Innovation as a Systemic Phenomenon: Rethinking the Role of Policy

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Abstract
This paper looks at the policy implications of viewing innovation as a systemic phenomenon. The first section provides a brief overview of conceptual approaches used in the recent literature on innovation systems. The second part of the paper looks at learning and technological knowledge at the firm-level, and explores the ways in which different theoretical approaches affect our understanding of innovation processes. This discussion focuses on the contrast between ‘systems’ models of learning and the concepts of knowledge which underpin the current ‘mainstream’ rationale for public policy in this area. The third section discusses policy problems arising from this broad field of study, focusing on two issues: the rationale for policy intervention; and policy capabilities and ‘knowledge bases’.

Key words: Innovation; Innovation systems; Innovation policy.

1. Systems Approaches to Innovation
1.1. The Basics of ‘Systems’ Approaches

‘Systems’ approaches to innovation are founded on one of the most persistent themes in modern innovation studies, namely the idea that innovation by firms cannot be understood purely in terms of independent decision-making at the level of the firm. Rather, innovation involves complex interactions between a firm and its environment. On one level the environment consists of interactions between firms – especially between a firm and its network of customers and suppliers. Here the argument is that inter-firm linkages often involve sustained quasi-cooperative relationships which shape learning and technology creation rather than being arms-length market relationships. On a second level the environment involves broader factors shaping the behaviour of firms: the social and perhaps cultural context; the institutional and organisational framework; infrastructures; the processes which create and distribute scientific knowledge, and so on. Environmental
conditions are often seen as specific to regional or national contexts, but they are also dynamic: their forms of operation change with political conditions, changing technological opportunities, economic integration processes and so on. The basic argument of systems theories is that system conditions have a decisive impact on the extent to which firms can make innovation decisions, and on the modes of innovation which are undertaken.

The relevance of ‘systems’ approaches springs from two hypotheses concerning innovation. The first is that innovation is central to competitiveness among firms; the evidence for this hardly needs documentation here. The second is that innovation is pervasive: it is in no sense a marginal phenomenon, and it underpins economic growth at the national level. The processes which effect innovation thus shape overall trajectories of economic development. Some empirical evidence of the interactive ‘systemic’ processes which underpin innovation will be presented below.

Systems theories involve a very strong overall hypothesis that differences in macroeconomic performance can be traced to underlying system differences. What factors suggest that a focus on national systems and national policy levels might be relevant? On the one hand we have persistent differences in national economic performance. The world economy essentially divides into two groups of countries, rich and poor, with little convergence between them; inside the rich group there is convergence in real income levels, productivity levels and so on – for a recent overview, see Dowrick (1991). However, even where economies are converging in terms of macroeconomic indicators, it should be noted that this is occurring on the basis of differences in growth rates of output and productivity which can be marked and persistent between the national economies involved. These differences appear against the backdrop of underlying structural differences.

Two important areas of structural difference are identifiable at a national level. Firstly, there are persistent variations in systems of governance: both narrowly in the sense of formal regulatory systems of corporate governance, and more broadly in the sense of rules of the game for corporate behaviour (Lazonick, 1991). Secondly, many countries construct and maintain quite specialized technological capabilities, reflected in patterns of R&D expenditure, patenting, scientific publication and so on (Archibugi and Pianta, 1992; Patel and Pavitt, 1994), such that firms appear to develop competencies and capabilities within specific national contexts, even when they are multinational in terms of production and operations (Patel and Pavitt, 1991).

It is sometimes argued that globalization is rendering the state (at whatever level) obsolete, and that the integration of product and capital markets removes the possibility of effective policy interventions by government. However, the continuing nationally specific character of much economic functioning suggests that, although the foundations and scope of policy may by changing, government will remain important in setting the context and framework for economic behaviour (Hirst and Thompson, 1996).

1.2. The Literature on Innovation Systems

The innovation systems literature is an evolving field; moreover it is one with strong connections to other theories and fields of study, both historically and in contemporary research. For example, systems theories often return us to long-standing debates in economic theory. These may be to do with the importance of national policy frameworks in economic development (often deriving from ideas of Friedrich

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List (Freeman, 1994)), or of institutional conditions (where the very extensive institutional economics literature remains important). More generally, they return us to the broad conceptions of the economy as a social process deriving from Marx; in fact Marx is one of the few really important theorists to attempt to combine a theory of technological change with a theory of development.

