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New directions in research and technology policy: Identifying the key issues

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1. Introduction

This paper outlines a conceptual framework and some empirical objectives for analytical work on research and innovation policy. It sketches some major changes which have occurred in our understanding of the links between science, innovation and technological change over the past twenty years, considers their policy implications, and then suggests some core priorities for research in such fields as research policy studies, growth economics, the economics of technological change, innovation and firm studies, etc.

The basic problem is to explore the policy implications of the move to a knowledge-based economy. This has a number of dimensions, which at a minimum include

- basic science policy,
- technology policies aimed at invention and innovation,
- diffusion policies, and all policies related to the adoption of new technologies
- technology policy aspects of industrial and regional policies
- human capital, human resources and mobility, including all aspects of education and training

This paper concerns only parts of these issues; it focuses on the conceptual basis, structure and content of a research programme directed towards industrial innovation and diffusion policy, at national and regional levels.

Over the past two decades, social scientists in a range of fields have in effect carried out a major programme of research on science, technology and innovation. If there is any unity in this research, it is simply the view that these activities are social and economic processes, not simply technical processes of discovery and invention. The argument here is that this research has reached the stage where it is both necessary and possible to rethink the rationale, objectives and instruments of policies in the general areas of science, technology, innovation and industrial change. At the same time, this background research work opens up new areas of policy-relevant questions. This paper therefore overviews some of the main themes in modern research in innovation and technological change, focusing on their implications for policy. How does recent research change our conceptions of the appropriate objectives and methods of science and technology policy? Against this background, what are the main unresolved problems facing policy-makers over the next ten years? What kinds of conclusions can we draw regarding research priorities and objectives for policy researchers in the years ahead? After discussing these issues, the next section explores how these problems can be investigated.

2. Theory and practice of technology policy in the post-war period

At the present time science and technology policy-makers are engaged in a far-reaching shift away from the ideas which dominated much science and technology policy during the post-war period. Rather than working with over-simplified models of the relationship between science and new technologies, they are seeking to achieve more sharply-defined policy objectives by trying to construct policy measures and instruments which reflect the real characteristics of innovation processes, both in industry and the public sector. What are we moving away from? Here we are not considering government policies aimed at achieving specific objectives (where government is the user of science and technology), but rather policies which aim at the general technological performance of industry, or the technological needs of society as a whole. For most of the post-war period this type of science and technology policy in Europe has been explicitly or implicitly based on some variant of the so-called 'linear model of innovation'.

The linear model had two dimensions, one widely recognised, and one more or less neglected. The first of these dimensions was an overemphasis on research (especially basic scientific research) as the source of new technologies. The second was a technocratic view of innovation as a purely technical act: the production of a new technical device. Technological change was seen as a *sequence of stages*, with new knowledge (usually founded in scientific research) leading to processes of invention, followed by engineering development resulting in innovation (or the commercial introduction of new products and processes). In this framework, technology development and engineering were usually seen as forms of applied science. Finally there was a stage of diffusion, in which the completed product spread into application. The linear model was therefore *research-based*, *sequential* and *technocratic.*

In this perspective the primary constraint on innovation was the supply of R&D. The basic argument for public-sector involvement was that problems of appropriability and risk led to under-provision of R&D (especially at the basic end of the spectrum) in market economies. Because of lack of mechanisms for sharing risk, and because firms could not appropriate all of the economic benefits of research, firms did not have incentives to invest in a socially optimal amount of R&D. A fundamental task of policy, therefore, was either to provide this research directly, or to construct incentives for private-sector provision. In practice therefore, in most countries, technology policy came to consist of R&D support measures such as grants, tax credits, infrastructure support (for university research, for example), and so on. Of course there have been differences in emphasis between national research strategies, and also differences over time within countries. Nonetheless, in essence we have had policies based on the idea that innovation rates depended on the volume of research, and that finance for R&D was the fundamental obstacle to innovation by firms or other social institutions.

But, as noted above, the linear model also embodied a second dimension: an implicitly *technocratic* approach to innovation. That is, technology was seen as a technical process of hardware supply, of the development of knowledge related to specific products and processes. Technological innovation was seen essentially in terms of construction of pieces of equipment. It was viewed as an act of production rather than as, for example, a continuous social process involving such activities as management, coordination, learning, negotiation and so on. Those aspects of innovation which involved non-R&D processes, such as exploring user needs, acquiring competence, managing new product development, financial management and so on, were neglected.

It is important to note that the linear model did not confine policy-makers simply to R&D support, or to any particular type of technology development. It was possible, without changing the basic view of how innovation occurred, to focus on a range technological objectives, military and civil. It was possible also to focus on the diffusion of new technologies, via policies organised around investment incentives, support programmes for the use of specific items of equipment (such as NC machine tools or CAD/CAM), licensing of research results from universities, and so on. But diffusion policies were also seen essentially in a linear way. For example, such approaches have usually been seen either in terms of "technology transfer", the shifting of results from fundamental research into industrial applications, or - less frequently - in terms of diffusion of allegedly critical items of technology. However neither of these approaches questioned either the prioritisation of research or the technocratic aspects of the linear model of innovation.[1]

In recent years, the linear approach has become less secure. On the one hand, it has become very clear that devoting resources to R&D does not automatically mean success in technological development, let alone economic success in the use of technologies. Countries such as Britain, the former Soviet Union and India have maintained large science bases, but have exhibited poor industrial performance, while the countries of the Pacific rim have strong growth records without large-scale fundamental science or public-sector R&D support. At the same time the technocratic aspects of the linear approach have revealed their limitations. Invention of new techniques by itself guarantees nothing; it has become increasingly clear that the innovation performance of successful corporations owes a great deal to organisational skill - to the identification of opportunities, to the development of a wider range of competences, rather than to purely technical achievements. Similar points apply to the use of new technologies in such socially important areas as health and education.

3. The changed policy environment

These changed views also relate to more fundamental shifts in the scientific, technological and economic policy environment, which has changed radically over the past twenty years. The primary changes are:

- the emergence of new fields of science, or processes of dramatic advance in existing fields (for example in molecular biology)
- the emergence of major new generic technologies, of wide industrial and social significance, which are highly internationalised in terms of their development
- profound change in the macroeconomic situation: increased international interdependence, in a context of economic instability, high unemployment and sharper international competition

[1] For a well-known discussion see Henry Ergas, "The importance of technology policy", in P. Dasgupta and P. Stoneman (eds) **Economic Policy and Technological Performance** (Cambridge: CUP), 1987, pp.51-96.

