases is made possible by the disaggregate nature of the model.

Another crucial issue pertains to trade. With one exception, we have shown that intra-European trade could experience an expansionary spiral, in spite of the presence of forces tending to depress imports, with potentially disruptive effects on trade. This stemmed on the one hand from the improvement of the competitive position of Europe in at least some industries, and versus some countries. It resulted as well from the international spill-over of the domestic expansionary effects of the shock. This allows an improvement of the trade position of the countries we focussed on, despite the fact that we explicitly introduced the assumption that third industrialised countries were benefiting from the shock too.

We should nevertheless emphasise that the magnitude, and even the very existence of this improvement of the trade position hinges very much on the assumptions made on the rest of the world, an all too familiar feature of this type of studies. The variants we performed suggested that although the net effects of lower export prices from the rest of the world were negative, locally positive effects could result from the terms-of-trade effect.

A major issue brought forward is the potential increase of unemployment associated with the growth of productivity, an obviously Keynesian result. In our view, much caution should be exerted in interpreting this outcome. It may result from too energetic

4 See Deleau et al.(1991).

labour supply (i.e., implicitly migration and participation) assumptions. It is associated with an increase of consumption per capita and of real wages. It results from a model where labour is not differentiated, except for the distinction between salaried workers and self-employed, which is of little relevance here, and which is anyway treated in too simple a way to be of any help. All this means that these 'findings' regarding unemployment can be associated with a variety of concrete situations, and might even be an 'aggregation artefact'. For example, one can think that the increase in real wages benefits primarily the scarce qualified labour force, leaving behind those who are unemployed or affected by the negative impact of unemployment on wages. This clearly calls for a more micro-economic analysis, and on the policy side, for structural micro-economic policies, such as training programmes or labour time reductions. Of course, macro-economic policies can help too, and we should emphasise in this respect that room is created for more dynamic demand policies, because of the improvement of the trade balances and of the government budgets.

We must admit that the conclusions reviewed so far barely exploit the potential of the model for the incorporation of shocks differentiated across countries and branches, so as to better reflect the specificity of information technology. Also, no detailed analysis of the outcomes of the simulations, for example in terms of bilateral trade flows, has been performed. Where does this discrepancy between the exceptional scale of the exercise and the results originate ? Essentially in a trade-off between 'depth' and 'coverage'.

Rather than investing in refining the model, and facing the resulting data collection and estimation problems, we have clearly given the priority to extending the horizon of multi-country simulations. One circumstantial reason for this is that no linked simulations beyond 1995 had been performed earlier with the system, so that our focus on the extension of the simulation horizon had the nature of an investment. No doubt, additional resources would have eased the constraints, but some trade-off of this type seems hard to escape. Devoting more time to the specifics of information technology does not dispose of the problems associated with the long-term macro-economic properties of the model one uses. In fact, the more one refines certain 'local' features of a model, the greater the chance that the overall properties of the model are altered and require more attention.

So far, we have not dealt with the interaction between the modeller and the 'sector specialist' (of information technology for example) which certainly provides a second reason for the difficulty of fully exploiting the potential of the modelling tool. In fact, this can be seen as an illustration of sociological factors lagging behind the possibilities of a particular example of information technology (large-scale econometric simulation). The dialogue between modellers and sector specialists is hampered by the absence of framework and tradition, resulting for example in huge differences in aggregation levels and time horizons which make a dialogue difficult.

There is no recipe for solving these problems. We would like nevertheless to state our personal ranking of the priorities regarding EC-wide, policy-orientated modelling of technology-related issues:

1. Encourage the confrontation of modellers and sectorial experts and policy-makers. Force them to communicate rather than politely listen (?) to each other while pursuing their own research programmes. This is a slow process to be monitored closely if it is to take place at Europe-wide level.

2. Invest in 'general purpose' models to be used as 'public goods' (Hermes has played this role in some respects). These models are particularly needed in respect of 'structural', long term issues to be treated at EC-wide level. Make them readily accessible - keep them therefore easy - and encourage their dissemination. Models are improved by users, and a wide array of users should have a positive feed-back on the robustness of the model. While these models will unavoidably be frustrating in some respects, their existence will save considerable energy to the specialised researcher, who can then concentrate on model changes or extensions. Their use may entail approximations to more sophisticated specifications. If so, explore the quality of those approximations, and compare the associated costs with those of setting up 'sui generis' models.

3. Finally, and only if the possibilities just mentioned have been exhausted, invest in specialised alternatives (vs. mere extensions) to 'general purpose' models.

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Comment : *Moreno Bertoldi*

"Information technology, Employment, and the Industries of Europe. A Model Based View" is a very interesting and challenging paper. Because of its very comprehensive nature and its complexity, I would like to limit my comments to its methodological and macro-economic aspects. I will not refer to the specific points concerning sectoral results.

1. Methodological Problems

In the paper the author discusses widely and clearly the basic assumptions and limits of the simulations carried out with HERMES model. In my view, the assumptions that technical progress is "manna from heaven", that the labor factor is completely homogeneous, and that government expenditure is exogenous, as well as the fact that it is not clear through which channels the introduction of information technologies creates a productivity shock, are important shortcomings for the robustness of the results obtained, especially for a long-term model calculating the cumulative effects on growth and employment of a productivity shock.

On the other hand, the HERMES model is an exhaustive model with a well developed supply-side and the ability to capture simultaneously the interrelations (both macroeconomic and sectoral) of the European economies. Implementation of this exercise using HERMES permits us to have a comprehensive view on the complex mechanism of diffusion (direct, indirect and induced) of technical progress shock on the whole economy of a country. The shortcomings related to the hypothesis of constance of productivity growth are reduced by an improvement of the model, introducing an S-shaped diffusion rule of technical progress that makes productivity variable.

2. Results Analysis

The measurement of the impact of productivity shock was carried out by comparing a reference projection with a productivity shock projection which had a technical progress diffusion of 50 years (I will omit here the alternative cases in which a different time lag is considered).

Comparing these two alternative situations, I will focus my attention on two main issues:

1) The effects of a productivity shock generated by the diffusion of new technologies on employment, wage increase, income distribution and economic growth.

2) The long term convergence or divergence of the European economies following the productivity shock.

Finally, I will explore some issues to take into account in future work.

1) As stressed in the paper, there are three direct effects of a productivity shock generated by new technologies which emerge from the HERMES model:

a) a (non immediate) decrease in prices;
b) a coeteris paribus decrease in employment;
c) an increase in wages.

The indirect repercussions of these effects on the whole economy have important consequences on investment and international trade and, through them, on the growth path of an economy.

In the model, investment depends, in a first round, on the evolution of demand (the accelerator effect) and, in a second round, on the productivity of capital (and thus on profitability considerations). There is consequently a strong link between investment, income distribution and growth. A growth in wages increases demand and spurs investments, even if, because of the substitutability between labor and capital factors, a decrease in employment dampens the demand effect on investment. On the other hand, an increase in wages has repercussions on the competitiveness of a country: the national mechanisms of wage determination, coupled with the degree of openess of an economy, has large effects on external trade and, in this way, on the demand side of the economy.

An important finding of this econometric analysis is then the relevance of the role played by income distribution, and in particular, by the economic and institutional mechanisms which underlie wage determination, in the spreading and consolidation of benefits of an exogenous productivity shock. In fact, the model shows that wage settlements and income distribution have lasting effects on economic growth; an outcome often stressed by heterodox growth theories (i.e. neo-Cambridgean, Kaleckian and regulationist), but rejected by the neo-classical one, for which long-term growth depends on marginal productivity of factors and technical progress (see, for a revue of the issue, Bradley and Whelan's contribution in this book).

2) The HERMES model also shows that a productivity shock amplifies the divergences in the growth path of European economies. If we look at table 1, we see that the productivity shock pushes the GDP growth rates to higher levels, but with different outcomes. A polarization between countries is perceptible: Italy and Germany improve their relative position with regard to France and especially to the United Kingdom. Standard deviation of GDP growth rates passes from 0.204 in the case of the reference projection and to 0.278 in the case of productivity shock projection, with an increase of 36%. Technical progress seems then to play a contradictory role: it accelerates growth, but amplifies differences in growth rates. If the results are positive for Italy and Germany, which more quickly approach France in terms of per-capita GDP, they are much less satisfactory for the United Kingdom, which accelerates its divergence from the experience of the three other countries. A careful analysis would have been required to study the mechanisms that cause these evolutions. To what extent do they depend on the stylised facts presented above (income distribution, accumulation rules, industrial specialisa-

Table 1. Average GDP Growth Rates 1991-2005

	1991-1995	1996-2000	2001-2005	1991-2005
GERMANY				
Reference projection	3.5	3.2	2.9	3.20
Productivity shock	3.7	3.7	3.2	3.55
FRANCE				
Reference projection	2.7	2.9	2.8	2.80
Productivity shock	2.9	3.2	3.0	3.07
ITALY				
Reference projection	3.3	3.0	2.8	3.03
Productivity shock	3.6	3.5	3.3	3.44
UNITED KINGDOM				
Reference projection	2.2	2.9	2.9	2.67
Productivity shock	2.3	3.2	3.1	2.86

Source: Our calculations based on HERMES data.

tion, external competitiveness) ? What are the industrial policy implications which underlie these results ? And, last but not least, to what extent do these results depend on the features of the model (amplifying the effects of a shock) or on the features of the economy, or both ?

The HERMES model shows that a productivity shock changes the growth path of large European economies. It would be interesting to know if the effects and the divergences detected between them can be found even within more recently developed European countries like Spain, Portugal, Greece and Ireland. These are all small open economies, with different institutional and economic characteristics. Will they converge or diverge ? To what extent does the openess of the economy amplify or dampen the productivity shock ? Is a productivity shock a danger or an opportunity for these economies ? Should the EC effort be increased in such an eventuality or can it be relaxed ?

Answers to these questions would help us to understand the conditions under which the whole European economy could maximise the potentialities resulting from a productivity shock and specify which kind of EC intervention would be needed to implement long-term convergence.

In my view, it is necessary to carry out this analysis, on one side, to improve existing econometric models (introducing in them other important variables in the determination of growth rates - skilled and unskilled labor for instance), and, on the other side, to build-up new models, endogenising (completely or partly) technical change and productivity growth to finally answer to the issues of cumulative growth and of convergence (or divergence) in the economic evolution of countries or regions.

Chapter 11 - La Formalisation du Long Terme : Quelques Problèmes de Méthodes

Paul Zagamé

Introduction

L'objet de cette contribution n'est pas de décrire les résultats d'une recherche originale mais de présenter quelques réflexions méthodologiques sur la formalisation du long terme inspirées d'un côté par la pratique des modèles et d'un autre côté par les progrès récents de la théorie de la croissance et de l'analyse des séries chronologiques longues.

Après avoir brièvement présenté les raisons et les formes d'une modélisation du long terme (I), nous examinerons d'abord comment peuvent être réconciliées deux grandes familles de modèles que l'on oppose souvent : les modèles économétriques traditionnels et les modèles d'équilibre général calculables et cela pour conjuguer leurs propriétés variantielles dans l'exploration du long terme (II et III) ; puis nous envisagerons l'apport possible à la formalisation du long terme des nouvelles théories de la croissance (croissance endogène) (IV) et des méthodes d'analyses récente des séries chronologiques (V).

1. Des modèles de long terme : pourquoi, comment ?

Après tout, il n'est pas indispensable d'utiliser des instruments formalisés pour décrire certains scénarios du long terme ; qu'apporte la modélisation dans cette perspective ? Trois utilisations principales de tels instruments peuvent être repérées :

- Décrire des scénarios tendanciels dans un cadre de cohérence c'est à dire indiquer où nous allons si les comportements ne sont pas fondamentalement modifiés.
- Décrire d'autres possibles, toujours dans un cadre de cohérence minimum, celui-là pouvant être simplement le cadre de Comptabilité Nationale : il s'agit en fait de refaire ce que les modélisateurs appellent des "chocs de structure" c'est à dire de modifier un certain nombre de mécanismes en les remplaçant par des hypothèses formulées en dehors du modèle : ainsi peuvent être, sur dires d'experts, modifiés la plupart des fonctions de comportement, (ex rupture sur le taux d'épargne) et bien sûr les hypothèses

technologiques qui sont à la base de la fonction de production progrès technique, élasticité de substitution.

- Enfin analyser les effets à long terme de mesures de politique économique, effets économiques, mais également incidence sur des phénomènes de très long terme. Par exemple effets sur la compétitivité, la croissance et l'emploi mais aussi sur les réductions des émissions, d'une politique de l'environnement destinée à lutter contre la pollution atmosphérique. Dans cet exemple le modèle économique est couplé avec un "module" décrivant le phénomène étudié (avec matrices d'émissions, pour la pollution atmosphérique) ce qui permet d'analyser à technologie donnée, les incidences sur les variables économiques d'objectifs en matière d'environnement mais également de façon réciproque, les effets sur les pollutions atmosphériques de différentes hypothèses sur les scénarios d'évolution : croissance plus ou moins intensive, part des services dans la croissance etc ....

Si l'intérêt de disposer d'un instrument de cohérence formalisé ne fait aucun doute, en revanche, la difficulté de la tâche rebute bien des utilisateurs potentiels. Le Commissariat Général du Plan français a souvent, à partir du Vème Plan (1965), éclairé ses travaux de moyen terme par les perspectives de long terme ; et depuis l'époque d'extension des modèles formalisés le C.G.P. s'est souvent penché sur les questions de méthodologie des modèles de long terme.

Cet intérêt a conduit le C.G.P. à commander des études et animer des séminaires sur les questions de méthodologie du long terme. Deux rapports semblent plus spécifiquement orientés sur le choix de la méthode de formalisation : le rapport ROUCHET (1982) et la recherche commandée au CEPREMAP et réalisée par BOYER MALGRANGE (1989). Je reprendrai certains de leurs arguments, mais, pour ma part, je distinguerai quatre types de modèles :

- Les modèles globaux, qui, généralement, peuvent combiner une approche globale aussi bien au sens géographique du terme que pluridisciplinaire donc nourrie de considérations externes à la modélisation ; géopolitiques sociales etc. L'approche retenue est souvent "systémique" c'est à dire fondée sur l'analyse des systèmes, mais peut ne pas exclure l'utilisation de modèles de types économétriques. Deux exemples peuvent être ici mentionnés : le modèle de FORRESTER (1971) qui, en dépit de fondements méthodologiques peu rigoureux (négligence des retours des saturations sur le fonctionnement d'ensemble), a été au centre de la controverse alimentée par le Club de Rome; on doit citer également le modèle Interfuturs de l'OCDE (1979) dont le sérieux de la méthode contraste fort heureusement avec l'expérience de FORRESTER.

- Les modèles multisectoriels détaillés : l'idée qui préside à leur élaboration est que l'évolution de longues périodes est le résultat d'une dynamique intersectorielle ; en ce sens la croissance macro économique est définie par l'évolution relative et absolue des différentes activités constituant l'économie ; ils sont, en général, très détaillés et sont construits à partir de matrices d'échanges sectoriels et ils fonctionnent en conjuguant effets mécaniques et dires d'experts. On peut citer ici les modèles de l'institut BATTELE de Genève. En principe les modèles devraient fonctionner de façon "remontante" du secteur vers la macroéconomie, mais en fait le fonctionnement est plus complexe car il s'appuie souvent sur un croisement des informations macro et détaillées (cf. le mode de fonctionnement actuel de DIVA).

- Les modèles économétriques d'ensemble. Il s'agit, en général de modèles économétriques de petite taille car les manipulations d'un modèle de grande taille seraient extrêmement lourdes sur un horizon reculé. Nous n'entrerons pas ici dans les discussions d'ordre méthodologique qui consistent à savoir s'il est légitime d'utiliser un modèle estimé sur 15 à 20 années pour lui faire décrire un horizon parfois plus éloigné. Il y a deux façons opposées de procéder pour l'extrapolation économétrique du long terme : prolonger l'horizon de fonctionnement d'un modèle de moyen terme déjà existant ou utiliser des mécanismes spécifiques du long terme. La première technique peut être illustrée par l'expérience de mini DMS énergie ; nous reviendrons ultérieurement sur l'élaboration de mécanismes spécifiques du long terme. En fait la plupart des modèles économétriques sont de facture "Néo Keynésienne" ce qui pose problème pour la description de scénarios de long terme : en particulier ils sont incapables comme nous le verrons plus loin de s'évader de l'hypothèse de déséquilibre "Keynésien" par insuffisance de demande, déséquilibre qui il faut le dire est davantage conçu pour la courte période.

- Les modèles d'équilibre général calculable sont eux fondés sur la tradition walrassienne ; ils décrivent l'affectation des ressources dans une économie de marché comme la résultante de l'interaction entre l'offre et la demande qui détermine des prix d'équilibre. Le mécanisme de ces modèles est composé des équations représentatives des comportements micro économiques des agents consommateurs, producteurs, des administrations et à l'équilibre entre offre et demande, le modèle d'équilibre général permet de déterminer les prix qui assurent cet équilibre ainsi que l'allocation des ressources et la répartition des revenus qui en résultent ; le caractère instantané de la réalisation de l'équilibre des marchés a fait dire que ces modèles étaient plutôt conçus pour des analyses de long terme.

Ces modèles se sont développés au début des années 70 lorsque H.SCARF (1967) a mis au point un Algorithme permettant la résolution d'un équilibre c'est à dire le calcul des prix d'équilibre ; ils ont été très développés à l'étranger comme en témoigne la très abondante bibliographie de A.M. BORGES (86) [1].

Comme le soulignent SCHUBERT et LETOURNEL (1990) les modèles d'équilibre appliqués ont eu récemment un renouveau de succès essentiellement pour trois raisons : la volonté de relativiser les enseignements tirés des modèles macroéconométriques traditionnels qui fonctionnent en insuffisance de demande, l'intérêt porté au long terme, qui s'accommode mal de cette hypothèse et enfin la confiance retrouvée par de nombreux économistes dans les mécanismes de marché.

La recherche a cependant été plus tardive dans ce domaine en France et ce n'est que récemment que l'administration (C.G.P., D.P.) a, associée à un laboratoire universitaire, soutenu la construction d'un tel modèle appliqué aux problèmes de fiscalité cf. SCHUBERT LETOURNEL (1990). Mentionnons toutefois les travaux plus anciens de F. BOURGUIGNON (1983) développés avec les organismes internationaux. Aujourd'hui les besoins d'expertise exprimés dans des domaines aussi divers que la fiscalité, les politiques de l'environnement, l'énergie, les déficits sociaux, domaines qui d'une façon ou d'une autre font apparaître des modifications de prix, devraient mener à la construction de nombreux modèles d'E.G.C.

Tous les modèles que nous venons de décrire ne peuvent dans la pratique remplir avec commodité les trois usages précédemment soulignés ; d'une part il est difficile d'utiliser les modèles globaux ainsi que les modèles multisectoriels jugés trop lourds pour réaliser des variantes ; d'autre part les modèles d'E.G.C. ne sont pas conçus pour l'élaboration de comptes prospectifs. Nous allons maintenant nous limiter à l'instruction des propriétés des modèles pouvant décrire aisément des variantes de politique économique c'est-à-dire les modèles économétriques traditionnels et les modèles d'E.G.C.

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[1] La bibliographie de A.M. BORGES répartit les applications en politique fiscale, politique du commerce international, politique énergétique, politique du développement, applications au cas d'un pays, autres applications ; depuis ces recherches ont été appliquées aux conséquences de la suppression des barrières tarifaires, (Europe) et surtout au politiques de l'environnement (cf. le modèle GREEN de l'OCDE, celui de JORGENSON et WILCOXEN 1989). Sur les E.G.C. cf. également l'article de présentation de SUWA A. (1991).

2. Deux approches que l'on oppose fréquemment : modèles économétriques et modèles d'E.G.C.

De nombreux points opposent modèles économétriques traditionnels et modèles d'E.G.C. tant du point de vue des méthodes de construction que du fonctionnement ou des utilisations.

Les méthodes de construction d'abord : les modèles d'équilibre général ne sont en principe pas estimés économétriquement ; certes ils peuvent emprunter certains paramètres à des travaux économétriques déjà réalisés lors de la construction d'autres modèles (par exemple les élasticités de substitution pour les fonctions de production) mais en général les paramètres des E.G.C. sont "calibrés" c'est à dire que : [1].

- D'abord est déterminée une banque de données pour toutes les variables ; cette banque est construite à partir de la Comptabilité Nationale mais aussi à partir de toute autre source d'information ; elle se réfère à un point de base, qui en général n'est pas une année précise mais une moyenne d'observations ; de plus certaines données sont rectifiées pour tenir compte de contraintes d'équilibre que doit décrire le modèle (marché du travail, balance commerciale etc...) ce qui donne un caractère un peu "a historique" à cette base.

- Ensuite, les paramètres sur lesquels existent des estimations économétriques considérées comme robustes sont intégrés au modèle.