These disparate frameworks are applied to develop an understanding of quite specific trajectories or processes of innovation and, since systems theories tend to argue that innovation and technological change fundamentally shape economic growth, what we have is an emerging empirical and historical approach which (potentially or actually) integrates a theory of innovation into a theory of growth and development. This kind of integration is a step beyond Schumpeter, whose treatment of innovation processes is rudimentary or partial.

Regardless of the genealogy of the approach, it stands in strong contrast to that of neo-classical mainstream in economics. This is particularly the case for the general equilibrium approaches which underpin the so-called new classical macro-economics; these approaches rely on optimization behaviour. But there is also a contrast with recent industrial organization theory. Mainstream industrial economics and organization theory has moved a long way from the models of perfect competition, deterministic environments, perfect information, constant returns to scale which characterize many textbooks and which are often used to caricature mainstream economics. For more than twenty years the dominant analysis has stressed strategic interdependence between firms, uncertainty, asymmetric information and increasing returns, and the literature on these topics is now very large. Nevertheless this literature has not addressed institutional issues, it has a very narrow concept of uncertainty, it has no adequate theory of the creation of technological knowledge and technological interdependence amongst firms, and it has no real analysis of the role of government. In addressing these core features of reality, the systems approach takes us, for all its possible limitations, into a more promising arena for policy analysis.

The modern literature, focused around national systems of innovation, but at least in recent years also acknowledging both localized and transnational dimensions, begins in the 1980s (Edquist, 1997; McElveen, 1991). Quite apart from the broad conflicts between neo-classical and more heterodox theories, there appear to have been two basic underpinnings to the national systems approach, both rooted in studies of innovation.

On the one hand, there were firm-level studies of inter-dependence between producers and users of technology, emphasizing sustained user-producer interactions in technology creation. These relationships were facilitated by industrial specialization and common cultural and policy environments. Teubal (1977) was probably the first to use the term ‘user-producer interaction’, but this notion was developed into a systems approach by Lundvall, Andersen and others. Their studies of export specialization in Denmark showed the importance of the Danish agro-industrial complex, and suggested that competitiveness in agricultural products was related to strong links between agricultural producers and specialized equipment suppliers (Andersen and Lundvall, 1987). Their analysis focused very much on search strategies and learning processes within this key area of specialization, without linking this specifically to a national level of institutional organization. In this approach, and in an important 1988 paper by Lundvall (1988), the national system was essentially seen in terms of inter-industry technological inter-dependence, based on the suppliers and users of capital and intermediate goods in areas of
competitive trade specialization. Groups of users and producers, engaged in interactive learning, create different complexes or clusters of technological capability which when taken as a whole define the diverse components of the national system. This is in effect an evolutionary approach, looking at the co-development of learning processes and competitive specialization.

On the other hand, at around the same time, Freeman (1987) was developing a somewhat different approach, based on an attempt to understand Japanese post-war industrial and innovative performance. Freeman focused on national-level policies, and social and institutional factors shaping firm behaviour. These included the role of MITI in forming economic development strategies, in forecasting, and in a range of actions related to technology acquisition from abroad. Freeman also stressed specific features of the internal organization and objectives of Japanese companies (especially large companies) with respect to the role and methods of innovation inside the firm, and to their ability to invest for the long term – in effect drawing attention to the national characteristics and effects of Japanese corporate governance. Finally Freeman placed great weight on the scale and character of education and training in Japan. Rather than having the evolutionary characteristics of the Lundvall approach, Freeman stressed discretionary decision-making, arguing that the combination of public policy, corporate governance, and education and training shaped the rate and flexibility of innovation in Japan, and underpinned extraordinary post-war performance.