In the mid-1980s, following the serious recessionary problems associated with OPEC-I and OPEC-II in the 1970s, science and technology policy-makers began to turn towards industrial competitiveness as an explicit objective, both in national policy thinking and in such transnational arenas as the EC's FRAMEWORK programmes. In many countries this resulted in some sharp policy changes. New roles, forms of organisation and levels of support have been defined for such infrastructural institutions as universities, publicly-supported institutes, and research councils. At the same time, price inflation in the context of generally rising unemployment made the control of public expenditure a key issue in many OECD economies during the 1980s: this too had an impact on science and technology policies, producing an emphasis on the need to concentrate resources on areas which were perceived as high priority in innovative terms, or where more or less direct economic results might be achieved. At the present time such issues are sharpened by the existence of extremely high budget deficits in OECD economies generally; in the US, Germany, the UK and Scandinavia, such deficits are at record levels, and are unsustainable. These issue too feed into the drive for a more 'effective' policy.

What must be said about these policy changes is that they rarely had a coherent rationale; they often had rather narrow approaches to the aims which they sought to achieve. They were certainly not based on superior understandings or consistent analyses of how new technologies are actually innovated and diffused. Broadly speaking, these were changes within the linear/technocratic paradigm, rather than an alternative to it.

However the linear model has also been shaken by rapidly expanding research on innovation. From the mid-1970s, research on science and technological change has grown very sharply in Europe and the USA, in fields such as history of technology and science, economics of technological change, management of R&D and innovation, and the sociology of technology. Some of the approaches and the broad conclusions emerging from this large transnational programme of research will be discussed below. Here it can simply be said that we now have research results which significantly change our views about

- the nature of innovation processes, in particular of the different roles of R&D and non-R&D inputs within them
- the role of social factors in shaping the evolution of technology and scientific disciplines
- the nature and importance of technology diffusion
- the role of tacit knowledge and human skills in innovation, and the nature of the learning involved
- the role of national and regional knowledge infrastructures and support services, and more broadly of the importance of 'national and regional innovation systems'
- creation of new firms and technological innovation
- the role of technological change in economic growth; in particular the development of at least three significant bodies of theory concerning the role of knowledge creation in growth

These changed approaches to innovation have also led to changed views about the economic *effects* of new technologies. The theme of the interaction between technological innovation and economic growth is an old one in economic analysis. But it seems clear, in the light of the research of recent years, that there remains much to be said about the causal links between innovation processes, international competitiveness and economic growth in the long run. A particularly important recent development is the elaboration of theories which attempts to explain growth rates primarily on the basis of technological change or externalities arising from R&D.

This combination of changed understandings and new policy objectives has led, for the first time, to rather basic questions about the scope, objectives and instruments of science and technology policy. By far the most important forum for policy-related thinking in this area has been the OECD's TEP (Technology-Economy) programme (1988-92) which has in effect introduced this body of general research into policy analysis and debate. We turn now to an outline of these "core ideas", after which the TEP contribution and future directions will be discussed.

4. Modern innovation research: Core ideas and implications

If modern innovation analysis has any one single source, it lies in the work of Joseph Schumpeter. Schumpeter's work is open to various interpretations, but it is based on three central ideas. First: that competition in industrial economies is primarily technological - firms compete not in terms of the efficiency with which they produce given products, but rather by changing products and processes. Second: that this dynamic process of change and replacement - "creative destruction" - is the source of both instability and economic growth in industrial economies. Third: that the generation and management of such change is the primary internal problem in the modern corporation. Each of these ideas has had major impacts on modern research; but broadly speaking we can distinguish two main themes deriving from the influence of Schumpeter:

- a theme which attempts to develop the theory of the innovation process itself - to explore how firms innovate, to develop a more subtle understanding of the processes involved.

- a theme which explores how innovation at firm level affects the evolution and dynamics of industrial structures, and general economic performance.

Underlying much modern research is a more nuanced concept of technology itself, in which technology is no longer seen in a technocratic engineering sense, but in its social and economic context. In the following sections we outline this broad approach, and then look at the key problems concerning the nature and effects of innovation which emerge from recent research. The following sections deal with these issues:

- first, the conceptualisation of technology as both a social and technical process,

- second, innovation as a non-linear process, involving not just research but many related activities (training, design, marketing and so on). Innovation relies on the creation of specialised competence and results in variety, diversity and "bounded vision" at firm level,

- third, innovation as a process of interaction between firms and their external environment; the conceptualisation of this environment in terms of "national or regional systems of innovation",

- fourth, innovation as an increasingly globalised activity,

- fifth, technological change as an increasingly science-linked activity, which is central to the growth of output and productivity,

5. The nature of technology

The point of departure for much modern research has been a concept of technology which sees the "hardware" aspects of technology in a dynamic social and economic context. What is technology? Firstly, technology involves *knowledge* related to production: it implies understanding and competence relevant to material transformations. This knowledge can range from abstract scientific knowledge - codified and widely available - concerning the properties of nature, through to engineering "know-how" or operative skills. The latter are often tacit, unwritten. Secondly, technology involves *organisation*: at the most direct level this means the management and co-ordination systems which integrate individual activities and through which production takes place, or through which public-sector activity is organised. Thirdly, technology involves *techniques*: that is, machines, tools or other equipment with their rules and procedures of operation, and their ancillary activities such as maintenance, repair, training and so on. Technology can therefore be thought of as *the integration of knowledge, organisation and technique*. However there is a further essential aspect: technology is produced by and exists within a *social framework*. The social system makes economic and political choices which influence the development and spread of technologies, and which - through education and general culture - develop the skills needed to operate technologies. Social values and decisions thus shape the path of technological development. It seems apparent that differences in technological performance between societies have at least some of their roots in social structure and cultural forms, although how these differences operate is as yet far from clear. At the same time, technological developments have important impacts on the social world: on the environment, on the way we work, on our general social inter-relations.