- Enfin les autres paramètres sont calés pour décrire l'année de base.

Mentionnons toutefois que JORGENSON (84) [2] utilise massivement les résultats d'un modèle économétrique pour chiffrer un E.G.C.

Pour le fonctionnement, les modèles E.G.C. s'appuient conformément à la théorie de l'équilibre général sur un comportement explicite d'agents économiques en situation de concurrence qui maximisent une fonction d'utilité ou de profit ce qui conduit à un équilibre entre l'offre et la demande : tous les chocs sur l'économie sont donc immédiatement absorbés par un ajustement de prix sur le marché.

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[1] Pour la méthode de construction des E.G.C. on peut se rapporter à l'ouvrage de SCARF et SHOVEN (1984) et à SCHUBERT LETOURNEL (90).

[2] Il est vrai qu'au départ JORGENSON ne s'était pas mis dans un cadre d'équilibre général mais qu'il l'a rejoint ultérieurement.

Les modèles économétriques [1] actuellement opérationnels sont pratiquement tous de facture "Néo Keynésienne" : les marchés n'y sont pas "équilibrés" et ils fonctionnent en situation keynésienne d'insuffisance de la demande. Si leurs estimations sont fondées sur des bases de données en grandeurs réelles, en revanche leurs mécanismes sont dépourvus de la cohérence quasiment académique des E.G.C. De nombreuses recherches consacrées aux propriétés de ces modèles ont mis en évidence certaines incohérences entre les différents blocs d'un même instrument ; c'est ainsi que par exemple BUREAU MIQEU NOROTTE (84), MALGRANGE (1991) soulignent que la demande de facteurs est déterminée en général par l'hypothèse Keynésienne de débouchés contraints dans un environnement de concurrence parfaite ; en effet l'offre est contrainte et le prix s'impose au producteur qui ne peut le modifier pour gagner des parts de marché supplémentaires ; tandis que le même marché du produit est traité dans les équations de détermination des prix comme étant en situation de concurrence monopolistique : dans la plupart des modèles le prix de production est déterminé en appliquant un taux de mark up sur le coût unitaire ce qui détermine le prix optimal de vente dans le cas de concurrence monopolistique, la proportionnalité avec le coût unitaire dépendant de l'élasticité à la courbe de demande (perçue) à l'entreprise. Par ailleurs dans les modèles Néo Keynésiens aucun lien n'est fait entre cette courbe de demande perçue (virtuelle) et la demande en fonction des prix adressée au système productif (solde du commerce extérieur, consommation, investissement ...).

Les utilisations des deux familles de modèles sont également bien différentes :

- Dans l'esprit tout d'abord ; les modèles économétriques ont une vocation principalement globale et s'ils sont fréquemment utilisés pour des opérations spécifiques, fiscalité, environnement, énergie c'est que soit ils comportent de telles variables d'entrée soit ils fonctionnent avec un module se rapportant aux phénomènes étudiés. Les modèles E.G.C. au contraire sont élaborés pour un problème bien déterminé ; ils ont davantage un aspect modèle "jetable". Les modèles d'E.G.C. ne peuvent prétendre à décrire un compte central prospectif ou prévisionnel puisque la base de données (1) ne s'y prête pas ; en revanche, ils peuvent être utilisés pour spécifier complètement un problème d'optimisation intemporelle et décrire de façon normative certains comportements d'adaptation qui suivent un choc notamment sur les prix.

- Du point de vue de l'objet on a souvent dit que les E.G.C. parce qu'ils décrivaient des équilibres ne pouvaient être utilisés pour traiter des politiques de stabilisation ; en fait la littérature récente sur le cycle conjoncturel réel explique les fluctuations économiques

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[1] Nous ne présentons pas ici l'ensemble des propriétés et des utilisations de ces modèles qui sont bien connues; nous nous arrêtons sur certaines caractéristiques que nous utiliserons ultérieurement.

en terme d'équilibre général ce qui élargit beaucoup les perspectives d'application des E.G.C.

- Les deux familles de modèles sont utilisées pour leurs propriétés variantielles avec les divergences d'appréciation que leur confèrent les différences de mécanismes : les modèles économétriques traditionnels filtrant les variantes usuelles en renforçant les aspects "demande" et en atténuant les phénomènes de réactivité de l'offre ; au contraire, les E.G.C. insistent sur cette réactivité et plus généralement sur les liens entre prix et comportements des agents économiques ce qui fait dire qu'ils sont plus adaptés à la description du long terme. Enfin, les E.G.C. ont des propriétés normatives pour les recommandations de politique économique ; ils permettent d'évaluer dans certains cas les variations de bien être ou de surplus qui résultent de l'adoption d'une mesure de politique économique.

En dépit de toutes ces oppositions nous allons maintenant tenter de rapprocher ces deux méthodes afin de composer leurs propriétés. Nous commencerons par nous interroger sur le point de savoir si le long terme des modèles économétriques ressemble aux E.G.C., et la réponse négative à cette question nous conduira à rechercher d'autres voies de rapprochement.

3. Des éléments de synthèse

Bien que les propriétés de long terme des modèles macroéconométriques ne ressemblent pas à l'équilibre général on peut envisager des modifications de leurs mécanismes qui y ramènent.

a) Les propriétés de long terme des modèles macroéconométriques ne ressemblent pas à celles des E.G.C.

Les chercheurs français, surtout ceux de l'administration économique (Plan, CEPREMAP, INSEE, DP) ont beaucoup traité de cette question des mécanismes à long terme des modèles économétriques. L'enjeu n'était pas tant d'évaluer les possibilités d'utilisation de ces modèles pour réaliser des projections à long terme, c'est à dire l'enjeu qui est le nôtre, que de simplifier et de dégager l'essentiel des mécanismes tendanciels ; certes ces travaux s'appuient sur un concept de croissance à taux constant [1] de l'économie

[1] Ce qui suppose que l'on ait réglé le problème de l'existence de ce sentier, c'est-à-dire que l'on ait modifié certaines relations des modèles opérationnels.

qui peut paraître un peu académique mais qui a conduit à des simplifications très éclairantes sur les mécanismes de long terme des modèles.

On pourrait en effet intuitivement penser que le long terme des modèles macro-économétriques les rapprochait des E.G.C. pour deux raisons :

- La première de pure technique d'estimation des modèles économétriques : la méthode des moindres carrés doit, lorsqu'on donne aux variables exogènes leur moyenne historique sur la période d'estimation, conduire à un sentier de long terme sur lequel les variables endogènes ont leur valeur moyenne historique; en ce sens, le sentier décrirait la structure moyenne autour de laquelle le passé aurait évolué. On retrouve là une propriété des E.G.C. construits à partir d'un point de base calculé comme la moyenne de plusieurs observations ; malheureusement cette propriété de point médian n'est pas applicable à toutes les relations comme le soulignent LOUFIR et alii (1990) surtout lorsque celles-ci comportent simultanément des taux et des niveaux ;

- La seconde c'est que l'on pouvait imaginer que dans les modèles économétriques néo-keynésiens, ce sont à court terme les éléments de demande qui prévalent (équilibres keynésiens) tandis qu'à plus long terme ce sont les éléments d'offre qui reprennent de l'importance ce qui conduit à une plus grande symétrie et à un équilibre de marché offre-demande ; au reste, cette idée était généralement acceptée dans les premiers temps de la modélisation avant le développement des travaux mentionnés. Or ces travaux nous enseignent que le long terme des modèles n'est pas un équilibre walrassien mais un équilibre keynésien où les entreprises sont toujours contraintes par l'insuffisance de demande.

Cette propriété a reçu différentes explications ; théorique tout d'abord : LAROQUE (1978) a en effet montré que dans un modèle d'échange où l'équilibre par les quantités a lieu au voisinage d'un point d'équilibre walrasien, les agents du côté long, donc rationnés, préfèrent l'allocation de déséquilibre ; dans les modèles néo-keynésiens, le producteur contraint par ses débouchés a donc intérêt à ce que le prix soit maintenu au-dessus du prix d'équilibre et il le peut dans le cas d'un équilibre de concurrence monopolistique. BUREAU et alii (1984) DELEAU et alii (1988), MALGRANGE (1985,1990) retrouvent également cette propriété en analysant le fonctionnement des marchés des biens et du travail d'un modèle type et en procédant à des simulations sur maquette :

- Le taux de chômage est déterminé par l'inversion de la courbe de Phillips au niveau du NAIRU, la "causalité" à long terme allant du niveau de croissance des prix sur l'état stable vers le taux de chômage ; le NAIRU, il faut le remarquer n'est pas le plein emploi car dans certains cas, le taux de chômage asymptotique peut être plus élevé que la moyenne passée.

- Le marché des biens est également contraint sur les débouchés et en sous-utilisation des capacités de production et fonctionne à long terme comme un marché de concurrence monopolistique.

b) Deux versions d'un même modèle

La première voie de rapprochement entre les E.G.C. et les modèles économétriques consiste à estimer deux versions d'un même modèle à partir de la même base de données, avec le même cadre comptable et les mêmes équations pour la plupart des fonctions de comportement. La version E.G.C. se distingue de la version macroéconométrique par plusieurs caractéristiques : les prix sont calculés par égalisation entre l'offre et la demande (au lieu de l'ajustement monopolistique précédemment présenté) sur chaque marché ; la fonction de production est une fonction effective et non potentielle. Il existe une règle de "fermeture" (dérivée de la loi de Walras). Enfin, cette version bien qu'estimée économétriquement doit être calibrée avec des variables d'ajustement pour décrire l'équilibre.

Un tel travail a été réalisé par CAPROS, KARADELOGLOU, MENTZAS (1990) qui construisent donc à partir des mêmes estimations économétriques deux versions d'un même modèle estimé pour l'économie Grecque. Ces versions sont relativement agrégées ; ne sont envisagés ici que trois marchés : celui des biens, celui du travail ainsi que le marché des changes qui est censé refléter l'équilibre extérieur. Une fois les deux instruments construits, les auteurs leur appliquent une batterie de variantes mettant en oeuvre à la fois des propriétés d'offre et des propriétés de demande (accroissement des dépenses publiques, accroissement du progrès technique, politiques fiscales, accroissement de la demande internationale, etc...). Les deux premiers exercices qui sont pratiquement des variantes pures de demande et d'offre conduisent, comme on s'y attend, de deux versions qui décrivent l'une plutôt la demande et l'autre plutôt l'offre à des résultats très différents : l'accroissement des dépenses publiques a des effets positifs et le choc de productivité des effets négatifs sur le modèle économétrique ; les résultats symétriques apparaissent sur la version E.G.C..

Si en un temps, on a pu souhaiter la diversification des instruments pour mieux encadrer la réalité, il faut bien dire que lorsque les résultats sont opposés, les modèles ne peuvent plus remplir leur fonction d'aide à la décision ! En fait, dans la variante progrès technique, la divergence provient essentiellement de l'hypothèse d'ajustement instantané de l'offre et de la demande par le mécanisme de prix. Peut-on donc envisager les résultats du modèle économétrique comme d'un exercice de court terme et les résultats de l'E.G.C. déduits d'un ajustement de long terme comme le suggèrent les auteurs, ce qui permettrait de définir un échéancier cohérent de mesures de politique économique ?

c) Les E.G.C. comme limites des modèles néo-keynésiens

L'équilibre walrassien peut-il utilement prolonger sur le long terme les équilibres néo-keynésiens des modèles macroéconométriques ? dans quel butet comment ?

En fait, dès que l'on rentre dans une logique d'évolution à partir d'un court terme néo-keynésien, on pense aux modèles de régimes, c'est-à-dire à la succession des différentes phases, chômage classique, inflation réprimée ; mais, outre que la résolution opérationnelle de tels modèles pose problème le but poursuivi ici n'est pas la description fine de l'enchaînement de ces différentes phases conjoncturelles mais plutôt la construction d'un compte neutre en conjoncture moyenne qui serait susceptible de décrire une évolution tendancielle de l'économie en donnant certaines caractéristiques structurelles : taux de croissance de long terme, intensité capitalistique, part des services dans les modèles plus détaillés, etc... Dans ces conditions, la référence à un équilibre walrassien où les composantes de l'offre et de la demande sont traitées de façon plus symétriques peut correspondre à la représentation un peu neutre que l'on veut se donner du long terme.

Un modèle construit sur ces principes, fonctionnement néo-keynésien à court-moyen terme, équilibre sur le long terme, verrait son champ d'utilisation élargi aux propriétés additionnées des modèles économétriques et des modèles E.G.C.

Comment modifier un modèle néo-keynésien pour qu'il converge vers un E.G.C. ? [1] Ce sont les voies de cette modification que nous explorons maintenant ; mais dans l'état actuel des recherches, nous ne pouvons que suggérer quelques orientations dont on ne peut préjuger de la fécondité.

Nous limiterons notre propos au marché des biens, c'est-à-dire que nous ne nous consacrerons pas spécifiquement aux équilibres walrassiens, qui incluent l'équilibre sur le marché du travail mais à l'équilibre sur le marché des biens, c'est-à-dire sur la ligne de

[1] Mentionnons la démarche de ERLICH (S), GINSBURGH (V), VAN DER HEYDEN (1987) qui partant d'un modèle d'Equilibre Général Calculable introduisent des rigidités de prix à court terme sur le marché du travail et donc des équilibres Néo Keynésiens (cf. SUWA 91).

partage chômage classique, chômage keynésien pour reprendre le vocabulaire de la théorie du déséquilibre.

C'est le fonctionnement "monopolistique" du marché des biens qui est à l'origine de la prolongation du déséquilibre ; cela se traduit par la détermination de prix de production conformes à la théorie du monopole :

$$p = \frac{1}{1 - 1/\varepsilon} \text{ x coût unitaire}$$

ε étant l'élasticité de la courbe de demande perçue.

Il s'agit là d'une concurrence monopolistique, cela veut dire que ε n'est pas égal à l'élasticité macroéconomique de la demande globale par rapport aux prix E ni à l'élasticité de substitution entre les firmes e mais à une combinaison des deux selon la formule :

$$\varepsilon = \frac{E}{n} + (\frac{1}{n} - 1)\, e$$

dans laquelle n désigne le nombre de firmes sur le marché.

A long terme les producteurs préfèrent toujours pratiquer un prix plus élevé et être contraints sur leurs débouchés ; on peut d'ailleurs calculer en fonction de ε ou ce qui revient au même du taux de mark up, la sous-utilisation des capacités de production à long terme ; celle-ci s'annule lorsque $\varepsilon \rightarrow \alpha$, ce qui ramène à l'équilibre sur le marché des biens c'est-à-dire sur la frontière chômage classique, chômage keynésien.

La théorie des marchés de concurrence monopolistique indique que certains facteurs de monopole disparaissent sur le long terme : relative immobilité des facteurs, segmentation des marchés, barrières à l'entrée, etc... ce qui entraîne une augmentation de l'élasticité e qui peut devenir infinie : on peut donc très bien justifier l'augmentation de ε sans remettre en cause la valeur de l'élasticité de la demande globale E et, du même coup, justifier un processus de retour à l'équilibre.

Mais cette endogénéïsation de la structure des marchés ne doit pas être considérée comme une véritable phase historique de longue période ; en fait l'incessant processus de "destruction créatrice" qui conduit à l'émergence de produits nouveaux [1] recrée des situations de monopole puis de concurrence monopolistique : l'équilibre concurrentiel est ici utilisé comme fiction méthodologique dans le but de neutraliser certains effets conjonctu-

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[1] Ce processus a été analysé par les Néo Schumpétériens.

rels à long terme sur lesquels nous n'avons qu'une faible capacité d'analyse et pour décrire des situations où offre et demande sont envisagées de façon plus symétrique.

A partir de quel horizon modifier le mark-up (ou l'élasticité demande) et sur quelles grandeurs l'endogénéïser ? Existe-t-il d'autres façons de rejoindre les équilibres ? Si en effet à long terme le mark-up doit tendre vers l'unité, il importe toutefois de ne pas mettre des forces de rappel qui "gommeraient" trop rapidement certains effets conjoncturels indispensables à la prévision et à l'analyse des politiques économiques. Pour l'endogénéïsation on peut penser à certaines grandeurs économiques telles que l'état de tension de la demande (entrée sur le marché), mais contrairement aux mécanismes de prix de certains modèles opérationnels il s'agira ici de relations plus structurelles de long terme qui passent par la modification de l'élasticité de substitution, et qui jouent de façon opposée. On conçoit alors les difficultés économétriques de séparation des deux phénomènes. De même, la profitabilité qui tend à attirer les concurrents doit à long terme faire augmenter l'élasticité de substitution et donc là également coexistent deux relations de sens inverse sur des horizons différents.

Il va de soi que ces suggestions, superficielles, ne sauraient remplacer un programme de recherche approfondi sur le choix des processus de convergence.

4. La croissance endogène

Contrairement au modèle Néo-classique de croissance qui a été présenté sous une forme unifiée (le modèle de SOLOW>) avec, il est vrai, quelques variantes importantes (progrès technique incorporé, effets d'apprentissage, etc...) on regroupe sous le vocable de "croissance endogène" un ensemble de théories très diversifiées, en pleine évolution, dont on date l'apparition à la publication du premier article de ROMER (1986). Quel est, en l'état actuel de cette évolution, le message que l'on doit retenir ? Que doit-on ou que peut-on en utiliser pour la formalisation du long terme ?

4.1. Les apports de la théorie de la croissance endogène

L'idée fédératrice de la croissance endogène est une réaction contre le schéma du modèle de croissance néo-classique traditionnel dans lequel les rendements d'échelle constants conduisent à des rendements marginaux décroissants sur le facteur accumulable et donc à une saturation de l'accumulation qui en l'absence de progrès technique se traduit par une stabilisation du rapport K/L : dans ce schéma la croissance d'équilibre est totalement dépendante de l'évolution de la population et du taux de progrès technique : elle est exogène.

Certes, il y avait déjà eu, il y a plus de trente ans, une théorie de "l'induction" du progrès technique et de la productivité, modèles de générations avec incorporation du progrès technique, "Learning by doing", fonctions de progrès technique de KALDOR etc... Mais aujourd'hui le terme "croissance endogène est plus précisément réservé à ces nouvelles théories qui font dépendre la croissance de comportements micro-économiques des agents en matière d'épargne, de stratégie de Recherche-Développement, de formation, etc... en ce sens, et comme l'ensemble des théories macro-économiques contemporaines la nouvelle croissance endogène s'appuie sur des fondements micro-économiques mieux établis que les précédentes.

- L'idée fédératrice de toutes ces croissances endogènes c'est que les facteurs accumulables ne butent plus sur une contrainte de saturation : leurs productivités marginales ne sont plus décroissantes en raison de rendements croissants et/ou d'externalités. Dans ce cadre, le facteur de croissance n'est plus le seul progrès technique mais tout ce qui est source d'externalités et de rendements croissants ou constants sur le seul facteur accumulable [1] ; le premier modèle de ROMER (86) se contentait de poser les rendements croissants ou constants sur l'investissement en raison d'externalités entre firmes, ou encore à cause du "Learning", dans les contributions ultérieures, les sources de la croissance se sont diversifiées, on peut les regrouper par [2].

- L'influence de la Recherche-Développement AGHION HOWITT (1989), GROSSMAN-HELPMAN (1990, 1991), ROMER (1990), GUELLEC-RALLE (1991).

- Le rôle de l'investissement dans le capital humain par l'éducation LUCAS (1988), AZARIADIS-DRAZEN (1990), BECKER, MURPHY, TAMURA (1990).

- Les effets des investissements d'infrastructures rendant des services collectifs (systèmes routiers et autoroutiers, distributions en réseau, etc...) (cf. BARRO (1990)).

L'existence de rendements d'échelle amène à repenser totalement la représentation du fonctionnement des marchés et remet en cause notamment le cadre concurrentiel traditionnel : la concurrence pure et parfaite étant dans ce cas "instable" car l'hypothèse de ren-

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[1] Plus précisément, pour qu'il y ait croissance endogène, il faut qu'il y ait des rendements au moins constants sur les biens reproductibles dans la production de biens reproductibles (cf. REBELO (90)).

[2] On peut se référer aux excellents "Survey" de SALA-I-MARTIN (1990) et en français de AMABLE et GUELLEC (1991) et d'ARTUS (1991). Ce dernier étant présenté de façon plus formalisé. On pourra se reporter également aux travaux en français du colloque de MARRAKECH consacré à ce thème.

dements entraîne des situations de croissance tendant au monopole. Pour cela des modèles adoptent l'une des deux représentations suivantes (cf. AMABLE et GUELLEC (91) :

- La différenciation de produit, la concurrence monopolitique conduit dans ce cas à un état stable.

- L'hypothèse d'externalités : dans ce dernier cas, les rendements individuels sont décroissants, ce qui permet d'atteindre un optimum tandis que les rendements collectifs sont décroissants.