What we have, then, in these ‘founding’ texts is different (although not necessarily incompatible) approaches: one based on the evolution of specialization and its associated patterns of interaction and learning, and one based on economy-wide features of corporate behaviour, policy and support processes such as education. These differences in emphasis were carried through into the two major studies on national systems published in the early 1990s: the first, a major extension of the work of Lundvall and his collaborators in Aalborg (Lundvall, 1992), and the second an international comparative study of fourteen economies under the leadership of Nelson (1992). The difference between these volumes can probably best be summed up in terms of two approaches to national systems, described by Lundvall himself. According to Lundvall a distinction can be made between a narrow and a broad definition of an innovation system respectively:

The narrow definition would include organisations and institutions involved in searching and exploring – such as R&D departments, technological institutes and universities. The broad definition ... includes all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as subsystems in which learning takes place (Lundvall, 1992, p. 12).

Nelson’s National Innovation Systems essentially follows the narrow definition. It consists of fourteen national studies of three groups of countries: large high-income countries, smaller high-income countries, and lower-income countries (three of which are however rapid developers). The studies are primarily descriptive, and are in effect detailed studies of R&D organization structures and allocations over time; as such they are very valuable but they often go to the conceptual core of the systems approach only in somewhat partial ways.

In National Systems of Innovation, Lundvall and his collaborators focused much more on a conceptual account of the characteristics and effects of learning. Their
definition of a system is as follows:

... A system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful, knowledge ... a national system encompasses elements and relationships, either located within or rooted inside the borders of a national state (Lundvall, 1992, p. 2).

In the Lundvall framework innovation is conceptualized as learning, since innovation is – by definition – novelty in the capabilities and knowledges which make up technology. The Aalborg school uses three basic concepts to understand the nature and dynamics of learning: the organized market, interactive learning, and the institutional framework.

The starting point for the analysis is the prevalence of vertical linkages between firms supplying intermediate and capital goods to each other through the production chain. The argument is that these market relationships are not arms-length, but instead persist through time and involve inter-firm co-operation in the development and design of products. Cooperation means that there are no independent demand and supply functions; product specifications are jointly developed. The markets are ‘organized markets’ in that they are based on explicit or tacit agreements to collaborate over time.

User-producer interaction in technology development means that learning processes are interactive – there are flows of data and information, and feedbacks concerning both needs and product performance between agents. Such arrangements require trust, and involve underlying cultural contexts which go beyond the contractual relationships of the pure market.

It is here that institutions become important, in the sense of culturally or politically established ‘rules of the games’. The institutional framework is wider than the economic sphere, but it has powerful impacts on the internal organization of firms, and on firm inter-relationships. Institutions imply routinized behaviour and actions: they ‘reduce uncertainties, coordinate the use of knowledge, mediate conflicts and provide incentive systems’ (Lundvall, 1992, p. 26).

Within this overall framework, learning involves the creation of both tacit and codified knowledge concerning not only technical characteristics of production and innovation, but also knowledge concerning how and why to search in particular ways, including knowledge of key (problem-solving) people within the relevant networks (Lundvall and Johnson, 1994).

From both of the perspectives overviewed above, processes of learning and knowledge creation emerge as central issues in innovation capability. Within the systems literature there is one major attempt to conceptualize knowledge creation and distribution at the system level in an important paper by David and Foray (1995). The paper seeks to describe the multi-dimensional character of scientific and technological knowledge. It should be noted that they do not look at all forms of knowledge or interactions relevant to firm-level economic performance: they leave aside knowledge related to finance, marketing, and design, for example, which are elsewhere seen as relevant to innovation. The David and Foray approach focuses explicitly on ‘learning systems for scientific and technological knowledge’, which is seen in a highly differentiated way, both in terms of its characteristics and functions, and its institutional features.

Firstly, relevant knowledge is classified in terms of its objects, and related actions, distinguishing between: knowledge of factual propositions; knowledge
which constitutes explanations and understanding; operative knowledge for performance of tasks; and knowledge of relevant actors. Technological knowledge bases are seen as either generic, infratechnological (meaning primarily methodological), applied, and product-process relevant. All of these types of knowledge can be either codified or tacit, and are producer under different modes of organization which shape different disclosure regimes.