Against this background, technology can be seen as generic or specific. A key element in modern innovation analysis has been the distinction between the technological knowledge-base of the firm - which is focused on particular products, and therefore highly specific - and the wider set of knowledge’s which provide the framework within which the firm operates. In referring to the wider dimension of technology, Richard Nelson has suggested that

> ... a technology consists [in part] of a body of knowledge which I shall call generic, in the form of a number of generalisations about how things work, key variables influencing performance, the nature of currently binding constraints and approaches to pushing these back, widely applicable problem-solving heuristics etc ... generic knowledge tends to be codified in applied scientific fields like electrical engineering, or materials science, or pharmacology, which are "about" technology.[2]

A technological paradigm, in this context, refers to the whole complex of scientific knowledge, engineering practices, process technologies, infrastructure, product characteristics, skills and procedures which make up the totality of a technology. Technology can be thought of, therefore, at firm level as a highly specific set of skills and competences focused tightly on specific niches and products; but these exist within a wider technological framework, which is evolving over time, and which structures activities inside the firm. In considering the technological performance of firms, we should therefore think of technology as consisting of both internal and external components; innovation always involves an interaction between the two.

6. Understanding the innovation process

In understanding the process of technological change, modern theory begins from Schumpeter's view that competition is primarily a technological phenomenon. The basis of competition is the quality, design characteristics and performance attributes of products. Firms seek competitive advantage on the one hand by continuous development of technologically differentiated products, and on the other by changing processes so as to generate these products with competitive cost structures. Usually, innovation takes the form of incremental change within fields in which firms have specialised skills and experience; that is to say, firms seek to establish a technically differentiated product range within an established technological paradigm. Alternatively, firms can seek to innovate by changing the paradigm itself; this is less frequent, but it does happen.

What is involved in the innovation process itself? Most modern research sees innovation

- first, as an interactive social process which integrates market opportunities with the design, development, financial and engineering capabilities of firms,
- second, as a process characterised by continuous feedbacks between the above activities, rather than by linear transitions,
- third, as a process characterised by complex interactions between firms and their external environments
- fourth, as a process which is continuous rather than intermittent.[3]

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[2]Richard Nelson, **Understanding Technological Change as an Evolutionary Process** (Elsevier: Amsterdam) 1987, pp.75-76

[3] For a wider discussion see S. Klein and N. Rosenberg, "An overview of innovation" in R. Landau and N. Rosenberg (eds) **The Positive Sum Strategy. Harnessing Technology for Economic Growth** (Washington, National Academy Press) 1986.

The primary problem for the firm is to build a set of technological competences and capabilities which will enable it to create distinctive areas of competitive advantage. Through marketing exploration, and general relationships with customers or product users, firms attempt to identify opportunities for innovation; but this is usually done within the context of an existing set of technical skills, and an existing knowledge base. Research - in the sense of a search for novel technological solutions - is usually undertaken only when firms face problems which they cannot solve within their existing knowledge bases. In other words, *research is not necessarily the primary process generating innovative ideas: it is better seen as problem-solving activity within the context of on-going innovation activity.*

A key point is that firms can combine these various components of the innovation process in many ways. Firms not only produce differentiated products, they generate innovations in different ways. This has two important implications.

- Firstly, the process of differentiation generates a high level of variety and diversity among firms. There is no single model of the innovation process: firms can differ very significantly in their approaches to innovation.

- Secondly, the fact that firms attempt to specialise around existing areas of competence means that there are limits to their technological capabilities and awareness. This leads to a phenomenon which Martin Fransman has referred to as "bounded vision":

> ... the field of vision of for-profit corporations is determined largely by their existing activities in factor and product markets, in production and in R&D, and by their need in the short and medium term to generate satisfactory profits. The resulting bounded vision implies that new technologies emerging from neighbouring area where the corporation does not have current activities are likely to take some time to penetrate the corporation's field of vision ... The need to generate satisfactory profits in the short to medium term therefore further bounds the vision of the corporation, contributing in some cases to a degree of "short-sightedness". One example is the creation of technologies for "the day after tomorrow" where the degree of commercial uncertainty is frequently great. In view of their bounded vision, corporations often tend to underinvest in the creation of such technology.[4]

"Bounded vision" is a phenomenon of considerable importance for public policy. On the one hand it means that the long-term strategic capabilities of firms can often be limited. On the other, it means that when firms seek to solve innovation-related problems, they must frequently look outside the boundaries of the firm for solutions: they draw in outside information, expertise, and advice. This can of course include inputs directly or indirectly from the public sector - from universities, from libraries and databases, from research institutes, and so on. The point here is that understanding innovation means understanding the internal capabilities of firms - how they are developed, maintained etc - at the same time as understanding their relationships with their external environments. The process of technological change,

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[4]Martin Fransman, **The Market and Beyond. Cooperation and Competition in Information Technology in the Japanses System** (Cambridge, 1990), p.3

considered broadly, is in part a process whereby technological paradigms develop (to a considerable degree on the basis of publicly-supported science and technology activity), and in part a process in which firms access, develop and refine the elements of the paradigm into specific products.

7. Technology-based and knowledge-based theories of economic growth

From a current policy perspective, the importance of understanding innovation processes in a more nuanced way lies primarily in the significance of knowledge creation and diffusion for economic growth. Perhaps the most important development in modern economics is the wide range of theoretical and applied research which suggests that research for scientific and technological advance is central to economic performance and particularly to economic growth. In this section we overview some of the key ideas and results which have structured economic thinking on these matters. We briefly overview four key bodies of theory in post-war economic thinking, and then some of the relevant applied results. The major theoretical approaches are:

- the neo-classical approach, and growth accounting
- evolutionary models and the work of Joseph Schumpeter
- "technology-gap" models of growth
- the "new growth theory"

Neo-classical growth analysis. The Classical economic thinking of the nineteenth century focused on three major problems, namely the ways in which economies allocated resources, the distribution of income, and the processes of economic growth. Economists such as Smith, Ricardo and Marx all considered the growth process to be a central scientific problem, and all saw what Marx called "the conscious application of science" as a key characteristic of economic growth. Within modern neo-classical economics, however, the focus has been primarily on resource allocation and efficiency, and on the equilibrium properties of economic systems. Within neo-classical economics, the theory of growth has not really focused on the factors which shape economic dynamics and which determine growth rates and performance, but rather on the question of whether equilibrium concepts are relevant to growing economies. In this context, technical change was seen as being interesting for its effects on the equilibrium properties of the system, and for the income distribution, but the role of technological change as a driving force of growth was downplayed. However the neo-classical school produced one major result which has had a powerful impact in shaping ideas about the links between technical change and economic growth. In the late 1950s a number of economists, the most important being Robert Solow, attempted to isolate the relative contributions of capital investment and technical change to the growth of productivity (output per worker) in the United States. In an important paper, Solow showed that the long-run growth of the US economy could not be ascribed to growth in labour or capital inputs, but was primarily influenced by a "residual factor", which Solow labelled "technical change".[5] This startling result led to a wide debate on the measurement of factors contributing to economic growth, as well as to a large research programme on "growth accounting", which attempted to quantify such factors as increasing labour skills, better capital goods, the role of technical change in shaping long-term growth patterns. One of the basic outcomes of this long programme of research has been that although technical change is no longer seen in quite the same dramatic terms as in Solow's original paper, it is now consistently recognised as one of the basic forces underpinning economic growth. However a consistent problem with the approach has been that it sees technical change as resulting from processes outside the economic system, rather than theorising it as a central aspect of activity inside the economy itself.