L'existence d'externalités amène à poser la question de la coordination des agents économiques ; en particulier, l'équilibre ne coïncide pas avec l'optimum et par conséquent l'existence d'opérateurs chargés de cette coordination ou d'échanges d'information peut s'avérer utile pour atteindre cet optimum. De ce point de vue ces théories apparaissent comme donnant un "second souffle" aux justifications de l'intervention de l'état et notamment d'une certaine "planification stratégique".

4.2. Quels enseignements pour la formalisation du long terme ?

Les études appliquées relatives à la croissance endogène sont aujourd'hui encore relativement rares : il faut dire que les besoins statistiques issus des nouvelles théories de la croissance sont immenses : l'analyse plus fine des facteurs de production, données sur la technologie, le capital physique, le capital humain, sur les investissements d'infrastructures, etc... Outre que bien souvent les séries longues relatives à ces différentes composantes font défaut, il apparaît que l'ensemble des phénomènes qui sont évoqués ont une origine essentiellement qualitative". De ce point de vue l'appréhension par un modèle formalisé macroéconomique peut poser problème.

Le domaine, qui, de loin, a été l'objet du plus d'applications est celui des effets de la Recherche et Développement ; ces travaux ont, il est vrai, largement précédé la "cristallisation" sous la forme de croissance endogène ; le nombre et l'intérêt des contributions présentées à ce colloque suffit à se persuader de l'importance de cette ligne de recherche.

Nous envisagerons tout d'abord les effets de la R. et D. dans le système économique puis donnerons ensuite quelques résultats de travaux économétriques.

a) Les effets de la R et D

Si l'on présente traditionnellement les effets de la R. et D. en innovations de procédés et innovations de produits, la distinction est introduite de façon plus complexe dans les modèles de croissance endogène. Les innovations de procédés sont présentées par un processus de modification des inputs intermédiaires servant à la fabrication du bien final selon deux logiques bien distinctes : l'augmentation de la productivité est due à l'accroissement du nombre d'inputs différents donc à une spécialisation accrue ; les auteurs parlent d'une logique "Smithienne"" (ROMER) (1990) ; dans l'autre cas de nouveaux inputs plus productifs se substituent aux anciens dans un processus de destruction créatrice qui rappelle la logique SCHUMPETERIENNE (AGHION HOWITT) (1990) ; si donc les gains de productivité passent par la création de nouveaux produits, ils résultent néanmoins toujours de ressources consacrées au secteur de R. et D. : l'arrivée de nouveaux produits est une fonction aléatoire des dépenses de R. et D.

Un modèle est consacré aux innovations dans le secteur des biens de consommation : il s'agit du modèle de GUELLEC et RALLE (1991) qui analyse l'innovation comme un processus de création de nouveaux produits qui satisfait le goût pour la diversité des consommateurs.

Quelles modifications ces phénomènes de croissance endogène doivent-ils entraîner sur les mécanismes des modèles traditionnellement utilisés pour les simulations macroéconomiques ?

Les modèles keynésiens (cf. supra) sont en ce qui concerne les enchaînements de mécanismes d'offre qui suivent une innovation technologique très pessimiste : l'incidence globale de gains de productivité est en général négative ; c'est à dire que les gains de compétitivité et de salaire réel qui en résultent sont insuffisants pour recréer les emplois perdus lors du choc de productivité initial. Ce résultat contredit totalement les études menées aux niveaux meso et micro économiques qui associent rythme d'innovation avec préservation de la croissance et l'emploi [1].

Plusieurs explications peuvent être avancées pour cela :

D'abord les modèles en *nomenclature fixe* ne tiennent pas explicitement compte de l'apparition de produits nouveaux ; seuls sont donc traduites les innovations de process et

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[1] On peut se référer aux excellents "Survey" de SALA-I-MARTIN (1990) et en Français de AMABLE et GUELLEC (1991) et d'ARTUS (1991). Ce dernier étant présenté de façon plus formalisée. On pourra se reporter également aux travaux en français du colloque de MARRAKECH consacré à ce thème.

de gain de compétitivité. Or, de ce point de vue les élasticités volume/prix du commerce extérieur sont insuffisantes pour traduire en relance des gains substantiels de compétitivité-prix : il apparaît en effet que les estimations économétriques des fonctions d'exportations recouvrent des périodes (et d'un point de vue global des secteurs) où le fonctionnement est tantôt gouverné par l'offre et tantôt par la demande [1] ce qui a pour effet de diminuer la valeur absolue de l'élasticité volume-prix. Un modèle de type régime de déséquilibre serait donc plus approprié pour décrire ces situations, mais il est de manipulation peu aisée ; pour ces raisons nous préférons sur le long terme des solutions de type modèle d'E.G.C. où offre et demande sont traitées de façon plus symétrique à la condition de raisonner les élasticités introduites dans la formalisation.

L'introduction de nouveaux produits et plus généralement d'une différenciation des produits permet d'enrichir l'analyse en tenant compte de plusieurs effets :

- Accroître les exportations (débouchés du nouveau produit ou préférence pour la différenciation).
- Augmenter l'investissement on le comprend si il s'agit d'un bien lié à une nouvelle technique mais c'est le cas également d'un bien de consommation en raison d'un accroissement de l'offre qui va précéder la demande.
- Accroître la demande selon le processus bien connu de cycle de vie du produit.

La traduction en termes formalisés de tels phénomènes est, on le conçoit, très difficile ; mentionnons toutefois quelques tentatives qui ont déjà été utilisées dans des modèles opérationnels.

La compétitivité liée à la différenciation des produits et d'une façon plus générale la compétitivité structurelle (toute celle qui ne transite pas par des effets prix) a été traduite par un lien entre flux du commerce extérieur et effort d'investissement du secteur (rapporté à l'effort des concurrents). Ce fut le cas avec l'utilisation du concept d'investissement "'efficace" CATINAT-MAURICE (84), PASSERON-ZAGAME (85) lors des travaux quantitatifs préparatoires à l'élaboration du IXème Plan Français[2]. Aujourd'hui ce concept a été systématisé par l'introduction de la variable effort d'investissement dans les équations du modèle AMADEUS de l'INSEE. En utilisant cette méthodologie pour l'analyse de la longue période et en se référant au lien (probabiliste mais qui doit s'expliciter sur les moyennes de long terme) entre R. et D. et innovation de produit, on peut

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[1] En effet, en régime de demande, les exports dépendent de façon négative des prix des exports et réciproquement.

[2] Etait efficace en investissement.

tenter d'introduire dans les fonctions du commerce extérieur de façon explicite les dépenses de R. et D. (cf. infra L. RAGOT (1992).

Pour la consommation, l'apparition de nouveaux produits peut modifier pour un temps la propension à consommer ; cependant si l'on examine sur la longue période les évolutions de la consommation et du revenu, on retrouve pratiquement toujours l'élasticité unitaire qui lie ces deux variables.

b) Quelques résultats d'application [1]

Le lien entre R. et D. et productivité a donné lieu à de très nombreux travaux économétriques qui sont présentés dans les "surveys" de GRILICHES (88) et MAIRESSE MOHNEN (90). Sans entrer dans le détail de la méthodologie de ces travaux (qui empruntent des méthodes souvent très différentes : données individuelles, estimations temporelles, données de panel qui croisent les deux-approches, etc... [2]. On peut insister sur les quelques idées qui semblent robustes :

- Le lien entre R. et D. et gain de productivité est confirmé par l'ensemble des études.
- Les externalités de la R. et D., c'est-à-dire l'effet d'entraînement sur les autres entreprises d'une dépense de R. et D. d'une entreprise (et l'inverse) semblent confirmées par toutes les études qui posent la question : le taux de rendement externe est significatif.
- Partant de là, le niveau d'agrégation retenu va être déterminant pour calculer l'effet des dépenses de R. et D.. En nous limitant aux études les plus agrégées, le rendement brut de l'investissement en recherche est très significativement supérieur au rendement de l'investissement physique. Ainsi MAIRESSE-CUNEO (1985) trouvent 20 % en plus; cela étant si l'on tient compte de la plus grande dépréciation du capital Recherche les auteurs aboutissent à la conclusion selon laquelle les rendements sont identiques.
- Si l'on se réfère aux travaux économétriques utilisant une fonction de production à trois facteurs (capital Recherche, capital physique, travail), l'élasticité de la production par rapport à la R. et D. est comprise entre 0,05 et 0,20 en fonction des méthodes et des hypothèses retenues. Il peut donc sembler utile de retenir comme ordre de grandeur

[1] Nous présentons les résultats d'ensemble de recherches qui recouvrent des travaux ne portant pas nécessairement sur la croissance endogène ; en particulier les rendements du facteur accumulable peuvent être inférieurs à l'unité.

[2] On peut également distinguer les travaux conduits à partir de fonctions de production des travaux menés sur les fonctions de coût.

0,1 pour un modèle formalisé. Certes l'explication de l'évolution de la productivité par la Recherche-Développement est une part relativement faible de l'explication totale mais une politique continue de soutien en faveur de la R. et D. doit sur le long terme avoir des effets non négligeables conformes à la théorie de la croissance endogène. De toutes façons, les travaux économétriques dans les différents pays seront conditionnés par l'élaboration de bases de données comportant des séries longues sur la R. et D., notamment, qui soient relativement harmonisées. Mentionnons de ce point de vue que depuis les années soixante et pour les seuls pays industrialisés sont collectées des données par des enquêtes suivant les recommandations de l'OCDE du manuel FRASCATI (cf. à ce sujet MAIRESSE-MOHREN Op. Cit).

- Récemment L. RAGOT (1992) a introduit dans une maquette économétrique (SILENE) des estimations de fonctions décrivant successivement le stock de Recherche-Développement comme : 1) facteur de production, 2) innovation dans le processus de production (appréhendée par la modification des coefficients techniques), 3) innovation de produits (appréhendée par un effet de compétitivité structurelle). En isolant les effets d'offre c'est-à-dire en ne comptabilisant pas les effets demande dus à une augmentation des dépenses de R. et D. il apparaît qu'une augmentation du stock de R. et D. de 1 % aboutit par ces trois seuls effets d'offre à une augmentation de la production d'à peu près 0,5 %, ce qui n'est pas négligeable, l'augmentation annuelle de la R. et D. se situant aux alentours de 8 % la première année, 2 % après.

Ces travaux doivent être aujourd'hui repris, amendés et précisés en utilisant les techniques récentes de l'analyse économétrique et des statistiques dont la quête va constituer un énorme effort.

5. La réinterprétation des mouvements longs

Le traitement des séries chronologiques a connu au cours des deux dernières années une évolution considérable : les développements récents de la modélisation économétrique a en effet par de nombreux aspects remis en cause la représentation traditionnelle des mouvements économiques ; de plus les développements récents autour de la notion de "co-intégration" permettent d'opérer un véritable tri entre des variables susceptibles de vérifier une relation sur la longue période.

5.1. La remise en cause des représentations

La représentation traditionnelle des mouvements économiques décompose ceux-ci entre une tendance déterministe, le plus souvent linéaire, et des fluctuations conjoncturelles autour de cette tendance. Les modèles économétriques usuels, notamment ceux de type "Néo-keynésiens", dans leur fonctionnement déterministe exhibent une telle configuration de mouvement : les chocs ponctuels conduisent à des fluctuations amorties et donc les simulations sont en fait des suites de fluctuations engendrées par des chocs ininterrompus.

Cela étant, l'analyse des séries temporelles remet en cause ce schéma ; il apparaît en effet que de nombreuses variables économiques peuvent être rapprochées du processus auto-régressif de type :

$$x_t = x_{t-1} + a + bt + e_t$$

expression stochastique dans laquelle e_t désigne un bruit blanc (O, σ) ; dans ce sens et même si les coefficients a et b sont nuls, on voit que la variable x_t ne peut être considérée comme stationnaire ; en particulier la variance de la série ($t \sigma^2$) croît avec le temps et par conséquent x t ne saurait être envisagée comme une variable qui fluctue avec des forces de rappel autour du trend b t + a .

Certes, la simple transformation $Y_t = Y_t - Y_{t-1}$ ramène la variable à une évolution stationnaire autour de cette tendance cependant, toutes les variables ne vérifient pas des relations aussi simples; mais ce qui est important ici c'est que le coefficient *unitaire* [1] du terme auto régressif fait que les chocs (ou les innovations) que subit la variable Y_t ne s'effacent jamais ; on parle alors de phénomène d'hystérèse (cf. NELSON et PLOSSER (1982)). C'est l'accumulation des chocs qui conduit à l'augmentation de la variance et qui prévient le retour de la variable sur la tendance. Par conséquent, il est essentiel que soit bien analysée l'évolution des séries temporelles et notamment repérés les phénomènes de non-stationnarité.

Quelques études ont déjà été réalisées sur les indicateurs [2] macroéconomiques des quatre grands pays européens : Allemagne, France, Italie et Royaume-Uni (cf. REICHLIN (1989)) ; il apparaît que pour aucune de ces séries ne peut être rejetée l'hypothèse de persistance (racine unitaire) ; mais remarque l'auteur "il apparaît de plus que la plupart de ces séries sont caractérisées par une durée temporelle suffisamment significative pour que

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1 Ce qui ne serait pas le cas avec $P\,Y_{t-1}$, $P \neq 1$.

2 PIB réel, PIB maximal, Emploi total, Taux de chômage, Production industrielle, etc...

l'on puisse conclure que leur évolution est "dirigée" et que leurs fluctuations autour de cette direction sont contraintes entre certaines limites et qu'il existe une direction générale de la dynamique des variables considérées".

Tout se passe donc comme si la persistance des chocs a engendré une instabilité du cycle économique qui se manifeste par une forte irrégularité de l'ampleur et de la périodicité des fluctuations, ce qui invalide notamment le schéma classique de fluctuations amorties à la suite d'un choc avec forces de rappel relativement régulières à une tendance économique. Cependant, ce mouvement n'est pas totalement chaotique puisque il existe une direction générale de la dynamique. C'est précisément un des buts de la modélisation de long terme que de la retrouver. Pour réaliser ce but il importe d'abord de caractériser la dynamique de chaque série puis d'en conduire les relations de long terme possibles.

5.2. Caractérisation de la dynamique des séries

La formalisation par un modèle de long terme doit être précédée d'une étude extrêmement précise qui doit permettre tout d'abord de caractériser l'ordre dynamique ou plutôt l'ordre d'intégration des séries. Une série est dite stationnaire [1] si la moyenne et la variance sont indépendantes du temps. Elle est intégrée d'ordre (1) si sa différence première est stationnaire et plus généralement intégrée d'ordre d si sa différence dième est également stationnaire, on note I(d). Une première façon d'appréhender la stationnarité des séries est d'examiner l'autocorrélation, on peut penser qu'il y a non stationnarité car les variables sont très dépendantes de leurs valeurs passées ce qui fait suspecter un faible oubli des chocs passés.

Mais la détermination de la non-stationnarité et celle de l'ordre d'intégration s'effectue par l'intermédiaire des tests de DICKEY-FULLER (1) (1981) encore connus sous l'appellation de tests de racine unitaire. Les modèles sous-jacents aux tests de racine unité sont :

$$X_t = cX_{t-1} + e_t$$
$$X_t = cX_{t-1} + a + e_t$$
$$X_t = cX_{t-1} + a + bt + e_t$$

expressions dans lesquelles et est un bruit blanc $(0, \sigma^2)$. Ces tests se fondent sur les statistiques associées aux estimateurs par les moindres carrés de ces trois relations et no-

[1] Nous donnons ici volontairement des définitions très simplifiées ; le lecteur qui voudrait approfondir pourra se reporter dans un premier temps à F. MAUREL (1989).

tamment de la valeur de c (racine unitaire). Les lois asymptotiques des estimations des coefficients permettent de tester l'hypothèse (Ho) :

$$X_t = X_{t-1} + e_t$$

La généralisation de ces tests présentés ici sous forme extrêmement simplifiée permet de les appliquer aux modèles plus complexes (cf. à ce sujet F. MAUREL (1989) et DICKEY et alii (1984).

Pour la mise en oeuvre de ces tests nous renvoyons à ces articles.

5.3. Les relations de long terme

Il peut être important de s'interroger d'emblée sur les relations que peuvent entretenir à long terme un ensemble de variables du modèle; la réduction à la forme long terme du modèle nous renseigne sur certaines propriétés variantielles asymptotiques, ce qui peut être intéressant pour tester dans la durée certaines mesures de politique économique à la condition toutefois que ces formes soient compatibles avec les évolutions historiques. De plus et cela constitue une deuxième raison pour s'intéresser aux formes asymptotiques, il peut être intéressant de les estimer avant même l'estimation des processus dynamiques, c'est ce que propose la méthode d'estimation en "deux étapes" (voir à ce sujet ENGLE et GRANGER (1987).

La recherche de cointégration a été réalisée par ces auteurs : on dit qu'un ensemble de variables x_t, y_t, z_t est cointégré si ces variables sont intégrées de même ordre (cf. supra) et s'il existe une combinaison linéaire, la relation de cointégration, qui est stationnaire. Cette propriété de stationnarité garantit donc que les variables ne peuvent, pendant longtemps et de façon importante, ne pas vérifier la relation de cointégration qui constitue donc la relation de long terme entre les variables.

Les tests de cointégration proposés par ENGLE et GRANGER (1987) sont en fait des tests de stationnarité des résidus $\hat{u}_t$ de l'estimation par les M.C.O. de la relation de cointégration supposée.

$$x_t + \mu y_t + z_t = u_t$$

A noter ici que les u_t étant estimés, ce sont plus les tables de DICKEY FULLER mais celles de ENGLE YOO (1987) qui sont utilisées.

En fait, cette notion de cointégration peut être présentée de façon plus générale ; il suffit pour cela qu'il existe une combinaison linéaire de plusieurs séries intégrées d'ordre d qui soit un processus intégré d'ordre d - b avec O < b < d.

Les tests de cointégration permettent également de justifier l'existence d'équations économétriques sous la forme de modèles à correction d'erreur : on sait en effet que l'écriture d'équations économétriques selon la méthodologie de HENDRY n'est en fait que la traduction d'une dynamique qui se décompose en une solution de long terme et un ajustement vers cette relation de long terme. ENGLE et GRANGER (1987) ont montré l'équivalence entre mécanisme à correction d'erreur et cointégration : la relation de cointégration fournit la relation de long terme, l'estimation du court terme se faisant sous la forme du modèle à correction d'erreur. Ces auteurs proposent de plus une méthode d'estimation en deux temps : 1) estimation des paramètres de la relation cible puis 2) estimation dont les variables sont par construction stationnarisées, ce qui évite la défectuosité de propriétés asymptotiques des estimations due à l'apparition de racines unité. Enfin terminons en mentionnant que ces tests ont été généralisés à d'autres processus.

5.4. Application aux modèles économétriques de long terme

La plupart des fonctions de comportement des modèles économétriques sont justiciables de tel traitement et de nombreuses applications de cette méthodologie ont déjà été réalisées. ENGLE et GRANGER (1987) ont appliqué les tests de cointégration sur les séries de consommation et de revenu ; c'est le cas de DROBNY et HALL, tout cela est bien compréhensible car c'est à propos de la fonction de consommation qu'a été pour la première fois par HENDRY et alii (1978) la spécification à correction d'erreurs.

La même procédure a été appliquée également par HALL (1986) pour dégager des relations de cointégration entre le salaire réel, la productivité, le chômage et le nombre moyen hebdomadaire d'heures oeuvrées (F. MAUREL - 1989) ; de même la dynamique de l'investissement (cf. par exemple GLACHANT - NIVET (1989)) a fait l'objet d'un tel traitement tout comme les fonctions d'exportation P. FEVE (1992).

Les résultats de ces études incitent à la modestie. Il apparaît en effet que nombre de relations que l'on croyait tout à fait justifiées sur le long terme ne sont guère susceptibles d'être cointégrées (cf. la question des fonctions de production). Mais cela ne doit pas nous rebuter : au contraire même, les remises en cause doivent nous faire porter l'attention sur des phénomènes souvent ignorés sous la forme où ils apparaissent et qui comptent pour le long terme : ils appellent donc d'autres travaux, peut-être l'incorporation des dépenses de R.D. sur l'évolution du progrès technique ? De toutes façons ces nouvelles techniques de traitement de séries chronologiques ne sont pas encore complètement rôdées et donc exemptes de tout défaut. Elles sont en outre en pleine évolution (cf. les nouvelles méthodes proposées par JOHANSEN (1991). Enfin, il faut insister sur la difficulté de mise en oeuvre de ces techniques en raison de la nécessité de disposer de séries chronologiques relativement longues (au moins cinquante observations) : pour notre sujet cela impose souvent un passage par les données trimestrielles, ce qui constitue une sorte de paradoxe pour un modèle de long terme.

Conclusion générale

Nous avons donc abordé aujourd'hui trois points de méthode qui me paraissent fondamentaux pour l'orientation des travaux de modélisation du long terme :

- Le long terme des modèles traditionnels est inadapté pour décrire des situations où ajustements d'offre et de demande ont convergé vers un équilibre de conjoncture neutre. Pour tester les effets à long terme de politique économique il est indispensable d'endogénéïser les structures de marché des biens : ainsi pourront être conjuguées les propriétés de deux approches différentes.