These considerations lead to a concept of 'knowledge-product space', which is essentially a way of categorizing different forms of knowledge by placing them with respect to three different dimensions:

- from completely tacit to fully codifiable;
- from fully disclosed to fully restricted; and
- from privately owned to publicly available.

The argument is that within this complex structure of differentiated knowledges, what determines performance is not so much knowledge creation as the 'distribution power' of the system: the system's 'capability to ensure timely access by innovators to the relevant stocks of knowledge'. The distribution power of the system affects risks in knowledge creation and use, speed of access to knowledge, the amount of socially wasteful duplication and so on.

David and Foray identify five processes of knowledge distribution relevant for innovation:

- the distribution of knowledge among universities, research institutions and industry;
- the distribution of knowledge within a market, and between suppliers and users;
- the re-use and combination of knowledge;
- the distribution of knowledge among decentralized R&D projects; and
- dual technological developments (especially civil and military).

This kind of approach clearly has policy significance, since several of the organizational channels identified by David and Foray – particularly the first and last – are in practice strongly shaped by policy decisions.

1.3. Other 'Systems' Approaches

The approaches described above are important as analyses of contemporary learning processes and patterns of innovation. But as noted above, they have been developed against the background of wider bodies of work which explore interactive phenomena, at the level of firms, industries, regions or even national contexts.

1.3.1. Approaches from the History of Technology. This field has developed rapidly in recent years especially around analyses which conceptualize technologies not as artefacts but as integrated systems of components and supporting managerial or social arrangements. A particularly influential body of work has been that of Thomas Hughes, whose history of electrical power generation and distribution emphasizes firstly that the development of this core technology of the 'second industrial revolution', must be understood in terms of 'systems, built by systems builders'. This work includes study of the electrification of the USA, UK and Germany between the 1880s and 1930s. As Hughes shows, the evolution of electric power systems was different in each country, despite the common pool of knowl-
edge to draw on. Reasons for these differences are found in the geographical, cultural, managerial, engineering and entrepreneurial character of the regions involved. The ‘networks’ which he studies refer not only to the technology but also to the institutions and actors involved. This systemic approach has also been used in general studies of the history of technology, particularly those of Mokyr (1992) and Gille (1978).

1.3.2. Approaches from ‘Science and Technology Studies’. The term ‘science and technology studies’ refers to a wide body of primarily sociological research that sees the development and use of technology within a social framework: thus differences in technological performance between societies have at least some of their roots in social structure and cultural forms (Jasonoff et al., 1995; Williams and Edge, 1996). The social system makes economic and political choices (via for example the evolution of consumption patterns) which influence the development and spread of technologies, and which – through education, training and general culture – develop the skills needed to operate technologies. This approach has been applied to such disparate particular technologies as electric cars, missile guidance systems, fluorescent lighting and the SONY discman. An important policy application drawing on aspects of the STS approach has been made by Bell and Callon (1994).

1.3.3. Approaches from Business Organization Studies and the Theory of the Firm. The pioneering work of Chandler in this field has focused on the evolution of business organizations – particularly large firms – in terms of vertical integration and the systemic integration of intra-firm functions (Chandler, 1962, 1977, 1990). Chandler analyses the growth of firms in terms of the ability of management to undertake major programmes of long-term investment in three areas: production, distribution and management itself. This work is important from a ‘systems’ perspective in that it relates inter-country differences – shaped by policy, financial systems and governance regulations – to major differences in economic performance. Perhaps more than the national systems literature itself, it draws the link between system differences at firm level, and differences in macroeconomic trajectories. Approaches developed from these ideas have explored these national performance differences explicitly: the work of William Lazonick is particularly important here, both in challenging the notion of ‘arms-length’ market relations as a prevalent form of economic organization, and in relating actual firm and market organizations to economic performance (Elbaum and Lazonick, 1986; Lazonick, 1991).