Joseph Schumpeter and evolutionary models of growth. The influence of the Harvard economist Joseph Schumpeter (1883-1950) has increased steadily since his death. In a series of powerfully argued books,[6] Schumpeter argued that competition in capitalist economies is not simply about prices, it is also a technological matter: firms compete not by producing the same products cheaper, but by producing new products with new performance characteristics and new technical capabilities. The search for new technologies is thus an integral part of competitive economies, and the development of new technologies is a continuous process. This leads in turn to what Schumpeter called "creative destruction", the removal of old technologies to make way for the new. Creative destruction is at the heart of the growth process, because new technologies led to increased investment, and resulted in the use of technologies with better performance and higher productivity. Schumpeter argued that growth occurred in discontinuous bursts, with "clusters" of innovations leading to investment booms and thus to cycles of growth: for him growth was not an equilibrium process, but rather a process involving major structural change. Economic growth, from this perspective, also creates many problems of adjustment in its wake. The Schumpeterian approach has been developed in recent years into a major research programme in so-called "evolutionary economics", which sees economic growth resulting from a search new technologies which introduce variety and diversity into the economic system.

Technology-gap models of growth. A key empirical feature of economic growth is the existence of significant differences among the growth rates of economies. This has led to a wide body of theory and applied research which seeks to explore the roots of these differences; such theory is of considerable importance for small economies such as Norway. The key idea is that we can distinguish between countries which are at the scientific/technological "frontier", and those who behind the leaders; they have a technological gap between themselves and the leaders. The follower economies of course have the opportunity to "catch up" with leaders by

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[5] Robert Solow, "Technical change and the aggregate production function", **Review of Economics and Statistics**, Vol 39 No 3, 1957, pp.312-320. See also Moses Abramowitz, "Resource and output trends in the United States since 1870", in N. Rosenberg **The Economics of Technological Change** (London 1971), pp.320-343.

[6] In particular, **The Theory of Economic Development**, (1912); **Capitalism, Socialism and Democracy** (1942), and **Business Cycles** (1939).

importing and diffusing the advanced technologies of the leader economies. From this perspective, rates of growth of output must inevitably differ. In leader economies, the growth of output is dependent on the rate at which the scientific/technological frontier moves; in small or follower economies it is determined by the speed with which such economies are able to adapt and use the technologies of the leaders. This in turn depends on research activities (among other factors): it has been shown that rates of growth in follower economies are strongly dependent on the rate at which such economies invest in scientific and technological activity.[7] These models therefore not only bring technological change directly into the theory of growth, they do so in ways which are of great policy importance for economies such as Norway, which import most of their technological requirements.

The "New Growth Theory". In recent years a new body of theory has emerged, usually known as the "new neo-classical growth theory". In these models, the basic process used to explain economic growth is the phenomenon of increasing returns to scale, which follow from the externality aspects of technological change.[8] Several of the most important approaches within this field involve modelling a specific "research sector" of the economy, which produces both specific new inputs, plus general scientific and technical knowledge. In these models, growth results partly from increases in the productivity of tools and equipment (intermediate inputs) resulting from technological change, and partly from "spillovers" of knowledge from one area to another. This field is a rapidly changing one, but it is important to note that for the first time we now have a body of economic theory which explicitly relates the R&D system (however abstractly it is modelled) to the economic growth process.

8. Some core research issues

The only place in which the above issues have been extensively discussed from a policy viewpoint has been the OECD's TEP (Technology-Economy) programme, which consisted primarily of a series of conferences and workshops sponsored by the OECD between 1988 and 1991.[9] The report which initiated TEP emphasised "the interdependence of technical, economic and social change", arguing that "technological change is, in its development and application, fundamentally a social process, not an event, and should be viewed not in static but in dynamic terms".[10] TEP was not in itself a research programme, and consisted essentially of a forum in which state of the art economic research could be presented. However the following main themes - which emerge also from the analysis presented above - were emphasised:

[7] Jan Fagerberg, "A technology-gap approach to why growth rates differ", in C. Freeman (ed) **Output Measurement in Science and Technology** (1987).

[8] For an excellent survey, see Bart Verspagen, "Endogenous innovation in neo-classical growth models", **Journal of Macroeconomics**, Vol 14 No 4, 1992, pp.631-662

[9] OECD, **Technology in a Changing World** (Paris: OECD), 1991; OECD, **Technology and the Economy: the key relationships** (OECD: Paris, 1992).

[10] OECD, **New Technologies in the 1990s: A socio-economic strategy** (OECD: Paris), 1988, p.11

- the need to rethink models of the innovation process
- the importance of technology diffusion
- the neglected role of technology in the analysis of corporate organisation
- the role of networks
- the role of human resources and intangible investment
- the role of technology in competitiveness and economic growth
- the increasing importance of globalisation in technology development.

The problem which remains unresolved after TEP is how these areas should be researched in the future, and how such research should be linked with policy measures and instruments.[11]We turn now to a discussion of some of these issues, looking at the policy issues involved, and some of the key research problems.

9. The basic rationale for public policy

The role and significance of technological change and innovation in the "agenda of government" depends in large part on its importance to the economic, social and cultural development of Norwegian society. Recent research suggests that innovation and technological change deserve a much more central place in the analysis of economic and social dynamics; but this remains an area requiring much more work, and new conceptual approaches.