- En mettant l'accent sur les externalités dynamiques, sur les rendements croissants du facteur accumulable, les théories de la croissance endogène donnent une nouvelle dimension aux phénomènes de long terme : il n'y a pas de saturation de l'accumulation et leurs caractéristiques s'affranchissent de l'évolution du facteur non reproductible. Mais ces phénomènes sont très difficiles à quantifier et ils militent en faveur d'une utilisation spécifique des modèles de long terme à partir de variantes de structure fondées sur des hypothèses raisonnées (cf. le cas de la compétitivité hors prix). Cependant, la multiplicité des sources de croissance endogène exclut une approche exhaustive et d'ailleurs les séries statistiques disponibles l'excluent. La relation qui paraît le plus immédiatement susceptible de donner lieu à quantification est celle de l'influence de la R. D. sur la productivité : certes la fourchette des estimations est encore très large mais elle permet déjà de découvrir l'importance du phénomène sur la longue période.

- L'analyse des séries chronologiques longues remet en cause la vision traditionnelle des mouvements de long terme conçus comme des oscillations autour d'une tendance, avec des forces de rappel régulières, vision qui est conforme à la cinématique des modèles traditionnels : de nombreuses séries exhibent en effet des "persistances" qui rendent les chocs cumulatifs et préviennent donc un retour sur une éventuelle tendance. Mais ces mouvements ne sont pas totalement désordonnés et l'on peut constater sur des séries macro-économiques relatives aux pays de la C.E.E. que des directions apparaissent encadrer ces évolutions ; mieux, les séries entretiennent entre-elles sur le long terme des relations qui peuvent être révélées par les techniques de cointégration ; à l'inverse, celles-ci peuvent remettre en cause des relations dont on ne doutait guère de la validité : par exemple les fonctions de production ; ainsi ces techniques peuvent être à l'origine d'un formidable renouveau de la formalisation du long terme à condition de trouver des séries statistiques suffisamment longues.

Car le renouveau de la théorie économique ainsi que les progrès des méthodes d'analyse économétrique des séries longues sont deux conditions nécessaires pour permettre une avancée dans la formalisation du long terme ; mais la dernière condition, la disponibilité de séries longues, limite dans de nombreux domaines les progrès envisageables ; il reste à réaliser là un patient et méticuleux travail de collecte de données sur des phénomènes pour lesquels l'évaluation quantitative demeure incertaine ; les améliorations seront donc nécessairement progressives et limitées.

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Comment : *Vivaldo Pereira-Mendes*

I. The paper presented by Professor Zagame discusses issues of considerable interest and, in order to comment upon it, let me summarise what in my opinion are the main points:

- that Computable General Equilibrium (CGE) models are better suited for analysing long-term economic activity than macro-econometric models.
- That CAGE models, as they are apparently directed towards the long-term, are the (equilibrium) limit to neo-Keynesian models of short-term disequilibrium processes because in the long-term the significant monopolistic characteristics of markets disappear.

II. Let us begin with the first point. The main argument behind it is that macro-econometric models are considered to be strongly based on Keynesian theory and, therefore, orientated exclusively towards the analysis of the short-term economic policy via insufficiency of final demand. While 'insufficiency of final demand' can hardly be applied to the long-term structure of the economy, CGE models, it is argued by economists working in this field, are particularly well equipped to deal with such structure as the supply-side of the economy can be adequately treated in General Equilibrium models. The instantaneous determination of CGE models and the simultaneous incorporation of all relevant markets and dimensions of the economy (leading, for example, to prices and quantities being both endogenously and simultaneously determined) constitute relevant supremacies over macro-econometric models to study the impact of external shocks in the long term upon the whole structure of the economy: production, consumption, distribution, and efficiency.

Despite the alleged intellectual attractiveness and the appeal of working with General Equilibrium Analysis, I have serious reservations for using such models for explaining economic behaviour in a dynamic setting and therefore to use them for explaining processes which lie in the long-term structure of the economy. There seems to be no clear agreement as to what should be the delimitations of a CGE model, as there are several types of models some of which are constructed upon procedures which violate fundamental principles of general equilibrium theory. The term CGE models in this paper, in order to avoid methodological confusion, follows the criterion put forward by Lars Bergman:

"CGE modelling is an extension of theoretical general equilibrium analysis; the numerical model is a tool for adding quantative estimates to the insights already gained from qualative models. Consequently, according to this view, the numerical model *has to be entirely consistent with* an explicit theoretical model; incorporating ad-hoc assumptions may make model results more 'realistic' but also difficult or impossible to interpret" (1990:15; my emphasis).

This criterion is useful to avoid the inconsistencies of models which have been frequently assumed to be CGE models but should not be taken as such, for example those of Johanson (1960) and Hudson-Jorgenson (1975). In Johansen's model which covered 20 sectors of production we find that capital was homogeneous and fully mobile, but at the same time differently remunerated across the 20 sectors. As this procedure shows, the accommodation of reality in a theoretical structure which sacrifices reality itself leads to serious contradictions. The Hudson-Jorgenson model, concerned with the US energy policy with 9 sectors (5 energy and 4 non-energy), was linked to a macro-econometric model in that aggregate consumption and investment expenditure were taken as constraints on the solution of the multi-sectoral model; however there was no endogenous mechanism to guarantee that, for example, the aggregate demand for capital by the 9 sectors at the equilibrium level of prices did not exceed the supply of capital determined within the macro-econometric model.

Given the criterion above, there are three basic reasons which seriously undermine the power of CAGE models:

II.1. In a stage of micro-economic theory where market failures are taken as pervasive characteristics of any contemporary economy (externalities, public goods, increasing returns to scale, asymmetric information, barriers to mobility, and transaction costs), it seems highly questionable that a framework which so emphatically stipulates that unassisted market forces determine by themselves the position and structure of an economic system (prices, quantities, efficiency, equity, etc....) captures the substantive features of economic activity and economic growth. Some of these 'failures' may be introduced to the structure of CGE models (such as, for example, externalities) at a very high cost for economic reality; however, there are others which emerge as very different issues to this kind of modelling.

II.2. Given the particular theoretical background of CGE models (the theory of value on which they are based: prices determined by marginal productivities and benefits), there are two fundamental characteristics of any capitalist economy which seem difficult, if not impossible, to accommodate in these models:

- *Increasing returns to scale*: these lead to nonconvexities in the production set which puts an irresistible question to the very existence of an equilibrium in competitive markets - decreasing marginal costs lead to monopoly as the socially optimal market structure, and by the theorem of Euler we reach the odd (to walrasian thinking) conclusion that factors of production cannot be remunerated by their marginal productivities; this contradicts the theory of value upon which the whole construction is built.

- *Money and other financial assets*: a fundamental assumption of walrasian equilibrium, the Walrus's law, consists in that consumers have to be on their budget constraint lines (maximising utility subject to a budget constraint) which means that at any set of prices the total value of consumer expenditure equals consumer income. This implies that there are no financial surpluses and no deficits. Money and other financial variables play no active role in economic affairs; we could scrap them, and in no way would the level of production and other real variables be affected at all. This introduces a serious shortcoming to CGE models, as they cannot incorporate in their structure monetary and financial policy issues. If we live in a monetary and financial economy of production, where money and other financial variables are not only endogenously determined but also fundamental variables affecting behaviour, motives and decisions, then it seems hardly acceptable that a theoretical body which claims itself to be 'GENERAL' confines itself to the 'partial' analysis of the economic process of resource allocation of real variables, a procedure much more in accordance with the analysis of a cooperative or a centralised economy rather than to a capitalist one.

II.3. Timelessness. CGE models are in essence static; time can be admitted within the model only in an extremely limited way: it is usually confined to savings and the correspondent accumulation of capital through a sequence of static equilibria with: (a) Perfect foresight and myopic expectations (ie, expected future returns on assets equal current returns); (b) full intertemporal optimisation, as if economic agents could foresee the future exactly and optimise without any level of uncertainty through several economic periods.

The combination of the three factors above presented leads, in my opinion, to a major weakness in CGE models: The introduction of technological progress is difficult, perhaps not even desirable, to accommodate in such models. As Borges pointed out, "given that these models are designed to look at long term issues it is somewhat contradictory that their structure does not include a more careful treatment of technological change, the implications of which can be far reaching in the long run "(1986:21). The reasons why the introduction of technological change is difficult in CGE models are mainly four:

- The introduction of the production of scientific and technological knowledge would violate a main principle of walrasian theory: as there exist *relations of complementarity* among factors of production (ie, between technological knowledge and tangible capital) it becomes really difficult to isolate the marginal productivity of each factor.

- Technological knowledge is subject to severe *market failures*, of which increasing returns to scale is perhaps the most important one. In this case, even if it were possible to identify each factor's marginal productivity, the factors could not be remunerated according to there marginal productivities as the theory claims.

- It is by now widely recognised that the production of science and technology is highly *affected by monetary and financial factors*, and these forces have no room in CGE models as explanatory variables of economic behaviour.

- Finally, the production of scientific and technological knowledge by its very nature lead to a *process of disequilibrium* in both the short and the long term, which collides with the tone that markets are always in equilibrium if market forces are not subject to constraints imposed upon them by the Government and other institutions.

Turning now to the macro-econometric models. These seem to avoid much of the shortcomings we encounter in CGE models. Macro-econometric models are constructed around macro economic aggregates which are easily found in organised National Accounts. While data is an insurmountable problem for CGE models, it is not for macro-econometric models. The latter models accept disequilibrium situations (that is, for want of a better definition, when markets do not necessarily - and frequently they do not - clear at a determined level of prices) which affords much more flexibility to incorporate features of reality which otherwise could not be taken into account without falling into the trap of the inexistence of a feasible equilibrium or even the existence of multiple equilibria. Behavioural equations can be adapted to data, without necessarily violating basic theoretical principles, in contrast to what happens to CGE models where it is data that is 'fitted' into the models' structure. Yet , the introduction of money and the production of scientific and technological knowledge (and the related consequence of increasing returns to scale) in macro-econometric models is possible as the equilibrium conditions of these models are much less restrictive than those within the walrasian tradition. Finally, macro-econometric models can also incorporate the dimensions of the supply-side as the input-output models show very clearly: we can simulate policies associated with changes in the structure of the final demand, but we can also simulate policies which affect the block of the intermediate inputs and so the supply-side of the economy.

III. Let us discuss now, briefly, the second main point of Professor Zagame's paper. As far as this point is concerned, it seems highly questionable that monopolistic characteristics of markets disappear in the long term. The problem is not only related to the phenomenal amount of information required to attain and sustain such equilibrium, but also and essentially to the continuous production of (asymmetric) knowledge which emerges as the outcome of scientific and technological activities. These activities have the following characteristics:

- They represent a continuous, progressive, and never ending race in the sense that "what you do today depends upon what you want to be doing tomorrow" and vice-versa. It seems very difficult to isolate short from long term phenomena.
- They constitute a cumulative process, which justifies the sustainability of monopolistic structures in any term structure of the economy.
- The costs of transferring knowledge are not negligible, which also helps to maintain prime-movers advantages and monopolistic, which also helps to maintain prime-movers advantages and monopolistic characteristics in markets.

The combination of these three factors presents serious questions to the assertion that in the long term, in contrast to the short term, monopolistic characteristics ae absent in markets.

Finally, in order to endogenise market structure - a condition proposed by Professor Zagame to establish a long term equilibrium situation - of an economic system (or sector) highly restrictive assumptions are required (symmetry of firms, myopic behaviour of firms, given market demand, etc...) , which is much more in accordance with a world of stagnation and inertia that with a world of struggle and effort to get ahead in a truly competitive and selective economic process.

The equilibrium in the long term is a fiction, and a model which bases its main conclusions upon such a fiction does not, I am afraid, incorporate the basic characteristics of the real world in its basic structure. It can satisfy the needs of our intellectual fantasies, but not the needs of our endeavours as economists searching for knowledge to act upon and improve the world in which we live.

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Part Three

Some Prospects about Quantitative Evaluation Methods

Chapter 12 - Designing Efficient R & D policies in a Competitive Environment : What About the Strategic Issues ?

Henri Capron and Olivier Debande

1. Introduction

Since Arrow's major contribution emphasizing the incomplete appropriability of the output of R & D activity, it has generally been accepted that public funding in this area should correct market failure. However, economic theory is presently unable to give normative guidance for public policy in the field of science and technology. The fuzzy and uncertain nature of R & D policy makes assessing the impacts of the instruments used a major analytical issue.

At the roots of public funding, there are strategic issues which motivate government action. So far, game-theoretic models and the probabilistic approach have increasingly been used to describe the process of technological competition. In the present state-of-the-art, what can we learn from such approaches in order to implement appropriate R & D policies ?

In addition to these conceptual approaches, the literature reports some more empirically-oriented studies which try to deal with strategic issues. Technological competition is strategic competition involving adjustments to improve the competitive position of a firm with regard to rivals. This is why public authorities have reinforced their science and technology policy and thoroughly integrated it as a structural competitiveness instrument of economic policy. With this in mind, what are the practical implications of the empirical strategic analyses and models for the design of R & D policies ?

This paper is divided into three parts : first, we present a survey of some important theoretical papers dealing with both technological rivalry between firms and public incentive policies promoting R & D investments; second, we discuss how some empirical studies deal with strategic issues in modelling technological race; third, we prospect the opportunities of modelling strategic issues in policy evaluation and impact assessment.

2. Technological Rivalry and Public Incentive Policies

2.1. Technological Lag and Public Policy

As technology has become a competitive weapon, technology policy is increasingly being viewed as a strategic activity. The role of governments in organizing, stimulating and funding R & D investment clearly is of the utmost importance in shaping a favorable environment and in channeling resources for technological innovation.

In economic theory, studying the strategic behaviour of the firm requires a microeconomic perspective. However, it is now evident that a firm cannot be regarded as a closed static system. It moves in dynamic interactive economic surroundings where the decisions taken by public authorities influence the allocation of resources.

Among the important strategic issues enterprises are faced with technological change is a crucial factor. We can distinguish between product and process innovations :

- product innovation is developing specialized (radical innovation) or improved (incremental innovation) products as part of establishing or protecting a competitive advantage based on product differentiation;
- process innovation is important to achieve cost or quality leadership within the product markets.

In order to establish a generic competitive advantage, a firm endeavours to develop capabilities that distinguish it from and cannot be copied by its competitors. It tries to implement a strategy that enables it to acquire uniqueness through differentiation and cost leadership.

Lunn (1986) has shown that the determinants of both product and process innovations are quite different and that the latter have a differentiated impact on the endogeneous variables of the firm (such as cash flow, capital intensity, advertising). Process innovation aims at reducing cost and, hence, is more directly related to concentration. Product innovation is related to product differentiation and advertising.

According to Weiss and Birnbaum (1989), a technological strategy is a functional strategy, i.e. "a set of means and errors chosen within a specific function within a business unit, which is a part of the overall strategy of a business unit". Especially in the technological field, strategies are long-term plans, created with a view to achieving general objectives, such as increasing the market share in high-technology industry or becoming the leader on the international market for specific products. However, the potential objectives and the behaviour differ with the type of firm. Larger firms do not pursue the same objective as small or medium-sized firms. Hence, they have recourse to different instruments to achieve their objectives.

In the past few years, the European industry has been losing world market shares in several high-technology industries. A comparison of the evolution of the market share of the manufacturing industry for the United-States, Japan and Europe in three different sectors, high-intensity, medium-intensity and low-intensity in R & D, sheds light upon the ever crumbling European technological position.

Table 1. European technological position

	High-intensity			Medium-intensity			Low-intensity		
	1970	1980	1984	1970	1980	1984	1970	1980	1984
US	35.4	30.5	31.2	26.0	22.5	20.5	16.1	15.4	14.3
Japan	15.0	21.3	28.8	10.1	17.1	21.5	15.7	13.7	15.5
EEC	33.0	33.4	26.1	40.1	39.4	33.9	34.4	37.9	34.8

Source : OECD (1986).

The crucial problem is the weak ability of European firms to integrate R & D into their global strategies in terms of product and market opportunities. European countries have a substantial research potential but they have trouble implementing the results of their R & D investments rapidly and building an offensive strategy that generates large market shares in high technology fields. This is the result both of R & D being oriented towards weakly expanding areas of specialization like chemistry and car industry and of the lack of efficient long-term policies identifying strategic opportunities to break into new markets.

On the basis of the above-mentioned arguments, one way to improve the European capability is to promote cooperation between firms through different research programmes. The debate on the potential advantages or disadvantages of R & D cooperation is still open and it might therefore be useful to have a closer look at the positive social welfare effects resulting from cooperation. Jacquemin (1988) distinguishes between the private and public costs or/ and benefits of cooperative R & D.

On the private side, three potential benefits can be identified. First, cooperative agreements can be used instead of pure market transactions or complete integration into an economic entity. Pure market transactions may, indeed, be costly and inefficient because :

- an R & D project requires repeated and prolonged interaction between the different partners to exploit or develop the necessary complementarities;
- the market transactions in the domain of R & D hold two main risks, moral hazard and adverse selection. Moreover, it is very difficult to assess the price of an R & D product, which makes the market transactions more difficult. Even if we suppose an individual who agrees to transfer all the required information, he cannot communicate everything about learning process and professional skill.

A merger or a take-over is not optimal to achieve an R & D project either. Indeed, an increasing size generates diseconomies of scale due to rigidities in the corporate structure. The time-span required for the research capabilities, strategies and partners to fit into each other is too long.

The second advantage of R & D cooperation is that it accelerates the speed of invention and innovation with less risk. Through cooperation, the money required to undertake an R & D project can be gathered more rapidly. Moreover, the partners profit from the risk-spreading advantage (i.e. sharing the benefits and the costs of the project) and the risk-pooling advantage (i.e. realizing more risky projects).

Finally, by pooling complementary resources in R & D, they can benefit by :

- better conditions on borrowed financial capital;
- sharing the high fixed and sunk costs of technological development;
- the creation of synergetic effects by pooling R & D knowledge from different firms which may be located on different but connected technological trajectories.

The potential benefits of R & D cooperation can be important but the implementation of R & D agreements remains a difficult task, especially at the European level. There are plenty of problems which depend on how work progresses. In the starting stage, an important impediment is the partner selection. Because enterprises do not exactly know the level of technological knowledge of potential partners, the risk of strengthening a competitor is real. An other restraint is the definition of a well-balanced contribution, i.e. a trade-off between collaboration and independence which is more easily achieved in vertical agreements than in horizontal ones. A direct consequence of this problem is that a complicated organizational structure will be set up.

In the operational phase, managing this complicated corporate structure is not without trouble. In order to fully exploit the benefit of cooperative research, concerted manufacturing development and cooperation in the marketing policy have to be implemented.

Jacquemin's conclusion is that "limiting cooperation to pure R & D or to the so-called precompetitive level will then exercise a strong deterrent effect on the emergence of such cooperative arrangements".

The description given above must be fitted to take into account the characteristics of each product or process. The risk and necessity to cooperate at the competitive level will be different depending on the innovation rate of the industry considered. With regard to the public cooperative R & D, the problem that needs to be taken into account is whether there is market failure or not, i.e. absence or not of complete appropriability of returns. With or without substantial R & D spillovers, the potential benefit for the innovator firm will lead to underinvestment compared to the socially optimal amount of R & D and to pricing R & D results at a cost above the marginal cost of dissemination. Cooperative R & D can be viewed as a means of :

- internalizing the externalities created by significant R & D spillovers;
- sharing information among firms more efficiently.

Other side-effects are generated through partial appropriation :

- inefficiently low levels of utilization by other firms;
- wasteful duplication of research;
- opportunism and asymmetric information limiting the effectiveness of the market for R & D.

Katz and Ordover (1990) suggest different ways to correct the gap between private and public returns to R & D investment and the insufficient sharing of the fruits of R & D projects, i.e. direct or indirect subsidies to restore incentives, strengthening incentives to engage in ex post cooperation and encouraging greater ex ante cooperation. Table 2 gives an overview of the advantages and disavantages of these alternative policies.

To evaluate the impact of ex ante cooperation versus ex post cooperation, we must take into account the induced effect (of the firms forming an R & D coalition) on the consumer surplus as well as the non-member firms' responses to changes in the R & D levels.