1.3.4. The Regulation School. The work of Boyer and his colleagues is particularly noteworthy for a systems approach based on the concept of ‘filière’ (Boyer, 1988). A filière is made up by a specific set of infrastructures, technologies, institutions, practices and actors. Behind the notion of a filière is the idea that technologies are best understood not as individual techniques, but as integrated systems. This view of the technology of a firm implies strong interdependence, because relevant technological knowledges are located in different firms, with interactions between firms in terms of technological capability. That is, the capabilities of any individual firm are shaped in part by its historical experience and its dynamic development of
competence, but also by accompanying developments in related firms. The development of specialization, accompanied by inter- and intra-industry flows of technology, implies that we should think of the technological structure of an economy not as an agglomeration of independent micro-level decisions, but as an integrated system shaped partly by the input-output relations between firms, and partly by intra-firm specialization of tasks.

1.3.5. Industrial Cluster Approaches. Closely related to the filière concept, these are analyses which explore the performance of industrial sectors in terms of the integration of different types of firms and industries, sometimes around key technologies, and which emphasize environmental conditions and inter-industry interactions in creating dynamic clusters or blocks of industry characterized by high growth of output, productivity and – sometimes – trade shares. The best-known example of this approach in recent years is the work of Porter (1990), but this approach actually has many antecedents; in particular the work of Dahmén (1970) on ‘development blocks’ and Hirschman (1958) on linkage effects. Although such work is strongly systemic in character, it is not necessarily focused on the specific dynamics of innovation and technology creation. The latter is taken up in what might be called ‘technological system’ approaches to the technological level itself. Advanced-economy technologies do not exist as individual artefacts: they usually take the form of integrated technological systems, in which component elements are incorporated into overall systems. For such key technologies as cars, computers, and aircraft, but also for a host of less spectacular products, there is in a sense no unified knowledge base at all: product producers are in effect system managers, whose competence relies primarily on the ability to specify and integrate diverse inputs. A recent major study in this area, looking at the integration of electronics, advanced manufacturing systems, and robotics in the context of firm interactions and academic infrastructures, is the work of Carlsson and his collaborators on the development and evolution of factory automation technology in Sweden (Carlsson, 1995).

To sum up, we might argue that systems approaches have three basic conceptual underpinnings, and we can distinguish among the approaches according to the emphasis which they place on the different underpinnings. They are:

- the idea that economic behaviour rests on institutional foundations, in the sense of legally or customarily established ‘rules of the game’ which evolve because of the advantages they offer in reducing uncertainty. Different modes of institutional set-up lead to differences in economic behaviour and outcomes.
- the idea that competitive advantage results from variety and specialization, and that this has path-dependence-inducing effects. That is, successful specializations are self-replicating, with system-creation as an outcome – particularly around specific industrial structures.
- the idea that technological knowledge is generated by interactive learning, and that technological knowledge in general takes the form of ‘distributed’ knowledge bases among different types of economic agents who must interact in some way if technological knowledge is to be applied.

This overview is a necessarily brief one, and the bodies of literature which are relevant might well be extended, and might also be categorized in different ways. The general point here is that interactive 'systems' approaches are not confined to
the national systems of innovation literature. On the contrary, they are a prevalent feature of research which relies not on assumptions about the nature of technology but rather on empirical analysis of its real character, and which is therefore relevant to thinking about policy against the background of a systems framework.

1.4. Innovation and the Agenda of Government: Empirical Evidence

Although this is not the place for an empirical overview of systems, it is important to take up one empirical point of evidence before turning to a discussion of policy foundations. In order for any particular approach to be considered seriously in policy terms, it is important that its practical relevance should be demonstrated. We have noted above that innovation systems approaches tend to be founded on two strong hypotheses. The first is that innovation is a pervasive phenomenon – central rather than marginal to the operations of firms. The second is that interactions between firms, and between firms and other knowledge-producing agencies, are central to innovation performance. Both of these propositions receive some support from available data on innovation.

Data from the Community Innovation Survey (CIS) of 1992 for four countries – Denmark, the Netherlands, Germany and Norway – shows that a sizeable proportion of firms have new products (introduced to the market within the past three years) in their product mix, the number of new products increasing with firm size (OECD, 1992). The figures imply rather rapid changes in product mixes in innovating firms. The data also shows that a substantial proportion of sales are coming from new products in all the countries examined and that, furthermore, innovation is not confined to ‘high-tech’ industries by appears to be pervasive across sectors.