While a wide body of applied research suggests there can be little doubt about the economic significance of innovation and technological change, there still remain unexplored issues in this field, especially from a policy perspective. Applied economic analysis has demonstrated, for example, that technical change is the most important factor in economic growth, that innovation performance (as measured by science and technology variables) underlies export performance and shares of world trade, that productivity and R&D are closely linked, and that returns to investment in R&D - even basic R&D in the university system - are high.[12]

However two major issues remain unresolved, Firstly, the theoretical bases on which some of these analyses have been made are open to question, and have been the subject of increasing debate in recent years. In some areas - such as growth theory and the theory of trade policy - there have been significant theoretical developments in the past few years. At the same time, the conceptions which underlie analyses of productivity growth and returns to R&D have also been questioned. There is now a real need to analyse the adequacy of our existing techniques for thinking about the

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[11]It is important to note that although TEP was not a research programme it initiated and supported one area of work which will prove of considerable importance in future policy-related work. This is in the field of statistics and indicators. TEP initiated a major programme of indicator development and revision, seeking to provide standard guidelines for industrial economies in twelve innovation-related area, the most important of which were innovation indicators, the technological balance of payments, science and engineering personnel, and bibliometrics.

[12] See, for example, C. Freeman (ed) **Output Measurement in Science and Technology**, (Amsterdam: North Holland), 1987; Jan Fagerberg, "International Competitiveness", **Economic Journal**, Vol 98 No 391, 1988; Z. Griliches, **R&D, Patents and Productivity** (Chicago, 1986); G. Dosi, K. Pavitt and L. Soete, **The Economics of Technical Change and International Trade**, 1990.

social and economic impacts of technological change and innovation. Secondly, there is an urgent need to think through what it is about the new conceptions of technological change which justifies public intervention, and provides a rationale for policy.

There are further questions here. The first concerns the priority which should be given to technology policy in the general "agenda of government". If it really is the case that technological change has the general effects described above, then it should be given a much more central role in public policy, both at national level and at the level of the EC. The immediate question is, what kind of priority should be given to innovation and technology policy within industrial policy? At the moment, we have industrial policies which are organised primarily around issues of competition, rather than around issues of innovation. If we seek an "innovation-oriented industrial policy" then this should be founded on a more comprehensive view of the role of new technologies in competitiveness, structural change and economic growth. However this leads on to a second question, which concerns the integration of technology policy with other forms of policy action, especially macroeconomic policy and education policy. Many policy actions in these fields have important consequences for the rate and direction of technological change, yet technology issues are rarely taken into account in decision-making. How can integrated policies, which take proper account of innovation perspectives, be formed and implemented?

What is needed here is not, primarily, new research so much as synthesis of the main themes and results of innovation analysis over the past two decades, and application of these results to a wider set of policy problems. There are two main areas to be analysed. First, we need critical overviews (not surveys) of the state of the art when it comes to the role of technological change in output growth, trade, productivity growth, etc; these reviews should aim to draw prescriptive conclusions concerning the general policy significance of innovation/technological change issues. As well as providing a basis for policy analysis, such reviews will of course define areas for future research. Secondly, we need analyses which relate existing results to other policy fields, in particular industrial policy, macroeconomic policy, education and infrastructure policies (in particular relating to telecommunications).

10. Understanding diversity: Typologies of innovation processes

It is now clear that past models of the innovation process are at the same time too narrow and have been generalised across industries in an unrealistic way. Innovation is a complex, highly differentiated process, and the time has come to seek a "map" of the myriad forms taken by innovation processes, and of how those forms are distributed across industries.

One of the key conclusions which might be drawn from the TEP program is that policy should take closer account of the real characteristics of industrial innovation processes, and in particular of the differing roles of research in industrial innovation. The interactive approach to innovation emphasised by TEP does not mean, however, that we have adequate alternative models or theories of innovation processes to replace the linear model. What has been achieved through research on innovation and technological change over the past decade is a kind of outline map of the complexity and diversity of innovation processes across firms and industries. Perhaps the single biggest study of innovation processes, the Minnesota Innovation Research Project in the US, emphasised that its primary result was "a complicated, somewhat unruly set of empirical observations that described the multi-faceted nature of innovations and that are often beyond the explanatory capabilities of existing innovation theories."[13] But if there is great variation in innovation processes, in terms of their objectives, organisation, cost, use of research, and so on, then it also means that there is variation in the problems and constraints which firms must overcome in order to undertake successful technological change.

How do innovation processes vary between industries? At the simplest level, there are differences in the amounts of research which industries must perform in order to innovate. The variations extend much further than this, however. Keith Pavitt, in a study of UK innovation activity, distinguished between four broad types of technical change processes corresponding to four types of firms: supplier dominated, production (scale) intensive, specialised suppliers and science-based. The nature of technological change differs sharply between industrial sectors, according to the types of firms within an industry.[14] The point here is that the main innovation-related problems which occur within a country or region are structure-dependent, and this is vitally important for policy. First, there is no point having a technology policy designed for science-based industries in an economy with predominantly supplier-dominated firms. But then there are wider questions about the links between technology policy and industrial/economic policy. On the one hand, policy-makers may wish to influence the evolution of industrial structure. On the other, there is no special merit in having high-technology (in the sense of R&D-intensive) industries when a country has resource advantages which can be exploited industrially, even if the resource-based industries do little R&D. What matters is that industries are technologically dynamic, even if they do not access their technologies through R&D; but this may involve issues in science and technology monitoring, investment policy (meaning both macroeconomic policies which affect investment, but also tax treatments of investment), infrastructure provision and public investment, education and training, etc. In order to know something about the appropriate balance and structure of policy measures, policy-makers need a more nuanced understanding of the types of innovation processes at industry level.

But recognising the variety in innovation processes should go further than this, down to firm level. Much economic policy is implicitly based on the economic concept of the "representative firm", that is the idea that firms are essentially similar, and that they will respond in similar ways to changes in their environment. This includes the environment of policy measures, and it is therefore assumed that any policy measure will induce common responses in firms; thus a subsidy or a tax will cause firms to respond in similar, or at very least predictable, ways. The problem here is that, in practice, firms actually differ sharply in terms of their internal cultures, management

[13] Marshall Scott Poole and Andrew H. Van de Ven, "Toward a general theory of innovation processes", in Andrew H. Van de Ven *et al* (eds) **Research on the Management of Innovation: The Minnesota Studies**, p.637.

[14] Keith Pavitt, "Sectoral patterns of technical change: towards a taxonomy and a theory", **Research Policy**, 13, (1984), pp.343-373.

systems, explicit or implicit objectives, growth strategies, capabilities in accessing and processing information, technological competences and so on. Policies which assume this diversity away - such as tax-based subsidies to R&D - are likely to founder on the problem of differential response. Of course it is out of the question to design policies which accommodate the multiplicity of company types, especially in economies with hundreds of thousands of companies in existence. But this leads to the question of whether we can construct workable typologies or models of innovation processes which are both descriptively sound and policy-relevant. In my view this is possible, via an appropriate combination of case-studies and statistical methods.