Table 2. Pros and Cons of alternative policies

Advantages	Disadvantages
1) Direct or indirect subsidies to restore incentives	
• effective in markets where technological spillovers are high	• insufficient dissemination of R & D results not corrected • moral hazard, i.e. the government has no perfect information about the cost structure of the firm... • require to levy additional taxes
2) Strengthening incentives to engage in ex post cooperation	
• incentive to conduct R & D because they allow a firm to appropriate the benefits of innovation more fully • better diffusion due to the better information control exerted by the innovator	• limit the possible spillover and, hence, the efficient sharing of R & D • reduction in R & D investment incentives for non first-generation innovators • risk of cartel by using licensing contracts in a downstream product market
3) Encouraging greater ex ante cooperation	
• greater amount of R & D investment : internalizes the externalities created by technological spillovers while continuing the efficient sharing of information • greater efficiency of R & D investment : - more R & D projects are started due to the sharing of the costs - the effective amount of R & D is higher - intangible assets are shared, financial problems resolved and the unavailability of insurance against the failure of an R & D investment due to moral hazard is made up for - eliminates wasteful duplication	• intense rivalry between the different firms at the competitive stage

When evaluating the global positive or negative effect of cooperative decision-making on the R & D investment, two elements should be taken into account. The first is the competitive spillovers. Even with strong intellectual property rights protection, R & D investment by one firm may affect other firms through competition in innovative activities as well as on the market. Without technological spillovers, cooperative decision-making reduces (increases) R & D incentives if the products are substitutes (complements). The second element is the technological spillovers. The intensity of the spillovers is function of the quality of the protection effected by intellectual property rights. When innovators are product-market competitors and intellectual property rights are strong (weak) cooperative decision-making tends to decrease (increase) R & D investment incentives (Katz and Ordover (1990)).

Reaching an agreement at the ex ante level might lead to an increased monopolistic power on the product market which can compensate for the gains accruing to consumers rather than to the firms, generating a lower collective effect of R & D. Katz and Ordover (1990) emphasize the international dimension of the competition between firms. The technology transfers through a cooperative agreement may substantially strengthen the foreign partner and diminish the rents accruing to domestic firms which are not members of the coalition.

An ex post cooperation is possible by concluding a licensing agreement against a fixed fee. When strong intellectual property rights exist, ex ante cooperation leads to weaker R & D investment incentives. Given that the licenser has the bargaining power, each firm is motivated to conduct R & D in order to appropriate surplus that might otherwise accrue to its rival. The collective R & D investment incentive under ex ante cooperation is lower than the individual incentive under ex post cooperation. When the protection afforded by secrecy is strong, when spillovers are high, ex post cooperation can be limited. The fact that the ex post market power of firms can exceed their ex ante market power implies that ex ante cooperation can lead to less severe monopolistic pricing distortions in the pricing of R & D results.

Thus, a potential strategic public policy is to implement cooperation in sectors with some specific characteristics, among which :

- the need to increase the international competitiveness of domestic firms;
- the stimulation of industries with a high spillover;
- the inducement of precompetitive research which furthers long-run relationships between firms and by-passes the problem of benefit sharing;
- the implementation of programmes dealing with complementary products.

The technological positions of the different countries are not unalterable. The capacity to innovate changes over time. Since the Second World War, the US has been the reference level against which the technological positions of the industrial countries have been evaluated. Any technological policy must build upon a check-up of innovative capabilities, i.e. assessing the present situation and the possible modifications of the "country's position" on a potential performance scale [1].

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[1] See, for example, the study of Glismann and Horn (1988) looking at the invention performance of the main industrialized countries on the basis of patents granted in the United States. Among other observations, the authors point out that the heterogenous economic structures which characterize European countries materialize in distinct technological advance rates.

An important factor determining the innovative performance and the catching-up process is the increase in the level of investment devoted to the inventive activities. Another major factor is the institutional change. The development of the European Patent Office, for instance, allows the European firms to develop innovation in a favourable context in terms of appropriability conditions.

The working horizon and the cost constraints are also crucial factors to implement an R & D program. Especially to develop technology, long-term investments that need not meet very short-term performance criteria have to be made [1].

An efficient public policy can be attained by focussing R & D investment on key inter-industrial linkages. Indeed, the firms composing this linkage are located on the same technological trajectory whose running requires specific forms of research of technological opportunities (contribution of basic sciences), of human capabilities (human capital) and of organizational and institutional structures. On this basis, technologies develop along relatively ordered trajectories shaped by specific technical properties, research rules, technical imperatives and cumulative expertise embodied in each technological paradigm [Dosi (1988)].

By investing in key inter-industrial linkages, a country will benefit from spillover effects spreading through all the firms belonging to the same technological paradigm. By playing on significant nodes, it will be able to accelerate the innovation process of the home firms and the learning process which is a function of the degree of externalities, of technological accumulation within the firms and of the level of R & D investment. So, it will induce a creative process of technological advance.

2.2. Models of R & D Strategy

Game-theoretic models are more and more used to describe the competitive process. However, a restriction to the use of this type of model is the great variability of results with respect to assumptions. Indeed, depending on the assumptions of the model, the conclusions can substantially differ. Reinganum (1984) showed how sensitive of the

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1 Mansfield (1988) showed that innovation time and innovation cost are central to success. Japanese firms tend to develop and commercially introduce new products and processes more quickly and cheaply than American firms. As a consequence, there has been a technological depreciation of American products. Here, it is worth noting that the perception of American and Japanese products has been completely inverted in forty years' time. This example illustrates how important a technology policy is to preserve and improve competitiveness.

result is to the selected assumptions by studying the model of Loury (1979) and Lee and Wilde (1980). These models use a process of stochastic invention in which the probability of success by firm i at the given time t is an exponential function. They only differ in the specification of costs, i.e. Loury uses lump-sum R & D expenditure (fixed cost) whereas Lee and Wilde use a flow cost of R & D expenditure. On the basis of these alternative hypotheses, they obtain the opposite results summarized in table 3. So, the predictive power of a game theoretic model is strongly limited by the assumption at the basis of the model.

Table 3. Compared results of two game-theoretic models

Loury (1979)	Lee and Wilde (1980)
1. The amount invested by an individual firm decreases with the number of firms engaged in R & D; however, aggregate industry investment increases with the number of firms.	1. The rate of investment by an individual firm increases with the number of firms engaging in R & D; a fortiori, the aggregate industry investment rate increases with the number of firms.
2. In a Nash equilibrium with unrestricted entry, there will be excess capacity in the R & D technology.	2. In a Nash equilibrium with unrestricted entry, there will be no excess capacity in the R & D technology.
3. At equilibrium, an increase in aggregate rival investment results in a decrease in investment by a single firm.	3. At equilibrium, an increase in aggregate rival investment rate results in an increase in the rate of investment by a single firm.

We will now have a quick look at several models that can be regarded as significant benchmarks of this theoretical research field.

- *Spencer and Brander (1983) model.* They present a theory of government intervention trying to explain the industrial strategy policies in the context of an imperfectly competitive world where the R & D rivalry between firms is important. The reason for the government intervention is to obtain a large domestic share of internationally profitable industries. The modelization of firm behaviour corresponds to a 2-stage game played by two competing firms located in different countries. In a first stage, they choose the R & D level and in a second stage, they determine the output level corresponding to a Nash equilibrium when the R & D levels are those ones obtained in the preceding stage.

They assume that outputs are close substitutes and that any increase of one of the outputs negatively affects the marginal revenue of the other. The effect of the R & D investment is to reduce costs at a decreasing rate. The Nash equilibrium level of the firm increases as its own R & D increases and decreases as the rival firm's R & D increases. In the first stage of the game, it appears that an increase in the other firm's R & D normally reduces the effect of one's own R & D on one's own profit. Moreover, on the cost side, the result of the overall cost minimization rule is an R & D overinvestment. In a further stage of the analysis, the government is introduced and assumed to set a subsidy rate on R & D expenditure in a period before the firms spend on R & D in the case of an international trade approach. To maximize the net rent accruing to the domestic country, the government can implement different industrial strategies.

First, the authors consider a subsidy per unit of R & D, affecting the levels of R & D committed by firms but not the resolution of the output game. A domestic R & D subsidy increases the domestic R & D and, depending on the reaction function of the foreign firm, will increase or decrease the foreign R & D [1]. The domestic benefit with a subsidy policy will be an increase of profit from export. However, the justification for a public subsidy is that by precommitting itself with a subsidy policy, the government will alter the perceived cost structure and will change the set of actions compatible with the 2-stage Nash equilibrium. This optimal positive R & D subsidy maximizes domestic rent earned from exports and gives rise to a situation similar to the Stackelberg-leader follower behaviour without subsidies. In a non-cooperative scheme where both countries subsidize R & D, the joint optimal policy is to tax R & D so as to just offset the negative effect of one's own R & D on the other firm's profit. If the two firms are similar, both countries are better off if they do not subsidize.

Second, they analyze the alternative cases of only export subsidies and both R & D and export subsidies. In the first case, they suppose that a subsidy per unit of exports is given after R & D has taken place. Given fixed levels of R & D by reducing marginal cost the subsidy will serve to increase the domestic firm's share of the export market. If R & D and export are simultaneously subsidized, but with export subsidies being announced before R & D is in place, the optimal export subsidy will be positive and the optimal R & D subsidy will be negative.

- *Dixit (1988) model.* He develops a model of R & D with heterogeneous firms and examines the net effect coming from two different kinds of externalities :

- positive externalities, i.e. non-innovating firms profit from the R & D process leading the innovator to reduce the amount of investment in R & D below the socially efficient level;

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[1] Depending on the slope of the reaction function, i.e. if reaction functions are downward sloping, the R & D undertaken by the foreign firm will be reduced.

- negative externalities, i.e. competition for the innovation leading to a socially excessive amount of R & D investment.

The necessity to implement a public policy to correct the market equilibrium is introduced in this model. By calculating the Pigovian corrective policy, he etablishes two features :

- the optimal policy is to alter the appropriable benefit of the winning firm by means of an award if the market is providing insufficient R & D effort or a tax if the market is providing excessive R & D effort. The direction depends on the balance between the two effects;
- the larger the firm or country, the more it will internalize negative externalities.

On the basis of this model, Stoneman (1991) has analyzed the impact of a levy scheme on R & D spendings. The general result of this extension is that the levy scheme can yield increases in the R & D expenditure of the firm and the industry, and an increase in the rate of technological change. In addition, he demonstrates that the levy rate will be below 1 and will be all the higher as the common pool effect is smaller and the spillovers larger.

- *Beath, Katsoulacos and Ulph (1988-1989) models.* In a first paper (Beath, Katsoulacos and Ulph (1988)), they studied the impact of the "easiness" of imitation in determining whether or not R & D expenditures will be larger or less when firms cooperate in a research joint venture (RJV) than under competition. They observe that :

- if imitation is easy, R & D expenditures will be less under competition than under co-operation because there is an incentive to let the rival innovate;
- if imitation is difficult, each firm will be primarily concerned by not losing the patent race because the increase in profits is substantial. In the competitive case, there will be an excessive competition leading to a higher level of R & D expenditures. Two forces determine the relative attractiveness of an RJV as compared to competition :
  a) a coordination effect : by cooperating and pooling their efforts, firms could get a higher hazard rate;
  b) a market competition effect : under an RJV, all firms will profit from the innovation which implies a more intense product market competition after innovating than under R & D rivalry.

From their theoretical analysis, they conclude that :

- in the case of easy imitation, an RJV is preferable because there is no market competition effect;

(19)

- in the case of difficult imitation, the market competition effect is potentially important, depending on the characteristics of the industry and of the innovation.

In a second paper, they deal with a technological race and the influence of a public policy on the firm's behaviour. They define two different forces driving the firm's R & D effort :

- the profit incentive which influences the amount of investment through the trade-off between the cost of investment and the generated increase in profits;
- the competitive threat which influences the level of R & D expenditure through the profit made if the rival innovates first or fails to do so.

The optimal solution is linked to the magnitude of these two forces. A major determinant of this magnitude is how easy it is to imitate.

If imitation is impossible (long-lived and effective patents) and a firm has an important advance on its rival in terms of productivity or product quality, the fact that the rival firm will be the successful innovator will increase competition and will erode the profit of the leader firm. So, the incentive to invest in R & D in order to prevent the rival firm from winning exceeds the incentive to undertake R & D to achieve a greater profit flow. This results from the fact that a new innovation for the leader firm brings it few benefits. So, the competitive threat is higher than the profit incentive. It induces the leader firm to undertake more R & D than would be optimal given the profits it would make if it were sure to be the winner. Its expected profits fall.

If imitation is easy, the competitive threat will be lower than the profit incentive. Firms are prompted to engage less in R & D and will increase profits by free-riding. Further, they question the results of Brander and Spencer (1983), and conclude that if the impact of a subsidy depends on the imbalance between the competitive threat and the profit incentive :

- if the competitive threat is higher than the profit incentive : a subsidy to the home firm will result in an increase in the R & D realized by the rival firm. There will be overinvestment in a situation of existing over-capacity;
- if the competitive threat is lower than the profit incentive : a subsidy is not optimal due to the free-rider problem.

- *Grossman and Shapiro (1987) model.* They focus their attention on the dynamic aspects of R & D rivalry, especially on how efforts can vary over the course of a competition, as one firm initially gains an advantage over its rival, and then perhaps the other draws even again. This model uses the seminal work of Lee and Wilde (1980), presented above. In a stochastic structure, used to express the uncertainty of the innovation process, the winning firm of this technological race is the one that achieves the two phases of

R & D, i.e. respectively, research and development. Each firm is fully informed about the position of its rival in this technological race and thus, knows if it has taken a lead or if it has fallen behind. This formalization allows to take into account the strategy of each firm with respect to its own position in the R & D process and to the position of the rival firm.

The leader always devotes more resources to R & D than the follower does. On the one hand, the leader increases his R & D efforts when his rival succeeds in attaining the development phase and, on the other hand, when there is a leader, his speed, i.e. his incentive to invest in R & D, exceeds that of the follower. When the race accelerates, the leader and the follower put in more efforts because the expected losses and gains are higher.

In the early stages of the game, the behaviour of the leader depends on two simultaneous opposite effects : a diminished rivalry effect due to upward-sloping reaction curves inducing less efforts and a pure progress effect causing the leader to increase its expenditure in R & D. The follower is also subject to these effects linked to the potential reward attached to catching up with the leader.

In addition to these first results, they look at the impact of various forms of cooperation while the technological competition is going on. These alternative forms of cooperation between leader and follower are most likely to increase the expected joint profits when competition without cooperative agreement is quite intensive.

2.3. Limits of Theoretical Models

Many authors have compared technological competition with a race. Indeed, with a view to capturing the largest share of the market (i.e. of the profits) in high technological products a firm or a country tries to be the first to make an industrial breakthrough. Besides, depending on the technological position of the other country or firm, the player will adjust its strategy (for instance if they are ahead or behind in the competition). This model could be adapted by substituting blocks for firms.

Suppose that a country tries to achieve a global research programme. The research programme is composed of different projects, dependent upon national firms. One can assume a profit-maximizing behaviour on the firm's part. There are two risk-neutral blocks : the country and the rest of the world. They compete for the introduction of an innovation, having a given (current) value.

To obtain this value, each block must complete the two stages of the research and development programme. The strategic variable is the flow of R & D investment. What characterizes a strategy is that, at every moment of the decision-making process for a block, the strategy precisely dictates what the block (or the payer) does. The race is made up of a sequence of actions, but blocks' moves only matter insofar as they contribute to an overall action plan, i.e. an R & D strategy.

Each block has to decide on the flow of R & D investment to be made at each moment. Such a formalization would differ from Beath, Katsoulacos and Ulph (1989) who assume that there is no learning by doing. It would be useful to extend the preceding models by making the assumption that the probability of a block achieving an innovation or discovering the new product or process in a given time interval, provided no one has initially discovered it, depends on the current flow of R & D expenditure undertaken by one block at the initial time and on the accumulated knowledge, i.e. a process of learning by doing. However, the introduction of this modified hazard rate makes the subsequent calculation very difficult and may justify the use of a more tractable form, the exponential curve.

An additional consideration is the potential implication of such a model. As we have seen and as is stressed in the literature about game theoretical models, the assumptions are important for the final recommendations to draw from the model. On the one hand, we are not convinced that these other assumptions will radically modify the present models advocated in the literature. On the other hand, some authors stress the limitation of results which do not take into account the learning effects resulting from R & D investment.

In the economic literature, as we have seen above, a great number of game theoretical models have been developed (Reinganum (1989)) that give theoretical results. These results give us a flavour of the existing relationships but require empirical tests. Given this field is still in an early stage of development, empirical studies are scarce. One difficulty, stressed by Cohen and Levin (1989), in testing the implications of game-theoretical models of R & D rivalry is that they analyze behaviors in highly simplified models, omitting important aspects of industrial competition. Moreover, the utilization of game-theoretical tools implies that we must use unverifiable assumptions concerning the distribution of information, the identity of the decision variables and the sequence of moves. Reinganum (1984) also questions the availability of data.

If theoretical developments yield statements which should be investigated empirically, they are, as such, of little help. Basic hypotheses drastically condition the results of theoretical models and very often, a slight modification of hypotheses results in controversial conclusions. However, the strategic game-theoretic approach is still in an early development stage and future researches will certainly substantially improve our understanding of firm behavior in the technological race framework. As Reinganum (1984) pointed out in her survey article "although individual models have unambiguous implications, the array of existing models still generates considerable controversy ... In order to move in the direction of empirical testing, we must both extend these models in more realistic directions to accommodate existing data, and attempt to gather the specific data required to test directly such models of firm behavior".

These different studies using the game theoretical approach have derived some general results regarding an optimal subsidy policy. However, in general, they only look at the effect of a subsidy at the R & D investment level and its direct effect on the market share, the competitiveness of the home firm compared to rival firms. Yet, they remain silent about the real design of public R & D policies. Regarding this last point, Fölster (1988) has tried to make out an optimal structure for a subsidy. He suggests that the government "can save public funds by supporting only projects that are socially valuable and that firms would not conduct of own initiative". But identifying research projects that are socially worthwhile in order to subsidize only projects that firms would not conduct without subsidies, on the one hand, and, on the other hand, in order to prompt firms to behave efficiently, requires a great quantity of information.

The incentive subsidy requires no ex ante judgement by the public authorities because the exact size of the subsidy is determined after the project has been conducted. This ex post judgement allows to have a more accurate assessment of social and private values of research projects. The incentive subsidy contains different elements that directly affect the cost function of the firm :

- compensation for a loss due to the project,
- tax on the profit made on the project,
- reward of a fraction of the social value of the project.

Such a policy implies that a firm does not apply for subsidies on the basis of a project that has an expected negative social value. According to Fölster, the incentive subsidy policy is socially more efficient than the normal subsidy policy or conditional loans. The arguments that support the incentive subsidy as a superior alternative are summarized in table 4.

Table 4. Comparison of some intervention instruments

Normal subsidy	Conditional loan [1]	Incentive subsidy
Advantage : Potential tool to correct the gap between the private value and the social value of the innovation process.	Advantage : If government uses ex post information, it allows to have a more accurate estimate of the social value of a research project than in the case of a normal subsidy. Ex post information allows to expect an increase in the social value of a project.	Advantages : . By playing on the reward fraction, the government is able to induce some improvement in the social value of the project, i.e. reward social efficiency. . The risk to subsidize a project that a firm would realize, whether it is granted subsidies or not, is minimized. . This subsidy takes the risk of losses for the firm more into account than the conditional loan thanks to the more efficient ex post reevaluation.
Disadvantages : . Normal subsidy uses only ex ante information, which causes the decision to subsidize to be based on less accurate information than the other two forms. . No reward for increase in social value. . The risk to firms is not reduced as much as with the other two means.	Disadvantages : . One cannot tax the firm if the project turns out to be privately profitable. . No reward for improvement in social value. . The ex post reevaluation is constrained by the size of the initial subsidy.	

[1] Its main characteristic is that the firm is required to pay back its subsidy if the project returns a private profit.

Source : Based on Fölster (1988).

3. Imitation, Purchase or Inducement : The Search for an Optimal Strategy

3.1. Set of Available Strategies : Their Advantages and Disadvantages

When a potential strategic public policy is being designed, the endogenous characteristics of each industry must be taken into account to use the most appropriate instruments. Indeed, different innovative contexts will induce different effects of R & D policies.

The firm's behaviour will be different depending on whether it is part of a high-, stable- or low-technology industrial sector. In the case of high-technology industries like aerospace, chemicals, pharmaceuticals, computers or other electronic and electrical industries, firms' incentives to promote internal R & D can be higher if the environment is rich in opportunities for appropriation by the firm and spill-over into other projects. If it is not the case, the firm may prefer to imitate or purchase in order to minimise the risks. Moreover, high technology industries are unstable, which property decreases the possibility of creating lasting advantage in these sectors.

The alternative potential ways of acquiring innovations are : imitation, purchasing, internal R & D. A cost-benefit analysis of these innovation routes is presented in table 5. As can be seen, each way has its own advantages and disadvantages and the choice between these alternative roads must be the result of a technological audit of the investigated sector.

3.2. Empirical Analyses Modelling the Choice between Alternative R & D Strategies

- *Braga and Willmore (1991) analysis.* Analyzing the case of Brazil, they have estimated a logit model to measure the effect of selected variables on the likelihood that a firm :

- purchases imported technology,
- engages in research and development,
- controls the quality of its production.