Interaction among firms can only be examined in a preliminary way with CIS data, however the data is suggestive. The CIS Survey asked firms whether they undertook R&D collaboration, and about external sources of information for innovation. Simply looking at technical R&D collaboration (which is of course likely to understate the general scope of collaboration) and asking whether collaborating firms are more innovative shows substantial differences across countries between co-operating and non co-operating firms. Looking at differences across sectors for one economy, Norway, co-operating firms once again appeared to be considerably more innovative. Figure 1 indicates that cooperating firms dominate turnover among innovators in 13 of the 17 classes of industry surveyed.

Although the data needs deeper examination and more formal testing procedures, there does appear to be an empirically-supported case to be made for some of the major propositions of the systems approach. We turn now to a discussion of the nature of the learning and knowledge creation processes which underpin innovation, and which are central to the policy issues.

2. The Nature of Technological Knowledge

If innovation is conceptualized as learning, then policy must concern itself with the nature of learning and the knowledge which results from learning. In fact this is a core issue for policy: as we shall see, current rationales for policy are intimately bound up with assumptions about the nature of technological knowledge. In this part of the paper, therefore, we addressed the problem of understanding technological knowledge, and in particular exploring those characteristics of
technological knowledge which imply: (a) the existence of ‘systems’; and (b) the need for new approaches to policies aimed at innovation. We begin with a critique of the ways in which production and technological knowledge are conceptualized in neo-classical theory, and the approaches to policy which are derived from that theory. Then we turn to ideas about technological knowledge drawn from modern innovation theory and analysis, and the ways in which this implies systemic relations between firms, and between firms and public institutions. The paper then moves to a discussion of policy issues.

2.1. Neo-Classical Production Theory and Technological Knowledge at Firm Level

Insofar as innovation policies have had a theoretical rationale in the past, it derives from ideas within neo-classical production theory concerning the nature of technological knowledge; these ideas have been powerfully influential in structuring views about the appropriate scope, objectives and instruments of policy. Although they have been frequently criticized in the modern innovation literature, especially when it comes to policy discussion (Metcalfe, 1994; Smith, 1991), it is worth looking in some detail at the debate here, since it has important implications both for the foundations of policy, as well as for the empirical operations of policymakers.

Neo-classical production theory is built on the idea that firms face a dual production decision. Firstly, they must decide what to produce. This decision is based on rates of return: potential product lines are known, and firms will allocate and reallocate capital among them in search of the highest returns. Then the problem is the choice of production technique: firms within an industry face a given and known array of production technologies and are assumed to have the competence to operate all available production methods. Armed with this knowledge, and with a knowledge also of present and future factor prices, and present and future

Source: Nás and Smith (1994)

Figure 1. Share of turnover from new products, Norway, firms with \((n = 165)\) and without \((N = 226)\) R&D cooperation, by industry class (%).
product prices, firms can make a profit-maximizing choice of technique. In this context technology is seen as knowledge, and firms are able to access knowledge in a relatively rapid and costless way. With these types of underlying assumptions, the technological dimensions of production are clearly relatively unproblematic.

The problem of technological change is also unproblematic, both with respect to adaptation to already-existing technologies, and to (exogenously-given) new technologies. This type of competitive theory rests on the ideas of rapid substitution possibilities across well-defined choice sets in production. In this framework firms move smoothly to new production configurations in response to changed environmental conditions. These environmental conditions are factor, input and output prices, with the firm adjusting its technology (that is, adjusting its capital-labour ratio) in response to changed factor or input prices; when prices change the firm moves rapidly, perhaps instantaneously, to a new position within the choice set. But the environment also includes technology itself. Within growth theory, rising productivity follows — in Solow's famous distinction — from movements of the production function as well as movements along the production function. This implies that firms are adjusting instantaneously and optimally to changes in the choice set itself, although these changes are seen as exogenous to the system.

In this type of approach, economic efficiency rests very much on flexibility, both at economy-wide level (where free entry and exit to activities are central to allocative efficiency) and at firm level (where the ability to change the technical configuration of production is central to profit maximization); these notions have had rather powerful policy effects. Both allocative and technological efficiency rest on freeing markets, removing barriers to entry (and not being too concerned about exit), removing barriers to change within the firm, and increasing competitive pressures as a form of generating incentives to optimize.