At the present time, policy remains more or less based on the idea that firms face only one problem in innovation, namely the finance of R&D. But the extreme diversity of innovation processes at both industry and firm level implies that firms face a variety of quite different problems. Innovation and technology policy should reflect this, with a more subtle and differentiated mix of objectives and instruments which correspond to the real characteristics of relevant innovation processes within the economy or region. The starting point for this can only be a wider range of models of innovation processes, and this is a key task for policy analysts in years ahead.

The starting point here should be an attempt to build better data sources on the structure and effects of innovation processes, using general survey techniques. This approach to innovation analysis has a firm empirical foundation. In recent years a number of empirical surveys of innovation activity, and of sources of innovative ideas and obstacles to innovation, have been undertaken in a range of OECD economies.[15] This is the basis of the EUROSTAT innovation survey, which will generate a significant body of micro-level data for innovation analysis.

11. External environments: National and regional systems of innovation

As technologies increase in complexity, it is more and more difficult for firms to acquire, maintain and develop knowledge bases which cover all of their technological needs. This means that they must look outside the firm to solve some of the problems which they encounter in innovation. On the one hand this opens up questions about the role of the public sector. But firms also look to inter-firm co-operation in problem solving. As we noted above, firms exist, technologically speaking, within networks of equipment suppliers, design specialists, universities and research institutes, customers, consulting engineers, and so on, and they seek to use these networks to resolve problems. Even quite small firms often have extensive

[15] There is as yet no full-scale overview of results from these surveys. But see OECD, **Description of Innovation Surveys and Surveys of Technology Use Carried Out in OECD Member Countries** (Paris: OECD), 1990; and Keith Smith "Survey-based technology output indicators and innovation policy analysis", in A.F.J. Van Raan, A.J, Nederhof, and H.F. Moed, **Science and Technology Indicators. Their Use in Science Policy and Their Role in Science Studies**, (DWSO Press: University of Leiden), pp.449-464.

formal and informal links with other firms.[16] Formally speaking, there are joint ventures, licensing and cross-licensing arrangements, acquisitions, and various co-operative research arrangements. Informally, there is extensive "know-how trading".[17] On one level these developments raise important questions about the boundaries of the firm, about what it means to speak of a "firm" at all in the context of networks.

As argued above, a substantial body of modern research emphasises the fact that firms never innovate in isolation: they do so inside technological paradigms or regimes which are external to the firm. But what is the concrete basis of a technological paradigm or regime? An important body of modern analysis sees this question in terms of more or less complex networks of formal and informal relationships. In part, these are relationships with other firms: suppliers, customers, sources of finance, even competitors. In part, they are relationships with factor markets, especially for skilled labour. In part, they are relationships with the public sector: with universities, technological institutes, standards-setting organisations, regulatory agencies and so on. A final element is the policy environment within which these institutions operate. Together, this complex set of institutions and environmental factors make up a *system of innovation*, which usually has specific geographic and political boundaries. Such systems can be understood either as a *regional system of innovation* (perhaps crossing national boundaries) or a *national system of innovation*.

One way of looking at this body of work would be to see it as an exploration of the problem of infrastructure. It is widely recognised, in public policy terms, that both physical and science-technology infrastructures are a key element in innovative and economic performance. But we have as yet no established theory of infrastructure, not do we have analysis of how infrastructures work; the "system of innovation" concept should be seen as a step forward in this area; but there remains much to be done to explore its implications.

12. Internationalisation in technological change

Finally, the capabilities of firms, and national and regional innovation systems, interact with powerful global forces in technological innovation and diffusion. There are those who argue that national borders have become meaningless in this new international context; but this remains an area of considerable uncertainty and debate. What cannot be denied is that rapid acceleration in foreign direct investment, the growth of intra-industry trade, the international movement of skilled personnel, the liberalisation of capital and foreign exchange markets all contribute to an increasingly internationalised context for technological change.

Given that firms exist in a wider economic/technological context, how does that context relate to the wider development of the global economy and its changing

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[16] John Hagedoorn, "Networks in research and production", **International Journal of Technology Management**, 1991, pp.81-95; Håkon Håkonsson, **Corporate Technological Behaviour: co-operation and networks** (London: Routledge), 1988.
[17] E. Von Hippel

organisation? The key issue is the fact that the relevant networks are international. Technology development and diffusion, like the overall operation of market forces, is more or less global. The problem is that policy is national or regional. Many policy systems have as their objective the competitiveness of national industries, an objective which often does not fit with the transnational dimensions of the technological change process. As the authors of a recent study of semi-conductor based industries remarked:

> ... the model of a battle between distinct and well-defined "national" industries is an inappropriately unsophisticated one in the case of microelectronics. Indeed, we would maintain that it is impossible to come to terms with competitiveness without first recognising and appreciating the international inter-relatedness of the industry.[18]

Let us describe just one implication of this for science and technology policy. For policy-makers concerned with a country or region, what matters for "competitiveness" is the ability of firms located within the region/country to engage and act within the transnational networks through which technology is developed or diffused. Of course this is in part a function of R&D performance at firm level. But only in part. It also depends on access to skilled personnel, access to the science and technology infrastructure, financial and marketing resources and so on. It is very important for policy-makers to conceptualise and operationalise these wider factors in technological competitiveness, if they are to devise appropriate policy instruments in the new international context.

A further international policy dilemma relates to fundamental science. The problem here is precisely the fact that science is, and always has been, international: it is based for the most part on open publication, and results are mostly non-appropriable. At the same time the links between science and technology are often tenuous. These points suggest that, for national policy-makers concerned with economic results, an obvious move is to reallocate resources away from fundamental science towards research which is more or less directly oriented to industrial applications. There is much to be said in favour of this, and certainly there should be nothing sacrosanct about the post-war allocation of scientific resources (which heavily favoured high-energy physics). But at the same time such moves mean that no national system has any incentive to develop scientific fields where there may be long-term opportunities, but no short-run benefits. To the extent that such fields exist - and however sceptical one might be about the linear model, there are many historical examples to show that they do exist - then strategies which are right for individual countries are wrong for the world. From a game-theory perspective, this is a straightforward Prisoners Dilemma problem. Like the Prisoners Dilemma, the solution lies in collaboration. But existing international mechanisms for support of fundamental science are either non-existent or inadequate, and an important policy challenge for the future is therefore to build appropriate collaborative institutions which can decide priorities, allocate resources and disseminate results.