They study the determinants of R & D at the firm level and examine different alternatives to increase the competitiveness of a firm. Their model can be regarded as a first attempt to measure different kinds of R & D strategy. The authors specify a logit model

Table 5. Cost-benefit analysis of each innovation channel

	Costs	Benefits
1) Purchase	. Purchase price of the technology. . The firm's specific requirements have to be met. An adaptative process must be implemented to integrate the new technology into the production process of the firm. Some additional training may be necessary to allow the manpower to assimilate the new process. . The organizational structure of the firm has to be modified to ensure an efficient internal transmission of the required information, ... The firm becomes dependent on external technology. The purchase of technologies must be incorporated into a long-term strategy aimed at acquiring one's own technology.	. Less technological uncertainty. In the innovation process, uncertainty arises because an abstract idea must be translated into a workable process design. By contrast, in the case of technology transfer, if the transfer process is efficiently managed, it can induce a technology mastery dynamic that could lead to innovation and diffusion.
2) Imitation	. Entails dependence and requires adaptation time. . Adaptation costs are higher than in the purchase case because the market only provides imperfect information (moral hazard, adverse selection) and there is little information about the characteristics of the imitated technology. The development of a technology involves learning by trial and error, which is more or less arduous depending on the ability and skill of the innovator firm. These elements are important to master a technology and not readily transferable (key personnel or laboratories). . Cost of the information related to the knowledge of all the available technology.	. Less technological uncertainty because the main characteristics of the most appropriate process design are known. . Need not be bought. . Improvement of the original product and production at a lower cost.
3) Internal R & D (or initiating technology)	. Direct cost of research higher than the sale price of a purchased technology. . Uncertainty of the research process. . Imperfect appropriability of the result.	. The results of the research process meet the firm's set of requirements and firms can sometimes appropriate some additional technical knowledge acquired during the innovation process. . R & D investment enhances the firm's ability to assimilate and exploit existing information.

with binary dependent variables to explain the existence or non-existence of a technological activity. The investigated activities are :

- the use of foreign sources for product design
- the use of foreign sources for production engineering
- the development of new products
- the expenditures on research and development
- the control of the quality of the plant's output.

Their results indicate that foreign technologies have an inducement effect on R & D, and, hence, show that the complementarity effect is more powerful than any effect of substitution between technological imports and technological effort. Yet, this conclusion is very specific to the Brazilian case-study, Brazil being still far away from the technological frontier. An other important variable is export, which has a significant positive effect on all the dependent variables.

- *Link and al. (1983) analysis.* He related the strategic behavior to "certain industry characteristics that describe the dominant stage of process development, the opportunities for innovation, and the degree of autonomy experienced by individual firms and to certain firm characteristics that reflect each firm's abilities and desires to deal with technological uncertainty".

The results show that since industry and firm characteristics play an important role in the decision to purchase or induce new process technologies, there is room for variation in the implemented public policies. In industries characterized by low technological intensity or high levels of product standardization, the optimal way to stimulate process innovation is to sustain the R & D efforts of the industry's suppliers. This segmentation of the R & D policies can increase the technological ability of each firm by forcing enterprises to adjust their technologies to their suppliers' ones.

- *Audretsch and Yamawaki (1988) model.* They have examined how the strategic aspect of Japanese R & D expenditures and industrial policies affected the balance of the US-Japanese trade during the late 1970's. By R & D expenditures, they mean expenditures on process innovations, product quality improvements, new products or new technologies and technology transfers. The latter variable is the total of the Japanese payments for purchased technology as well as the allocation of technology purchased from the United States, Europe and Japan. The industrial policy component is related to the role of the Ministry of International Trade and Industry (MITI). The action of the MITI takes different forms such as tax depreciation subsidy or legal cartelization status.

Their empirical results indicate that additional Japanese R & D expenditures improve the Japanese trade balance. Consequently, the hypothesis that the R & D behavior of the trading partner of the United States has no impact on the trade performance of the United States is rejected. Moreover, the hypothesis suggests that R & D expenditures in the two countries do not have identical impacts on the trade balance. Additional R & D expenditures have more impact in the Japanese case than in the American case. If we look at the different types of R & D expenditures, we note that certain elements are more efficient to promote the Japanese comparative advantage. They conclude that "Japanese R & D expenditures which have been oriented towards improving upon the quality or reducing the costs of existing products have been more effective than R & D allocated towards developing new products and technology".

Regarding the purchase of foreign technology, R & D coming from the United States has a significant effect in promoting the subsequent Japanese comparative advantage whereas purchases from Europe and domestic firms have no significant effect. This is consistent with the American leadership in the sixties and the seventies.

The different public policies elaborated by the MITI have a differentiated impact on the trade performance of Japanese firms. Highly subsidized depreciation industries tend to demonstrate a relatively favorable trade performance. It is not the case for industries benefiting from the legalized cartel status. However, the effectiveness of this public policy cannot be inferred from this. It is to be seen as an assistance process to industries with high technological potential.

3.3. Modelling Choices between Alternative Strategies

By subjecting the amount of subsidies granted to the R & D strategy adopted by a firm, i.e. by granting a certain amount of subsidies if, for instance, a firm imitates and a different amount if the firm purchases a licence, public authorities have a powerful tool to induce firms to improve their R & D's. This selective approach incorporates the specific technological trajectory of each industry by allowing firms to choose between several optional ways of improving technological efficiency : imitation, purchase and R & D initiation. Besides, they can also choose not to engage in R & D at all.

If the firm is rational, i.e. makes choices that maximize its expected benefits, the expected welfare that firms get from a specific choice can be measured by the income flow.

This income flow can be decomposed into different variables. On the one hand, we have variables that are functions of the selected option and, on the other hand, we have variables which are independent of the selected option. For the former, the main variables are expected profits, subsidies and/or tax credit from public authorities. For the latter, the structural characteristics of the firm which are not affected by any alternative have to be considered. To model and assess the determinant of alternative choices whose impact on the firms can be assumed to be constant, it is preferable to resort to conditional logit rather than multinomial logit [1] [Hoffman and Duncan (1988)]. A mixed conditional logit is used because some explanatory variables are sectoral characteristics and the other variables are characteristics related to the selected alternatives i.e. varying from one option to another. The function associated to the firm i under the option j is, then, defined as the following latent variable :

$$V^e_{ij} \{P^e_{ij}, S_{ij}, T_{ij}, X_i\}$$ [2]

where P^e_{ij} : expected profits of firm i under the option j
S_{ij} : subsidies to firm i under the option j
T_{ij} : tax credit to firm i under the option j
X_i : structural characteristics vector associated to firm i.

In fact, V_{ij} stands for the value of alternative j to firm i. Such models are especially well suited for the analysis of situations in which the government policy affects the attractiveness of an alternative by changing some relevant characteristics. Obviously, to assess the effect of government policies such as a subsidy policy, when possible, the policy parameters have to be directly included in the choice structure.

Assuming that the indirect utility function is additive, we have :

$$V^e_{ij} = \beta\, P^e_{ij} + \gamma\, S_{ij} + \sigma\, T_{ij} + \theta_j^{'}\, X_i + \varepsilon_{ij}$$

where $\beta, \gamma, \sigma, \theta_j^{'}$: unknown parameters
ε_{ij} : residual that captures the effect of unmeasured variables and the imperfection in the optimization program.

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[1] By contrast, the multinomial logit model hypothesizes that the explanatory variables (individual characteristics) are constant across the alternatives. So, it measures the specific impact of these characteristics (across individuals) on each choice.

[2] Other variables can be used such as the level of R & D expenditures which differs across industries and alternatives. The variables selected here are only a potential representation which must be modified according to the amount of available information.

The mixed conditional logit is based on the assumption that the error terms in V_{ij}^e follow an extreme value distribution and are independent across alternatives. This independence assumption is crucial because any other assumption leads to substantial computational difficulties involving the computation of multivariate integrals.

With a set of n firms facing m options, we can define :

- $C_{ij} = 1$ if the i^{th} firm makes the j^{th} choice

  i.e. $V_{ij}^e = \max \{V_{i1}^e, \ldots, V_{im}^e\} \qquad j = 1, \ldots, m \qquad i = 1, \ldots, n$

- $C_{ij} = 0$ otherwise.

If we assume that ε_{ij} are independently and identically distributed with an extreme-value distribution, then the probability P_{ij} that the firm i chooses alternative j, in the mixed conditional logit, is :

$$
\begin{aligned}
P_{ij} &= \text{Prob}\,(C_{ij} = 1) \\
&= \text{Exp}\,(\beta\, P_{ij}^e + \gamma\, S_{ij} + \sigma\, T_{ij} + \theta_j' X_i) \,/ \\
&\quad \sum_{k=1}^{m} \text{Exp}\,(\beta\, P_{ik}^e + \gamma\, S_{ik} + \sigma\, T_{ik} + \theta_k' X_i)
\end{aligned}
$$

The estimation of the structural parameters of this equation through a maximum likelihood procedure allows to simulate the different policies and determine the consequence of policy changes on the rate of R & D effort of each alternative. The expected profits P_{ij}^e can be obtained by using questionnaires or sound estimates based on past profits.

Another possible application of this sort of model is to classify the firms in respect of their R & D expenditure. Once again, using subsidy as an explanatory variable, we can study the effect of modification in the subsidy level on the R & D expenditure of the firm. However, to measure the impact of the subsidy on the technological efficiency, it is preferable to use a measure of output such as the number of patents issued.

3.4. The Setting-up of a Complete R & D Strategy

The Japanese economy is becoming a classic case. It represents the evolution of a country which has been able to set up a fully integrated adaptative industrial policy. The technological strategy is an incremental approach to innovation in which successive small improvements are made. Japanese firms prefer this strategy rather than radical innovation, which involves more risk and requires more time. However, a new trend is appearing in the behaviour of the Japanese firms. As they are leaders in some industries, in order to preserve their leading position in high-technology fields they must allocate funds to basic research. So, they have developed informal links with Western universities and independent research laboratories : they are actually shifting from a medium-term perspective to a long-term one.

The process followed by Japan is part of a global multi-level strategy. Indeed, the technological integration process of a country is a three-stage process aiming at :

- the knowledge mastership,
- the technical mastership,
- the technology mastership.

These notions [1] can be seen within a larger framework : the notion of total capital. It includes physical investment in new structure and equipment, human investment made through formal education and on-the-job training, and knowledge investment aimed at improving or reinforcing technological competitiveness. Initially, the country must invest in infrastructure (physical investment) and in human capital to raise its technological ability up to the level of that of the most industrialized country. The return on capital invested is realized by providing the trade partner with products that are improvements on the initial ones. That way, a development process is engaged that involves the mastery of the techniques and allows the country to incorporate the technology of the technologically most competitive countries. The next stage is participating actively in the production process of technologies, which requires a policy or strategy of intensive investment in technology and human capital. At this stage, through investments in R & D and basic research, the country should be able to produce radical innovations.

Capron (1988) has diagrammatically represented the interdependence between the achievement requirements of technical progress and their strategic incidences.

The economic development policy of a country must be planned long beforehand to simultaneously strenghten the assimilation, adaptation and advance capabilities. The applied policy must take the technological trajectory of the country and the socio-institutional environment into account. For instance, Japan has now reached the stage of technological advance at which it is obliged to invest more in basic and applied research to create new products and processes.

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[1] Capron (1989).

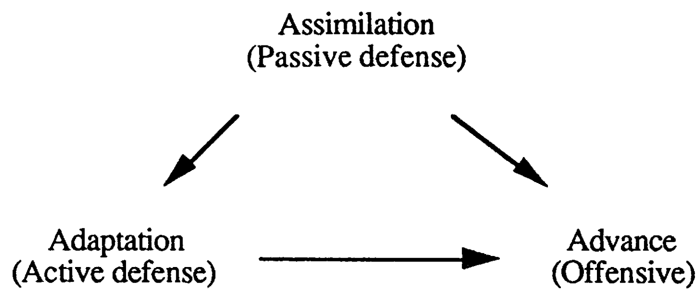

Figure 1. Interdependencies between the conditions of realization of technical change and their strategical incidences

To each component of figure 1 there corresponds a specific policy. A first one is to further assimilation, but this is a minimalist policy of passive defense inducing only few positive effects on the competitive ability of a country. The most efficient policy is to support technological advance, i.e. work out a complete R & D policy which, of course, requires substantial financial, educational and institutional means. The implementation of a technological strategy, as part of a global industrial strategy, will generate and create cumulative and absolute trade advantages. Of course, such a strategy will take into account the positions of products and processes on the life-cycle. All these elements are summarized in figure 2.

To each of the different objectives, one of the different alternatives presented above can be associated. This three-stage strategy can be illustrated by referring to the trajectory followed by the Japanese firms. At present, the Japanese firms have completed a technological integration process. After having recourse to a sustained imitation policy, they are now able to make radical innovations. Of course, this picture could be extended to other countries.

3.5. The European Centres of Excellence as a Way to Induce a Dynamic R & D Strategy

Through setting-up R & D programmes a country can avail itself of strategies that go beyond the subsidy policy. So, a potential alternative policy is to develop European centres of excellence in research and innovation.

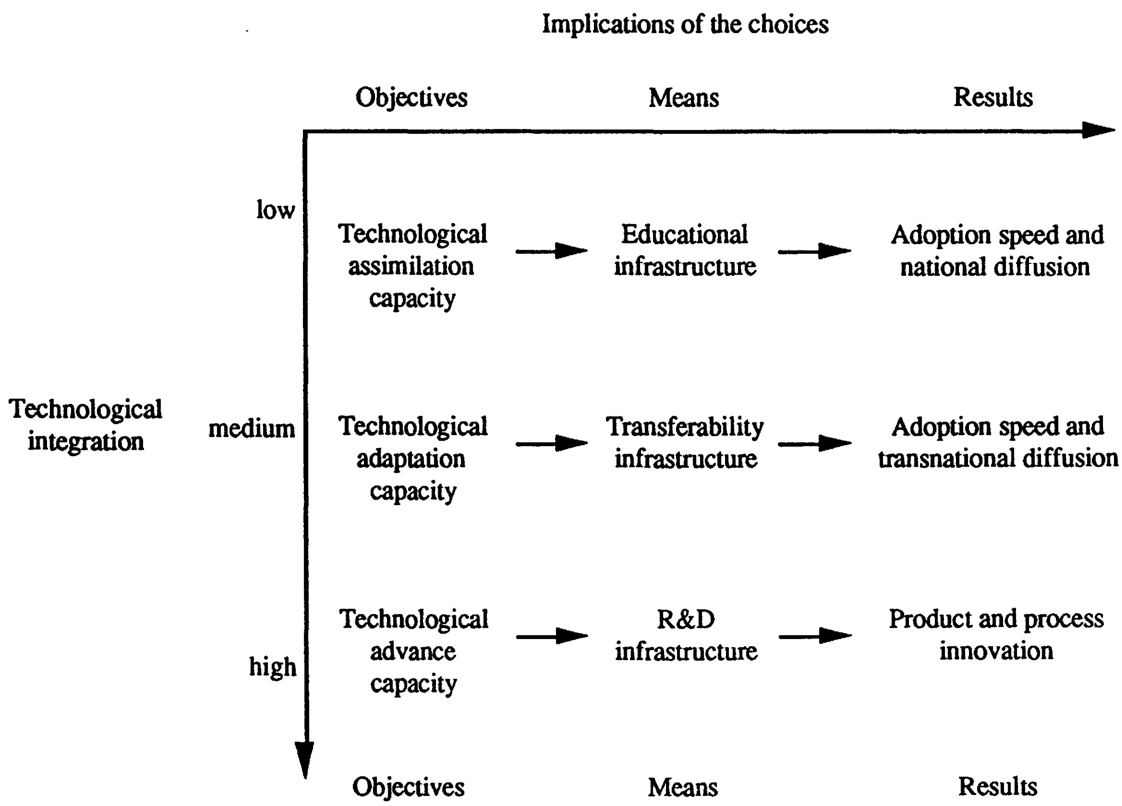

Figure 2. Components of the technological integration process

The creation of a centre of excellence is a cumulative process if decisions taken previously increase the likelihood of locating a research facility in a European centre. Hence, repeated investments in these centres strengthen their international positions and their R & D ability, so creating agglomeration effects. These agglomeration effects may result from the user-producer interaction. Indeed, users' sophisticated requirements support the research facilities of the technology producers and the ensuing feedback and joint testing procedure leads to incremental technological improvement. In addition, such centres of excellence improve the diffusion process and make a wider range of technological products available to the users. However, a major potential cause of failure is that these centres are 'locked in' to a path of technological development.

At the European level, the creation of centers of excellence, which go beyond the national boundaries, allows to develop and reorganize a network of research facilities. It is important to strengthen the interaction between the different centers and to organize the participation of the European countries in function of their technological ability in a specific field and not in function of political considerations of balanced representation.

Cantwell (1991) tested the significance of such a proposition on the basis of the previous argument that research tends to agglomerate geographically. He showed that the geographical concentration of technological activity has risen outside the U.S. and that Japan has increased its share. His analysis emphasizes the fact that many sectors show an agglomerative consolidation of their comparative (dis)advantages [1].

This analysis stresses that technological concentration exists and that the Japanese position is stronger, both in absolute and in comparative terms. The U.S. position is weaker and the European situation is relatively contrasted. One observes, however, a positive correlation between the technological position of a country and its industrial competitiveness. The poor performance of the U.K. points to the weak performance in its industrial sector whereas Germany affirms its dominant position both in absolute and in comparative advantage terms. The existence of a European network of centres of excellence requires the availability of research professionals, i.e. a highly skilled human capital. Once again, a manpower that is highly skilled in the scientific and engineering field is a crucial factor to increase competitiveness. Besides, it is important that a favorable institutional environment, both on the labour market and on the capital market, should be created. In this respect, the completion of the European internal market offers the possibility to generate an environment conducive to R & D investment.

4. Technological Competition and R & D Policy in Oligopoly

4.1. Optimal R & D Policy in Oligopoly

R & D is a non-price competitive element and requires to be associated with all the other elements of the firm's strategy. The issue of a firm's optimal levels for all decision instruments has received considerable attention in the marketing literature. These extensions of the profit maximisation rule have tried to take into account other decision-making process variables than just the price. All these normative models have been developed along the lines defined by Dorfman and Steiner (1954)'s theorem for monopolistic competition.

Following the original contribution of Dorfman and Steiner, Hay and Morris (1991) have recently presented a basic model of innovation. Besides the firm's own decision

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[1] He also assessed the contribution of foreign-owned research facilities to technological agglomeration and concluded that the location of foreign-owned research has, in general, contributed to technical agglomeration but not in a significant way.

variables, they also include the rival's decision variables as determinant of the firm's demand.

The demand curve for firm i is a function of its own price p_i and its own expenditure on R & D, x_i, and of p_j and x_j vectors of prices and R & D expenditures of other firms. The expenditure x_i shifts the demand curve, $\partial q_i / \partial x_i > 0$, but at a diminishing rate.

The first order conditions can be obtained from the profit maximization process π_i :

$$\pi_i = p_i \, q_i \, (p_i, x_i, p_j, x_j) - c \, (q_i) - x_i$$

where c (q_i) is the production cost.

By deriving, we obtain :

$$\frac{\partial \pi_i}{\partial p_i} = p_i \cdot \frac{\partial q_i}{\partial p_i} + q_i - \frac{\partial c}{\partial q_i} \cdot \frac{\partial q_i}{\partial p_i} = 0$$

$$\frac{\partial \pi_i}{\partial x_i} = p_i \left(\frac{\partial q_i}{\partial x_i} + \frac{\partial q_i}{\partial x_j} \cdot \frac{\partial x_j}{\partial x_i} \right) - \frac{\partial c}{\partial q_i} \left(\frac{\partial q_i}{\partial x_i} + \frac{\partial q_j}{\partial x_j} \cdot \frac{\partial x_j}{\partial x_i} \right) - 1 = 0$$

Then $\frac{p_i \cdot - \frac{\partial c}{\partial q_i}}{p_i} = \frac{1}{|\varepsilon_i|}$ with ε_i : price elasticity of demand

and $$\frac{x_i}{p_i \, q_i} = \frac{p_i \cdot - \frac{\partial c}{\partial q_i}}{p_i} \left(\frac{\partial q_i}{\partial x_i} \cdot \frac{x_i}{q_i} + \frac{\partial q_i}{\partial x_j} \cdot \frac{x_j}{q_i} \cdot \frac{\partial x_j}{\partial x_i} \right)$$

$$= \frac{1}{|\varepsilon_i|} \, (\eta_i + \rho \, \eta_j)$$

where η_i : elasticity of response of sales to one's own R & D expenditure

η_j : elasticity of response of sales to other firms' R & D expenditure

ρ : conjectural variation, i.e. degree to which the firm expects an increase in its own R & D expenditure to be matched by rivals.

According to the market situation ρ can take different forms. ρ is equal to zero in the Cournot case, i.e. there is no reaction from rivals.

In conditions that are optimal with respect to the level of R & D expenditures, we note the impact of the price elasticity of demand regarding R & D expenditures. The higher the elasticity with respect to the price, the lower the part of R & D expenditures in the total output of the i firm. A strong price inelasticity stimulates R & D investment by the firm due to the fact that non-price instruments are more efficient to obtain important market shares.

However, this model is too simple to express a real situation. Considering zero conjectural variations is irrealistic. But the definition of rational conjectural variations is not easy due to, for instance, the great part of uncertainty associated with R & D investment. Moreover, each different non-zero conjectural variation implies a different type of reaction function and, therefore, another equilibrium.

Lambin and al. (1975) have derived an optimal marketing behavior model that is more consistent for the analysis of oligopolistic competition. We can extend this model to incorporate R & D and obtain an expression in terms of market share.

In the process of maximization, a firm can use a set of decision variables, among which the level of R & D expenditure, the purpose being to determine the conditions in which each decision variable is likely to yield maximum profit.

We can derive the optimality conditions, considering first the company profit function for the case of monopolistic competition :

$$\pi = q \cdot [p - c\,(q, o)] - x$$

where p : price
o : organizational cost
x : R & D expenditure.

Let us write that u' = (p, x, o), this variable representing the company decision variable vector.

Deriving π with respect to each decision variable included in the u' vector and setting these expressions equal to zero, we obtain :

$$\frac{\partial \pi}{\partial u} = \frac{\partial q}{\partial u}\,[p - c\,(q, o)] + q\,\left(\frac{\partial p}{\partial u} - \frac{\partial c}{\partial u} - \frac{\partial c}{\partial q} \cdot \frac{\partial q}{\partial u}\right) - \frac{\partial x}{\partial u} = 0$$

After transformation, one obtains :

$$- \eta_{q,p} = \eta_{q,x} \cdot (\frac{q\,p}{x}) = \eta_{q,o} \cdot (\frac{p}{o\,(\frac{\partial c_i}{\partial o})}) = \frac{1}{w*}$$

where $\eta_{q,m}$: elasticity of demand to the m decision variable

$w*$: percentage of gross margin [1].

which is similar to the Dorfman-Steiner rule.

At the optimum, marginal cost must be equal to marginal revenue for each decision variable and the marginal revenue product of R & D expenditure must be equal to the inverse of the percentage of gross margin :

$$p\,\frac{\partial q}{\partial x} = \frac{1}{w*}$$

Otherwise, from the preceding optimality conditions, one deduces that :

$$\frac{x}{q \cdot p} = - \frac{\eta_{q,x}}{\eta_{q,p}} = \frac{\eta_{q,x}}{|\varepsilon|}$$

We find a result similar to the one obtained by the first model where $\frac{x_i}{p_i \cdot q_i} = \frac{1}{|\varepsilon_i|}$ $(\eta_i + \rho\,\eta_j)$. In this case, we see that the ratio of R & D expenditures with respect to total output or sales is equal to the ratio of R & D elasticities with respect to price elasticities. $\eta_{q,x}$ corresponds to $(\eta_i + \rho\,\eta_j)$ when ρ, representing the conjectural variation, is equal to zero. Thus, we have a Nash-Cournot equilibrium.

The preceding relation shows that the higher the percentage of gross margin w* is, the lower the marginal product of R & D expenditure is and the higher the profitable level of R & D expenditure is since we expect diminishing returns on R & D expenditure. We know that $\frac{1}{w*} = |\varepsilon|$. Hence, the previous situation implies a low price elasticity, i.e. the possibility for the firm to charge high prices.

A competitive situation is characterized by strong interdependences between rival firms. In parallel with the concept of conjectural variations, one can express two different forms of interdependence. First, the performances of any firm depend on the level of its rivals' decision variables, in particular R & D expenditure. Second, if a firm modifies its R & D expenditure, other rival firms will react.

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[1] $w* = (p - MC) / p$ where MC = marginal cost.

To extend the model, let us decompose the $E_{q,u}$ vector of total sales elasticities into three components which are :

1) the industry sales or output effect;
2) the direct partial effect in the company market share due to a change in the company decision variables [1];
3) the indirect partial effect in the company market share due to modifications in rival firms' decision variables, i.e. brought about by a change in the competitive mix pressure of rival firms.

By definition :

$$m_i = \frac{q}{Q_T}$$

where m_i : market share of the company
q : company sales
Q_T : industry sales.

$$q = m_i \cdot Q_T$$
$$= m_i (u, U) \cdot Q_T (u, U, Z) = m_i (u, U (u)) \cdot Q_T (u, U (u), Z)$$

where u : company decision variable vector
U : competitors decision variable vector
Z : environmental variable vector.

We derive q with respect to the u decision vector :

$$\frac{\partial q}{\partial u} = m_i \frac{\partial Q_T}{\partial u} + m_i \frac{\partial Q_T}{\partial U} \cdot \frac{\partial U}{\partial u} + Q \cdot \frac{\partial m_i}{\partial u} + Q \cdot \frac{\partial m_i}{\partial U} \cdot \frac{\partial U}{\partial u}$$

where $\frac{\partial U}{\partial u} = [\frac{\partial U_1}{\partial u}, \ldots, \frac{\partial U_n}{\partial u}]$.

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1 The company market share can be represented as :

$$m_i = \frac{k_i \, p_i^{e_1} \, x_i^{e_2} \, o_i^{e_3}}{\sum_i k_i \, p_i^{e_1} \, x_i^{e_2} \, o_i^{e_3}}$$

where the e_j are the market share sensitivities with respect to each decision variable and for each firm the numerator of this relationship can be defined as the competitive mix pressure of the firm. The elasticity of the market share to each variable is defined as :

$$\varepsilon_j = e_j (1 - m_i)$$

Then : $E_{q,u} = E_{Q,u} + E_{m_i,u} + R\ [E_{Q,U} + E_{m_i,U}]$

where E refers to elasticities and R to multiple competitive reaction (i.e. multiple conjectural variations).

According to Lambin and al. (1975), this result can be summarized regarding the alternative types of behavior and the nature of the industry demand :

Non expansible industry demand ($E_Q = 0$)	Expansible industry demand ($E_Q \neq 0$)
No reaction ($R = 0$)	
$E_{q,u} = E_{m_i,u}$	$E_{q,u} = E_{m_i,u} + E_{Q,u}$
Simple competitive reaction ($R = R_d$)	
$E_{q,u} = E_{m_i,u} + R_d\ E_{m_i,U}$	$E_{q,u} = E_{m_i,u} + E_{Q,u} + R_d\ [E_{m_i,U} + E_{Q,U}]$
with R_d, diagonal matrix from R	
Multiple competitive reaction ($R \neq 0$)	
$E_{q,u} = E_{m_i,u} + R\ E_{m_i,U}$	$E_{q,u} = E_{m_i,u} + E_{Q,u} + R\ [E_{m_i,U} + E_{Q,U}]$

Taking into account the intrinsic characteristics of each industry and using a multiple competitive reaction behavior, one can measure the R & D-output elasticity for the different cases.

First, we consider the case of an industry in its maturity phase. We know that in this case, the total demand is stable and has no influence on the R & D-output elasticity. This elasticity is only made up of market-share components. One can write this decomposition in the following form, capital letter subscripts referring to competitors :

$$\eta_{q,x} = \eta_{m,x} + \rho_{P,x} \cdot \eta_{m,P} + \rho_{X,x} \cdot \eta_{m,X} + \rho_{O,x} \cdot \eta_{m,O} \qquad (1)$$

This expression represents a general multiple competitive reaction in a stable industry demand. ρ expresses the different reactions of rival firms to an alteration in the level of R & D expenditure. Using this approach, one can formulate the reaction of American and Japanese firms to a modification in the R & D expenditure level of European firms. Moreover, all strategic variables could be taken into account so that one should be able to describe different kinds of strategic behaviour.

Second, we look at an industry using new and expanding technologies (high-technology industry). This kind of industry is characterized by an expansible industry demand. In this case, R & D-output elasticity must take into account the reaction of the total demand to a modification of the R & D expenditure level and the impact of the induced multiple competitive reaction of rival firms on the total demand. So, we have the following decomposition of the R & D-output elasticity :

$$\eta_{q,x} = \eta_{QT,x} + \eta_{m,x} + \rho_{P,x} (\eta_{QT,P} + \eta_{m,P}) + \rho_{X,x} (\eta_{QT,X} + \eta_{m,X}) + \rho_{O,x} (\eta_{QT,O} + \eta_{m,O}) \quad (2)$$

In comparison with the first equation, we note that R & D-output elasticity includes both market share elements and total demand elements. The former equation is a particular case of the latter equation when the total demand is stable, which implies that $\eta_{QT,X} = \eta_{QT,P} = \eta_{QT,X} = \eta_{QT,O} = 0$.

The previous analysis allows to analyze the effect of public policies. By stimulating the R & D decision variable, the public R & D policy will have a direct effect on the behaviour of the firm and on the competitiveness [1]. The last two equations (1) and (2), defined in terms of R & D-output elasticity, allow to take into account the reaction of the demand to an increase or decrease in the R & D subsidy and the impact of the induced multiple competitive reactions of rival firms on the demand. Moreover, the differentiated effects linked to the type of industry are integrated into the model.

These relationships based on a concept of competitive mix show that a competitor may react to a change in R & D expenditure not just by changing his own R & D expenditure (simple competitive reaction) but also by changing other non-price instruments or the price itself (multiple competitive reaction). This approach allows to express competitive interaction in terms of market share and to model the existing competition between European, Japanese and American firms.

4.2. Modelization of the Technological Competition in a Dynamic Market Share Approach

This approach using market share models can alternatively be used to describe the technological competition between the American, European and Japanese blocks.

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[1] In such a case, for the sake of convenience, one can define x_i as being the sum of both private and public R & D. However, more complex analytical hypotheses should be investigated by taking these two variables into account separately, public R & D not being a company decision variable.

Indeed, if one assumes that :

MS_{E_t} : market share of European firms for a specific industry at time t

MS_{A_t} : market share of American firms for a specific industry at time t

MS_{J_t} : market share of Japanese firms for a specific industry at time t

then, one can try to study the evolution over time of these respective market shares.

In other words, our purpose is to value the evolution dynamic of market shares. To do that, we can define a transition matrix in which the different elements are probabilities of technological dominance (or alternatively competitive dominance) of each block. This matrix can help analyze the evolution of tendencies towards change inside the industry. By linking market shares and this matrix, we obtain an estimate of market shares in the next period. For example, a way to define this matrix is to use patent statistics. One knows the limits of such a measure but it gives an idea of the technological ability of each block. So, the process can be summarized as follows :

$$(MS_{E_t}\ MS_{A_t}\ MS_{J_t}) \begin{pmatrix} P_{EE} & P_{EA} & P_{EJ} \\ P_{AE} & P_{AA} & P_{AJ} \\ P_{JE} & P_{JA} & P_{JJ} \end{pmatrix} = \begin{pmatrix} MS_{E_{t+1}} \\ MS_{A_{t+1}} \\ MS_{J_{t+1}} \end{pmatrix}'$$

where MS_{it} = market share of i at period t

P_{ij} = transition probability of technological dominance of block i within block j.

By definition, the sum on a line is equal to one and, in our example, P_{EE} is equal to the number of patents granted in Europe to European industries divided by the total number of patents granted in Europe for a specific industry. The fact that the sum on a line is equal to one allows to relate it to the market share concept, since the sum of the market shares is also equal to one. Thus, the transition probabilities also correspond to market shares in terms of patents. Obviously, more complex technological indexes (or, alternatively, competitiveness indexes) could be designed.

In order to define robust market share indicators, we can use the "sales" variable. Thus, MS_{ik} (i = E, A, J) is equal to country i's volume of sales divided by the total volume of sales for a given industry k. A correction or extension can be made to take into account or specifically analyze imports and exports.

Through this approach, an equilibrium structure can be measured, i.e. when t tends towards infinity, one has :

$$(MS_{E_t}\ MS_{A_t}\ MS_{J_t}) \begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix}^n = \begin{pmatrix} MS_E^* \\ MS_A^* \\ MS_J^* \end{pmatrix}'$$

where $n \rightarrow \infty$.

The equilibrium value is obtained after n iterations and gives an estimation of the technological leadership.

However, we know that the absolute equilibrium value is a function of the endogenous characteristics of each industry. The position of a product on the life cycle influences the level of demand. To take this effect into account, we can combine this approach with a diffusion-modelling framework. In this way, we can draw a parallel with the two expressions decomposing the R & D-sales elasticity which have been discussed in the preceding section.

The matrix of transition probabilities can be interpreted as being the result of two sets of interactive parameters, a retention factor r_i which can be interpreted as a measure of the acquired technological advantage (or, alternatively, acquired competitive advantage) and an attraction factor a_i as a measure of technological dynamism (or, alternatively, competitive dynamism) where $\Sigma\, a_i = 1$, all $a_i \geq 0$ and $0 \leq r_i \leq 1$.

Thus, we have :

		Market shares acquired over the next period		
		Europe	U.S.	Japan
Market shares acquired over the last period	Europe	$r_E + (1 - r_E)\, a_E$	$(1 - r_E)\, a_{US}$	$(1 - r_E)\, a_J$
	U.S.	$(1 - r_{US})\, a_E$	$(1 - r_{US})\, a_{US} + r_{US}$	$(1 - r_{US})\, a_J$
	Japan	$(1 - r_J)\, a_E$	$(1 - r_J)\, a_{US}$	$r_J + (1 - r_J)\, a_J$

This matrix defined in terms of patents must only be viewed as an example. More representative indicators of technological competition should be substituted for this elementary variable.

This model remains very prospective and needs further investigations.

5. Conclusion

What can we really learn from theoretical models ? If they sometimes give useful tracks for empirical investigations and help to understand the relevance or the irrelevance of specific public interventions, they are unfortunately unable to cover all the facets of the economic behaviour simultaneously. Their hypotheses are as many methodological short cuts which reduce their operative field and disconnect them from the real economic game. When summing up a U.S. cross-industry study of public technology policy, Nelson (1980) points out : "Perhaps the lesson that economists should draw from their earlier attempts to base prescription for government R & D policy on theoretical arguments is that this is a dangerous game. Economic reality is too complicated for any simple theory to fit well. More complicated theories generally point in different policy directions depending on the quantitative magnitude of certain key parameters. The design of good policy depends on hard empirical research, and not simply on theoretical reasoning".

More recently, Reinganum (1989) concluded her impressive survey of game-theoretic models by writing that "but since it is largely restricted to these special cases (e.g. deterministic innovations, drastic innovations, two firms, symmetric firms), this work has not yet had a significant impact on the applied literature in industrial organization; its usefulness for policy purposes should also be considered limited. For these purposes, one needs a predictive model which encompasses the full range of firm, industry and innovation characteristics". No need to add that such a model is still a long way off.

The theoretical approach presented here can appear very eclectic. But it is the image, no matter how imperfect, of the present state of the literature regarding R & D policies in strategic terms. The firm is at the heart of the public R & D policy and the design of an efficient public policy cannot ignore the firm's behaviour.

The conduct of public R & D policy is largely grounded on a pragmatic approach. The optimal public policy must be suited to the endogenous characteristics of an industry, among which its position along its technological development trajectory plays a predominant role. However, the search for an optimal public policy will remain for a long time a "trial-and-error process" based on compromises trying to overcome both market and government failures. The normative approaches will give some guidelines as to the opportunities for public intervention but are not likely to be very helpful regarding the practicabilities of public activity in the field of R & D. The efficiency of public policies depends more on the management of R & D policy than on the observance of pervasive normative principles. As the competitiveness of enterprises is more and more determined by their ability to adopt a strategic behavior, public R & D policy cannot ignore the competitive interactions which are at the heart of the technological race. So, global competitive interaction models could be usefully implemented for the analysis of strategic issues of public R & D policies.

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Comment : *Sergio Cesaratto*

A sense of dissatisfaction prevails in the conference as a result of the perception that, in spite of the quality of the papers, a big gap exists between the urgent need of analytical instruments for the evaluation of R&D policies and the available theoretical and quantitative models. The paper by Professors Capron and Debande, which attempts to assess a wide range of theoretical approaches to firms' strategic behaviour *vis à vis* the design of an effective R&D policy, seems to augment our uncertainty. In particular they select three groups of models.

The first group concerns itself with the well-known advantages and obstacles to technological cooperation. The authors regard technological cooperation as a possible answer to the difficulties of European firms to translate their research potential into innovations and market shares. I wonder how much technological cooperation, somehow or other artificially stimulated by the EEC, can substitute an autonomous capacity of firms to think more in terms of world markets and invest more long-term R&D. From this point of view the EEC and national governments should not put obstacles in the way of expansion of European firms, whether through the acquisition of other European or extra-European companies. But, if I may permitted a digression, a second type of cooperation has not been discussed here, namely social cooperation. I believe that after all this talk about the role of social institutions and customs in Japanese post-war development, Europeans have forgotten to look at their own national experiences of social partnership. I am convinced that the European social charter could be a positive instrument of industrial policy, quite the opposite indeed of what some narrow-minded governments, industrialists and economists may think.

A second group of models reviewed by the authors concerns game-theoretic models. Although the authors have some sympathy for this approach, they correctly point out their "highly simplified" nature. The application of game-theory to industrial economics has brought some "rigour" to the field, but has somehow increased its distance from the real world. The authors also admit that these models "remain silent about the real design of public R&D policies".

In the final part of the paper the authors present some developments of a third approach, namely the Dorfman-Steiner condition, originally developed for the case of the optimal advertising policy in an oligopolistic market and subsequently extended to the case of R&D. The authors regard this approach promising in so far as it allows the consideration of industry specific circumstances in designing R&D policy. I sympathize with this conclusion since the empirical work carried out in many European countries on innovation surveys has revealed the existence of a considerable variety of technological behaviours in the manufacturing sector.

In their conclusions the authors propose two quotations from Richard Nelson and Reinganum, both of whom are skeptical as to the possibility of drawing policy prescriptions from highly theoretical work. So let me make two final remarks on the distance between economic analysis and the real world.

The first consideration is that, in economic analysis, there is some objective distance between theory and the complexities of the real economies. The constant discontent with econometrics (also in this conference) depends perhaps on the often too heroic attempts to fill this gap. I hold that abstract models and econometric exercises, if they want to be of any practical interpretative use, should more frequently be placed in wider contexts in which historical and institutional features can also be taken into account.

The second consideration concerns the theory itself. The heroism in filling the gap between models and applications is sometimes augmented by the doubtful foundations of the theory. This is the case, in my opinion, of neoclassical analysis of accumulation and technical progress. This seems true both for the old Solowian versions of that theory and for the most recent "endogenous" growth models (see the interesting survey by Bradley and Whelan in this conference). The capital theory controversy of the sixties showed the analytical inconsistencies of the "aggregate" version of the marginalist theory (see Metcalfe, 1987). Since then, the only rigorous version (i.e. not a parable) of this theory is the short term neo-walrasian approach, which is not exactly a long period theory of growth. The Cambridge (U.K.) criticism applies as well to the neoclassical attempts at productivity measurement so that most of the econometric exercises are not only heroic, but analytically inconsistent (see Steedman, 1983). The criticism seems also to apply to new growth theories, in spite of the attempt to hide or neglect the problem of measurement of capital. It is worth noting that both the old and the new neoclassical approaches share the same idea that growth and (in the new version) even technical progress depend on the social propensity to save and leave little, if any, scope for technical change and Schumpetarian competition as a determinant of investment. The keynesian criticism taught us that, within the limit of existing productive capacity, it is investment that determines saving. The Cambridge criticism suggested how to extend the idea of the independence of investment from saving to the long period (Garegnani, 1978). If investments are independent of saving, a promising field of research is open to investigate the role of technical change in the determination of the rate of accumulation.

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Chapter 13 - Technology Diffusion : Tracing the Flows of Embodied R&D

John Dryden and Andrew Wyckoff

Research and development (R&D) is a key source of technological change, both directly through the creation of new products and processes and indirectly through the purchase of these products by other firms. These indirect flows of R&D, called embodied R&D flows because the R&D is embodied in actual goods or services, have become increasingly international as trade has expanded. For many industries, and some countries, this indirect acquisition of technology may be more important than the development of technology internally.

The indirect flows of R&D -- a facet of R&D diffusion -- are the focus of an ongoing OECD study in the Directorate of Science, Technology and Industry. These flows will be estimated by using R&D data in conjunction with input-output tables and international trade flows to estimate the embodiment of R&D in capital equipment and intermediate inputs. These estimates will indicate the flows and magnitude of the indirect use of R&D, providing a picture of the technological interdependencies that exist between industries and countries. The project will also analyze how the inclusion of the indirect use of R&D might reorient which industries are considered to be "high-technology" industries.