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[18] R. Langlois et al, **Microelectronics: An Industry in Transition**, (London: Unwin Hyman), 1988, p.3.

The 1980s saw a significant step forward in the internationalisation process; in the past, internationalisation has been discussed mainly in terms of multinational corporations. But over the last decade, internationalisation came to affect almost all aspects of the industrial economy. The most obvious development was the liberalisation of capital markets so that the world now has integrated 24-hour capital and foreign exchange markets; one effect of this is that ownership of corporations is becoming more diffused internationally. But production also became much more internationalised: global foreign direct investment grew at 20 percent per year through the 1980s, which was very much faster than the growth of international trade (which grew at less than 5 percent per year). Instead of producing from national bases and then exporting, large companies now produce globally: US firms now produce eight times more output outside the USA than they export from the USA. This is not just a matter of multinational companies: in almost every important industry and product group, products are produced through integrated global manufacture. Even a simple product such as a piece of clothing involves primary production, cloth manufacture, design, fabrication, finance and so on occurring in several countries. Most firms, regardless of their size, are involved in complex relationships (including sub-contracting) with suppliers and customers which often go beyond national boundaries. This internationalisation process extends into the technological sphere: even small companies in small countries (such as small electronics producers in Norway) have joint ventures, R&D co-operation, licensing arrangements, technology trade and so on which are international in scope. (A recent survey of Norwegian R&D-performing firms showed that 38 percent of them were performing co-operative R&D with partners outside Norway). The technical division of labour involved in the production of industrial products is now thoroughly internationalised. These internationalisation processes take different forms in different industries, and are far from complete. But they do form a real and significant trend.

What are the implications of all this? On one level, there are real questions about whether we can think about companies, especially large companies, as "national" entities. When the ownership, management, finance and technology of a company are integrated across many national boundaries, it becomes unclear whether there is such a thing as a national company. This has obvious implications for industrial and technology policy. Can we have a national industrial policy in the context of internationalised industries and companies? What problems of international policy co-ordination are raised by the internationalisation process?

Most of the questions raised in science and technology policy only make sense against the background of these internationalisation processes. One critical issue concerns location of industry. Should there be some kind of international "rules of the game" on incentives for companies to locate in particular countries or regions in order to prevent competitive bidding - in terms of tax breaks, subsidies etc - by countries? A second issue concerns public research systems. How should the public support of industrially-oriented R&D be organised in this new international context? What are the appropriate objectives and methods? Is it possible to have a national technology policy of the traditional kind, namely R&D support to national companies? Or should industrial policy be focused on the education/training/basic science infrastructure? In the latter case, there are serious questions about the role of international collaboration and co-ordination. This question also takes us to the second major trend indicated above, namely the role of science in technological change.

13. New technologies, economic growth and the science base

The increasing recognition of research and technology as supports to economic growth has also directed attention to the use of science in industrial innovation. If we reject so-called 'linear' models of innovation, this should not imply that science is unimportant in industrial innovation processes; rather, it is a question of how science fits into these processes. If we take the view that firms do research in order to solve key problems either in existing technologies or planned innovations, then it is clear that many industrial innovation problems at the present time require basic science in order to be solved. Nathan Rosenberg has emphasised the fact we do not possess an adequate scientific understanding of many aspects of advanced industrial technologies. This is often the case with quite fundamental processes: for example, combustion processes, airflow over aircraft wings, and aspects of computer architectures are all areas where technological development lacks a basis in scientific knowledge, and where industrial processes remain based on 'trail and error'.

Technology is not simply applied science, and new technologies do not necessarily flow from previous scientific research. More often, fundamental science has its problems and search areas shaped by practical needs (often military rather than commercial). Since this kind of science is characterised by high levels of uncertainty in research output, and by long lags between research and identifiable applications, economic evaluation is more or less impossible. But there are plenty of examples of the use of fundamental or university-based research which are relevant in understanding the evolution of industrial innovation, and there is some evidence that this scientific role is increasing. Perhaps the quantitative indicators in this area are the references to basic research literature in patents. A number of writers have shown that patented inventions are increasingly drawing on academic science, as measured by academic journal literature in patent applications.[19] But how does this occur? What are the main channels of knowledge flow? What are the main industries whose technological problems now require scientific solutions? There is a serious "mapping" problem here, which will feed into some of the other problem areas described above, and which is of great importance for policy-makers.

There is evidence that the connections between industrial innovation and fundamental science are becoming closer. Although there is no general or linear relationship between basic or fundamental scientific research, on the one hand, and product or process innovation activity on the other, there are nonetheless industries and activities where the two are closely related. The fastest growing industries within world trade are without exception research-intensive, and in a number of these industries - chemicals and pharmaceuticals, electronic and photo-optic products, and

[19] F. Narin and E. Noma, "Is technology becoming science?", **Scientometrics**, 7 (1985), 369-381, and F. Narin, "Technology indicators based on patents and patent citations" in A.F.J. Van Raan (ed) **Handbook of Quantitative Studies in Science and Technology** (Amsterdam, 1988), pp.465-507,

so on - tight links can be demonstrated between the invention process, and underlying fundamental research. In Europe, Japan and the U.S.A., research policy is increasingly directed towards attempts to enhance competitive advantage in industry, with both companies and policy-makers believing that future competitiveness will spring from the exploitation of results in basic scientific research. So industrially-oriented research at the present time finds its priorities not just in innovations based on reasonably well-understood technological principles, but also in large-scale research programs in basic science areas such as recombinant-DNA, biotechnology, superconductivity, new materials and so on. Whatever the long-run historical relationship between science and technology in the development of the West, there can be little doubt that at the present time the links are close.

The following problem arises. If countries concentrate their science policies on "oriented basic research", aimed at areas where specific industrial applications are envisaged, what happens to more general areas of science where results are not easily appropriated or linked with industrial applications? Science is a "public good", in the sense that it is non-marketed and that published results are easily transferred. This gives countries an incentive <u>not</u> to provide basic research, but to utilise the results of research carried out by others. If everyone takes this perspective, there will be a general underprovision and underfunding in scientific areas where results are not easily appropriated. The only way around this problem is some general international commitment to co-ordinated funding of such scientific areas. There are obvious problems concerning levels of funding, selection of research areas, and institutions.

14. Technology and the environment

A key current policy issue concerns the technology policy aspects of environmental change. Apart from natural shocks such as volcanic eruptions, environmental problems generally stem from an interaction between population increase, economic growth, and the underlying technologies on which economic growth is based. In the case of greenhouse gas emissions, for example, we are dealing with the effects of long-term use of core industrial technologies related to energy supply and use, and reducing the scale of emissions must involve either a significant reduction in the scale on which these technologies are used, or their more or less complete replacement. In either case, a move towards environmental stability must entail large-scale technological change. For environmental policy, therefore, the understanding of technological change in systems of energy supply and use becomes a key issue. The question of environmental stability and sustainability is therefore central to modern technology policy, both nationally and internationally.

15. The Norwegian context

So far these issues have been discussed in a general framework. But the major objective of the STEP Group is to contribute to Norwegian policy development, which means that the issues described above must be set in the context of specific Norwegian circumstances, and Norwegian economic and social challenges.

What are the major issues facing Norwegian policy-makers? Any list here must be rather provisional, but the following issues are among those which deserve attention:

- The Norwegian industrial structure is heavily dependent on large 'traditional' industries (such as food products, timber products, non-electrical machinery) which are characterised by low R&D-intensities, and which do not access technologies primarily through R&D. What are the appropriate policy support measures for such industries, and should they receive higher priority from policy-makers?
- 'Intangible investment' (in R&D, marketing, training etc) in the Norwegian economy is now higher than physical investment; are there aspects of intangible investment (such as design services) which deserve public support?
- Norwegian industrial structure is heavily based on small firms; what is appropriate policy on venture capital support for creation of new firms; how should the science and technology infrastructure (especially the institute sector) relate to these firms?
- The Norwegian government has, and will continue to have, the objective of maintaining a regional distribution of the population, and therefore of economic activity. (This objective of course connects with that of the 'traditional' industries mentioned above). With the exception of Oslo and Trondheim, no regional districts of Norway possess the strong regional technology networks and infrastructures which characterise the successful manufacturing regions of Southern Germany or Northern Italy. What are the implications of this for regional science and technology infrastructures and support services?
- Norway maintains a large sector of technological institutes. What are the real functions and effects of this system, and to what extent does it contribute both formally (via R&D performance) and informally (via know-how exchange and mobility of personnel) to industrial innovation in Norway? In general, how can we understand - both conceptually and empirically - the real structure and effects of the Norwegian science and technology infrastructure?
- How important is the service sector in Norway in overall innovation performance, and what support services might be necessary for it?
- To what extent is the disciplinary structure and organisation of Norwegian universities appropriate to the industrial and social needs of Norway in terms of innovation and diffusion activities; what is the real contribution of the university system? In general, what are the primary forms of human capital development in the Norwegian system, how do they function, what are their interactions, and how appropriate are they for innovation-oriented activities?

Finally, we should note that in terms of the statistical needs identified by the TEP programme, Norway is well placed. Norway has good R&D statistics, and SSB and other institutions have developed a range of other statistical resources, in the fields of intangible investment and innovation, for example. However the various statistical resources have not been used as well as they could be in policy analysis, and an important objective of STEP should be to improve the quantitative inputs to policy decisions.

16. Identifying core policy issues

In this section we try to draw together the threads of the arguments in the above pages, attempting to identify some of the major policy-related issues which remain unresolved in the social and economic analysis of science, technology and innovation. Some of these are potentially very broad, relating to clarifying the general economic role of innovation; others, much more specific, are related for example to conjunctural developments and specific Norwegian needs.

General policy issues:

1. The role of scientific and technological change in economic growth and social development; endogenous growth theory
2. Rationales and methods for public support of innovation and R&D policy
3. International collaboration in science; megascience programmes, the appropriate role of FRAMEWORK etc
4. Mapping the use of science in industrial innovation
5. Social and economic factors in the diffusion of technologies
6. Characterising innovation processes across firms and industries: typologies of innovation and their policy significance
7. Acquisition, development and management of technological capabilities inside firms
8. Internationalisation and cross-border linkages in innovation
9. Technology policies for sustainable development
10. Education, training and technological capabilities
11. Coordinating science and technology policy with industrial, financial and educational policies

Norwegian policy priorities:

1. Government budgetary policies for research and innovation
2. Inter-agency co-ordination in innovation policy
3. R&D and innovation performance in Norwegian industries; quantitative mapping
4. Innovation processes, learning and growth in 'traditional' industries
5. Mapping the national and regional innovation systems; institutional roles in Norwegian research and innovation performance; innovation infrastructures and support services
6. Non-R&D aspects of innovation in Norway: industrial finance, design, training and intangible investment
7. Role of the service sector; innovation and economic performance, inter-industry linkages
8. Small firms, firm creation and the finance of innovation
9. Creation of human capital; education, training, mobility of researchers and the diffusion of human skills
10. Development and operation of integrated statistical systems

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STEP group

STEP-gruppen ble etablert i 1991 for å forsyne beslutningstakere med forskning knyttet til alle sider ved innovasjon og teknologisk endring, med særlig vekt på forholdet mellom innovasjon, økonomisk vekst og de samfunnsmessige omgivelser. Basis for gruppens arbeid er erkjennelsen av at utviklingen innen vitenskap og teknologi er fundamental for økonomisk vekst. Det gjenstår likevel mange uløste problemer omkring hvordan prosessen med vitenskapelig og teknologisk endring forløper, og hvordan denne prosessen får samfunnsmessige og økonomiske konsekvenser. Forståelse av denne prosessen er av stor betydning for utformingen og iverksettelsen av forsknings-, teknologi- og innovasjonspolitikken. Forskningen i STEP-gruppen er derfor sentrert omkring historiske, økonomiske, sosiologiske og organisatoriske spørsmål som er relevante for de brede feltene innovasjonspolitikk og økonomisk vekst.

The STEP-group was established in 1991 to support policy-makers with research on all aspects of innovation and technological change, with particular emphasis on the relationships between innovation, economic growth and the social context. The basis of the group's work is the recognition that science, technology and innovation are fundamental to economic growth; yet there remain many unresolved problems about how the processes of scientific and technological change actually occur, and about how they have social and economic impacts. Resolving such problems is central to the formation and implementation of science, technology and innovation policy. The research of the STEP group centres on historical, economic, social and organisational issues relevant for broad fields of innovation policy and economic growth.