Data Sources and Methodological Approach

The methodology builds on previous work that constructs estimates of embodied technology flows between industries by weighing intermediate and capital purchases (both domestic and imported) by the R&D intensity of the industries of origin. [1] The capital flows tables will be separated into domestically supplied and foreign supplied capital through the use of an import proportionality assumption that assumes that all industries using a particular type of capital equipment, purchase imports of that equipment in proportion to the overall ratio of imports for that good. A similar assumption, supplemented by country surveys and more detailed data, will be made for intermediate inputs.

[1] See Lester Davis, "Technology Intensity of US, Canadian, and Japanese Manufactures Output and Trade," U.S. Department of Commerce, 1988.

(21)

The addition of the capital flows tables will allow a differentiation between the R&D embodied in capital versus intermediate products. The separation of domestic from foreign sourced intermediate inputs and capital will provide a mechanism for estimating the role of imports in R&D diffusion.

This project will be carried out for six countries for which the OECD has internationally consistent input-output (I/O) data -- Canada, France, Germany, Japan, the United Kingdom and the United States. This database typically contains three sets of I/O tables for each country, spanning the period from the early-1970s to the mid-1980s, which allows a historical analysis of R&D embodiment to be performed. Through use of OECD's Analytical Business Enterprise Research and Development (ANBERD) expenditures database, the analysis will be carried out at a relatively fine level of industrial detail (22 manufacturing industries) that is oriented towards technology and trade intensive industries such as aerospace, computers, and communication equipment & semiconductors. This level of detail will enable the identification of clusters of industries that share R&D through embodiment and present a clearer picture of the trends that have occurred in the R&D embodied in international trade.

Chapter 14 - Sound Operational Evaluation Recommendations : How to Marry Theory and Practice ?

Clara de la Torre and Alain Dumort

1. Framing the Problem

1.1. The EC R&D Context

Ex-post evaluation of public policies, although not always implemented and less often well accepted, is one of the primary tools to improve the management of public resources.

It can be carried out with many different objectives, the most frequently used being :

a. Judgement of past activities or undertakings.
b. As a learning process involved in feed-back mechanisms.
c. As a decision-making support for future action.

In our specific case - EC R&D programmes - evaluation's main objective is to give elements for programme managers and politicians whenever a new action is to be undertaken, although features of what we call the learning process appear.

Until recently, R&D public spending was evaluated on the basis of purely scientific and technical criteria. R&D programmes were conceived and designed nearly only by and for the scientific community. But fortunately, awareness of the importance of science and technology for economic growth has gone beyond the frontiers of scientists, engineers and economists specialised in R&D. Given the importance from both qualitative and quantitative aspects of decisions in R&D policy, more and more information and analyses are requested by decision-makers to achieve a solid and sound basis for R&D policy.

Qualitative assessments of R&D achievements are very often used. However, despite their being more adapted to problems in which many non-measurable and complex factors play a prime role, they are nearly always contested due to the incorporation of a fair amount of subjectivity and value judgements.

At first view (better, from an outsider's view), quantitative methods could avoid this sort of criticism. However, quantitative methods can also be subject - and in fact are - to the same weakness.

The problem becomes more complex if we restrict our object of analysis to EC R&D programmes. Let us remind ourselves of some of its true outstanding features for the purpose of this seminar.

Firstly, EC R&D funding is only a small proportion of the total R&D resources (even if we only consider public resources).

Secondly, it is a selective funding with fairly broad coverage. Many different scientific and technological fields are covered, whereby an uneven (in form and in funding volume) influence is apparent.

Thirdly, the EC R&D action is intended to be only of a "precompetitive" nature (precompetitive being intentionally an unclear economic concept with ill-defined borders). This prolongs the time lag between EC action and the appearance of effects.

Fourthly, the first direct effect sought (apart from the obvious production of knowledge) is the creation of networks of laboratories, universities and industry. Networking mechanisms add a considerable degree of complexity to the analysis, namely in external effects.

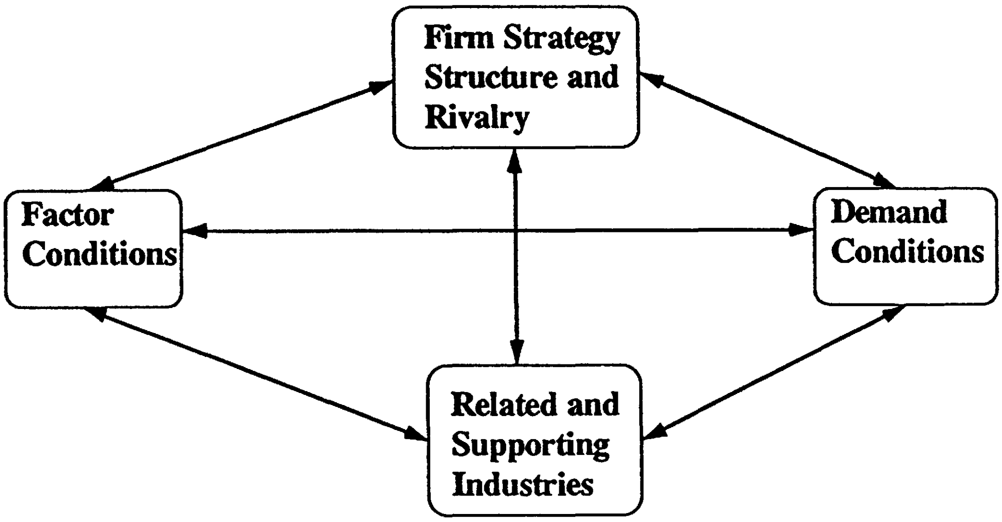
Fifthly, EC R&D funding is intended to produce a catalytic effect in the sense that its mechanisms are aimed at mobilising resources which otherwise would not be allocated to R&D. It does not, however, discriminate between public and private, which means that effects in both sectors are supposedly produced.

Finally, the EC R&D policy, being carried out at a multinational level, the number of factors (other policies and other measures conflicting and/or supporting R&D) increases dramatically, so that effects are hidden even more than at a national level. Michael Porter distinguishes four factors explaining the different paths of innovation and competitiveness among countries (figure 1) :

- The availability of highly qualified human resources, S&T infrastructure and dynamic public services;

- Demand conditions leading to an appropriate level and diversity of consumption patterns;
- A broad and well interconnected industrial network;
- Level of competition between firms.

Figure 1. Factors of innovation and competitiveness



Source : Michael Porter, Seminar in European Microeconomics.

Apart from the normal technical problems of aggregation, this gives a good flavour of the complexity of the analysis when referred to the EC as a whole.

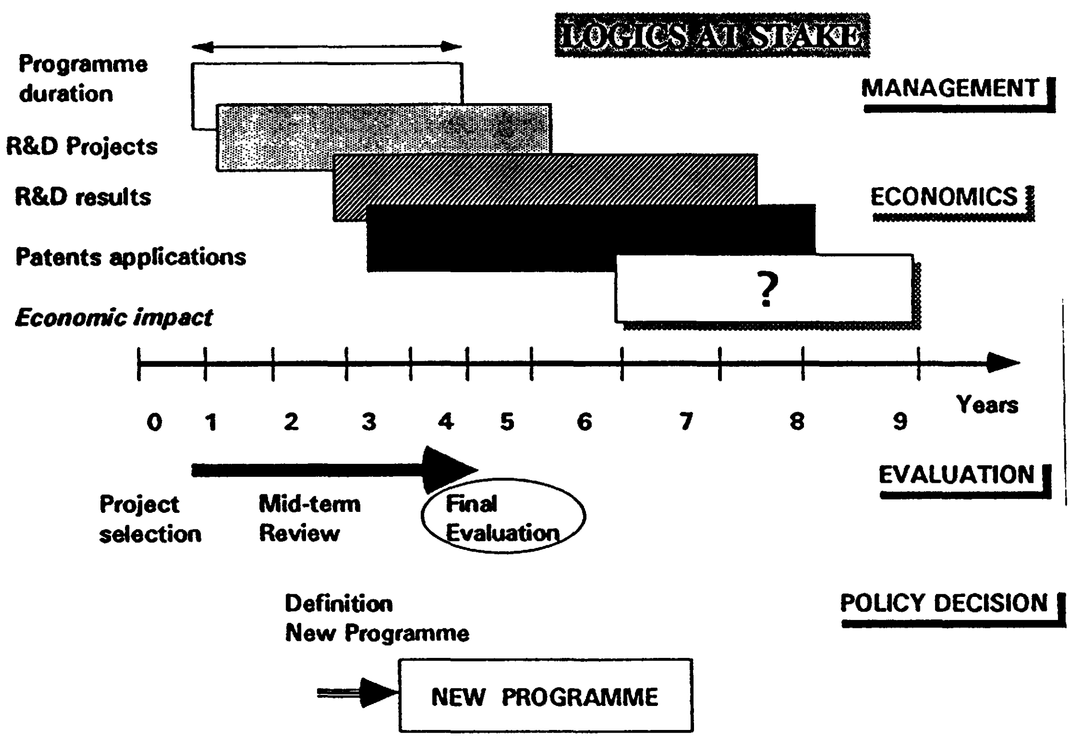
It is not only the multiplicity of countries but also the interconnection with other policies. The analysis of the induced technical progress allows the investigation of the results of economic policies not specifically directed towards the technological change. In fact, if, as seems to be the case, technological change is sensitive to changes in the price of industry outputs, a policy changing such prices could affect the technical change in an industrial sector and those related to it. Therefore, it is not of much use to analyse the technological policies in isolation.

Last but not least, EC R&D programmes have legal constraints among which the evaluation timing that is strictly defined by the end of the programme. The scheme which is in the legislator's mind is of a very different nature than the economic analysis.

From a legal point of view, a linear scheme is applied. Public funds are allocated to specific R&D actions and these are supposed to produce identifiable effects in the short term. A mid-term evaluation or review is to be undertaken so that the programme can be reoriented. Once the programme is finished and results become apparent, they are evaluated and on the basis of such evaluation a new decision is adopted.

Legal sequences are not in line with the R&D results and impact cycle as shown is figure 2.

Figure 2. The logics at stake



Firstly, each programme has to meet specific objectives in conformity with the overall objectives set in the Single European Act and the Maastricht Treaty.

The trade-off between strengthening the scientific and technological basis, encouraging competitiveness and strengthening the social and economic cohesion is established. However, no definite hierarchy between objectives appears clearly to evaluators.

Secondly, from the moment a programme is adopted (usually for four or five years) up to the moment research is in fact started, 10 or 12 months (very often even longer) are spent. After that, the research has to be undertaken, tested, exploited, disseminated through the economic system and finally the impact, if any, is produced.

Unfortunately, economists know the pre-conditions, pre-requisites for economic growth and development much better, and its actual measure much less. Therefore, why shouldn't evaluations concentrate on the analysis of such pre-conditions instead of the analysis of the impact ?

1.2. Management and Economics : Two Different Approaches

As we have seen, more and more complex questions are addressed to EC managers, such as socio-economic impact of R&D programmes, technological risk assessment, evaluation of techno-globalism, infrastructure, targeted projects, human capital. New questions are raised in the context of the new political agenda in a changing world economy.

The paradox is that methodologies which used to be applied in the evaluation process remain mostly the same : interview, peer review, wise men, questionnaire. Evaluation reports by independent panels contain lists of recommendations; some are really interesting and useful for the policy-makers; some others are obvious but often beyond management's control or just platitudes. None of these conventional approaches are appropriate to match relevant issues of measuring economic impact. The implementation of adequate quantitative tools is obviously required.

However, non-economist managers are not prepared as customers for sophisticated economic methods. The challenge for economists is to extract clear recommendations from theories and models applicable to actual management actions.

The lack of communication between business and economic schools cannot be solved easily, specially in the field of R&D.

1) Most of EC managers with an economic background are no longer in touch with the on-going theoretical debate in economics.

2) State-of-the-art of the economic thought, is, as usual, a little bit confusing for non-specialists for two reasons :
   - Many methods and models are being developed. Prof. Capron's report analyses more than 20 methods and much more if econometric techniques are distinguished;
   - Part of the results depend strongly on the methodology that is chosen : school line of thought, type of models, time period analysed, level of disaggregation.

Managers, attempting the implementation of economic theories are likely to face scepticism, failing in translating global issues into concrete actions. If they tried to understand the meaning of economic models, they would be disappointed in front of disparities of logics and results among models. Last but not least, they risk feeling blue in reading that public R&D investment is unproductive compared to private R&D. The best thing civil servants involved in R&D management would feel would be a "change of business", and this is obviously not the evaluation aim nor the conclusion of this paper !

1.3. The Strategic Context

R&D priorities are changing every 4-5 years with the adoption of subsequent new Framework Programmes. Thinking about appropriate tools for the evaluation of the second Framework Programme does not matter anymore for managers. What is at stake for economists is to promote up-to-date methods for the forthcoming programmes. Otherwise, the effectiveness and usefulness of analytical tools could not be established.

The 2nd Framework Programme for the period 1987-1991 was based on two principles for cooperation : normative and pre-competitive research. Networking has succeeded on this basis. The exact definition of pre-competitiveness is of less interest now; it has been an essential incentive for various partners and potential competitors to cooperate.

The 3rd Framework Programme 1991-1994 is characterized by fewer programmes and projects closer to the market with special emphasis on diffusion of R&D results and valorisation of intellectual resources. Nevertheless, overall objectives are similar : strengthening the scientific and technological basis of European industry, encouraging competitiveness.

Driving forces for the 4th Framework Programme 1994-1998 are being discussed. Arbitrations between new targeted projects and current sectoral programmes will certainly change the current situation.

The shape and content of EC programmes are moving to more industrial oriented actions, addressing key issues to specific sectors (electronics, biotechnology...). But supports to horizontal actions are going to be reinforced : enhance qualified skill, human capital and mobility. The different types of actions imply different levels of analysis for the measurement of economic impact : microeconomic and macro-sectorial levels for focussed projects, macroeconomic approach with special focus on human skill factor for the global actions.

Models and data bases have to be continuously adapted to political issues to ensure operational models relevant to the strategic thinking concerning the allocation of R&D budget. But this is, of course, hard and onerous to undertake.

2. Dead Ends and Promising Ways

The link between R&D and technological innovation has been the object of analysis well before public authorities (or private) realized that evaluation is essential for good resource management. Moreover, it can be said that it is the other way around. Many studies (empirical and theoretical) have tried to understand the innovation process but the debate is far from being concluded.

Unfortunately, methods and tools not suitable for the analysis of R&D economic impact (specially for EC programmes) appear much more clearly than those which are more promising. In this section we have made a selection of those which apparently would be of use for our purpose but that have such limitations that we propose to restrict their use, always referring to our purpose.

2.1. Survey of Methodological Limits

Before entering into the specific problems of each selected method, let us remind ourselves of the main drawbacks of the results issued from econometric models which have been well synthesized by Prof. Capron; these are :

- theoretical and methodological problems;
- problems in the measure of a certain number of variables;
- availability of data;
- whether, for the purpose of shedding light on the future, the most appropriate view can be attained when we look at the past. This would be the case if one accepts that production and technical progress are to continue evolving as they did in the past;
- biases derived from the aggregation process;
- the neglect of a certain number of variables.

Beside this, one should bear in mind that econometric analysis (including data collection) are always long and expensive.

2.2. Walking through the Literature

Let us start with the analysis made concerning the impact of public R&D funding on productivity. Results of the analyses of Terleckyj[1], Griliches and Lichtenberg, among others, show that it can be either positive, negative or insignificant (as in most of the cases). But is this of any help to programme managers ? We do not think so because we are afraid that if we did this exercise once more, trying to concentrate on EC R&D spending, whatever the result, we will be confronted with a situation in which it is difficult to realize whether we have estimation problems, bad quality of the data, an inappropriate model and that, obviously, would be in contrast with some other study.

The main point is : let us suppose, for our demonstration, that we find a clearly significant relation between EC R&D public spending and productivity. If the relation appears to be negative, one can imagine the problems of political acceptation of such a result. If the relation is significant and positive, would it be credible for those that know that in most of the other analyses the result has been insignificant ? Moreover, why should the relation be significant in the specific case of EC R&D expenditure ? Would it have an economic theory rationale ?

How should we interpret Scott's analysis where he does not relate productivity and public R&D expenditure, which could mean, according to Prof. Capron, that it is likely that governments are subsidizing totally useless private expenditures ?

As we have mentioned at the beginning, one of the aims of EC R&D funding is to act as a mobilizer of national (private and/or public) R&D spending.

If this is the case, it could be of use to try to apply the analyses which have been carried out for other purposes to relate public and private R&D funding. Unfortunately, this question is not one of the most addressed in literature. Some have found that R&D publicly funded tends to reduce private R&D expenditure. This means that instead of the complementarity sought, there is a substitution process. In contrast, other economists argue that an increase in one of the sources leads to an increase in the other.

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1 His analyses are based on different data sets giving alternative measurement of total factor productivity growth.

Mansfield has, for example, shown that for a sample of firms in the energy sector, publicly funded projects led to an increase in performance and productivity. This increase would be only half of what could have been achieved if the firm had invested the same amount of resources itself. Can this analysis lead to the conclusion that public authorities should create an environment which is more manageable for firms to invest in R&D instead of giving direct public support ?

In contrast, Scott and Levin and Reiss, have shown that public R&D funding has, in fact, a positive effect on private funding which is strongly contested by Lichtenberg.

With this in view, what is the reliability of a new trial specifically designed at seeing the mobilising effects of EC R&D spending ? We are sure that whatever the result, it will always be contested and thus lose credibility to decision-makers.

Allow us to take the meta-production function approach. As a reminder, these are production functions which include, apart from the normal production factors, other variables supposedly influencing the production structure.

According to Griliches' analyses, the output is a function of capital, labour, level of technological knowledge plus a residual; the level of technological knowledge being determined by the total expenditures in R&D (past and present).

This specification relies on the following :

- the time lag between the investment in R&D and real innovation;
- the time lag between innovation and its diffusion in the market;
- the depreciation of the stock of knowledge.

This method, even if appearing as useful for our purposes, suffers from several criticisms as Prof. Capron has pointed out. These are :

- R&D expenditure is not the only source of technological innovation (think of the case in which a firm or country buying new equipment already incorporating technological innovation);
- series of good statistical data are not available for all EC countries and for a long period;
- lack of decreasing efficiency and increasing cost of R&D.

This approach, the same as other based on production functions, has also the limitation in the measurement of capital.

As Scott says, the measure of capital which appears in the production function is fundamentally incorrect. The production function is concerned with the change in the net stock of capital, i.e. gross investment less depreciation. But Scott says that machines which are properly maintained can run for years, even longer than the theoretical depreciation period. Others suggest using the measure of gross investment less scrapping. Scott says that when a machine is scrapped it is because it is not adding any net output, and therefore there is no loss when capital is scrapped. But this shouldn't lead to the idea that the best measure of capital is the gross investment. According to him, the production function should be abandoned and changes in capital should be used (gross investment) to explain changes in output.

However, analyses have been done to find the elasticity of research with cross-cut estimations (instead of using time series) at firm level. These analyses have given less contradictory results than many others and could perhaps be tried for our purpose. This sort of analysis (Minasian, Griliches, Mairesse, Schankerman, Cunéo, Jaffe, Sassenou and others) could perhaps be applied by sectors at EC level and comparing the results yielded using a sample of firms having participated in EC programmes with another sample including firms that have not participated.

3. Conclusions : Pre-Requisites for Possible Solutions

Three evidences can be highlighted in view of improving economic background for R&D programmes' management.

First of all, economic analysis does require strong statistical material. Substantial efforts are being made by the EC statistical office to produce harmonized statistics on R&D. However, data are provided by Member States and priority for improvement has to be assured at national level. The set-up and the follow-up of specific economic indicators should be systematized within each EC programme.

Secondly, assuming that the legal obligation for evaluation schedule remains as currently, there is little room for "sophisticated" economic models in the evaluation process. Mid-term evaluations can focus only on implementation and management of programmes. The economic and strategic analysis should be launched separately of the evaluation agenda and in parallel with the implementation of the programme. Issues and recommendations would be available when requested for the preparation of the next programme. Conclusions would be added in the final evaluation report at the end of the programme.

Thirdly, none of the existing economic analysis methods is ideal. Managers have no other choice but combining tools and methods, and whatever limits of econometric models are (coping with usual statistical scarcity, difficulty of assumptions and scenario definition, complexity of methods), they bring essential coherence and consistency to the analysis.

As an overall recommendation, the models and tools must be conceived as "dialogue boxes" between economists and managers. Three conditions are specially required to bridge the gap between both ways of thinking :

- Flexibility, regarding the broad spectrum of political considerations they are supposed to deal with, in a short period of time;
- Transparency of main mechanisms and assumptions;
- Appropriateness and credibility of results and messages for the attention of managers and, furthermore, policy-makers.

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EUR 14740 - Proceedings of the Workshop on Quantitative Evaluation of the Impact of R&D Programmes
(23-24 January 1992 - Brussels).

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1992 — VIII, 328 pp. — 21.0 x 29.7 cm

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