However both these types of adjustment, and hence the policies which are built on them, rest on an implied form of technological knowledge with very particular characteristics. What exactly are the underlying assumptions about the characteristics of technological knowledge?

One of the key points about neo-classical theory has been that although it deals with the economic characteristics of knowledge as a commodity, it does not contain any differentiated concept of knowledge itself. But of course it is possible to describe the characteristics that knowledge possesses in the neo-classical approach, even though they are implicit within the analysis. We could argue that in neo-classical analyses, technological knowledge must have the following attributes if the production theory is to work:

- It is generic. That is to say, an item of knowledge, or a particular advance in knowledge, can be applied widely among firms and perhaps among industries.
- It is codified. Transmisibility implies that knowledge is written or otherwise recorded in fairly complete useable form.
- It is costlessly accessible. On the one hand this can involve the idea that transmission costs are negligible, but it can also mean that firms do not face differential cost barriers in accessing knowledge or bringing it into production.
- It is context independent. That is, firms have equal capabilities in transforming such knowledge into production capability.

With these kinds of tacit assumptions about knowledge, firms can readily make optimal profit-maximizing choices. This is basically because, within this context, the
production problem of the firm is essentially a problem of calculation rather than a problem of technological capability and organization.

This calculation activity has two further elements which are important to note. The first is that if the feasible industry technologies are available to all then the production/innovation decision of any firm is independent of decisions made by others; interdependence or interaction between firms is simply not an issue – as Andersen (1992) has pointed out, neo-classical analysis normally presupposes an extreme degree of flexibility in the relationships of the economic system which can only be founded in independence. Secondly, if market forces move rapidly to weed out firms who fail to make optimal choices, then there will essentially be only one optimal way for firms within an industry to produce, and inter-firm differences will be negligible or non-existent.

However, if these kinds of assumptions and analytical procedures make the acquisition and operation of technologies unproblematic within equilibrium theory, they raise acute problems when it comes to the development of technology, and in particular to the invention of new technological principles.

Perhaps the most influential approach to business-sector R&D, and hence to policy, derives from two classic papers by Nelson (1959) and Arrow (1962) respectively. Although different in objectives, the papers have close analytical similarities. Both argue that technological knowledge has distinctive features, which lead business firms in a market economy to perform less R&D than is socially optimal.

Arrow begins by identifying technology with knowledge: technology in the most general sense is ‘know-how’, and therefore the process of invention ‘is interpreted broadly as the production of knowledge’. This question then is, what are the technical and economic characteristics of knowledge, and how do these characteristics affect the amount of new productive knowledge which firms might seek to produce?

The first problem is that of uncertainty, which in this case means that knowledge outputs are not predictable from inputs: producers must commit resources to a knowledge production process without knowing the results with any accuracy. Arrow’s first point is that although market economies have a number of mechanisms for sharing risks – such as insurance, contingent markets, or equities – these rarely apply to research activities. Insurance, for example, would be impractical because it would weaken incentives to succeed; only the existence of large companies, with sizeable portfolios of relatively small projects, resolves this problem (because the companies act, in effect, as their own insurance bodies).

Then there is the problem of appropriability: it is difficult or even impossible to create a market for knowledge once it is produced, so it is difficult for producers of knowledge to appropriate the benefits which flow from it. Firstly, ‘there is a fundamental paradox in the determination of demand for information; its value for the purchaser is not known until he has the information, but then he has in effect acquired it without cost’. Secondly, any purchaser of the knowledge can in effect destroy the market, since he can reproduce the knowledge at very low, perhaps even zero, cost. If producers cannot appropriate the benefits of knowledge, then they have no incentive to produce it, and market economies will therefore under produce which would be socially beneficial if it were produced.

A final characteristic of technological information is indivisibility. That is, the underlying knowledge must exist on a certain minimum scale before any production at all take place, and this necessary minimum is independent of the rate of production. A familiar example of such indivisibility would be a railway, which
must be constructed in its entirety before any trains can use it; and it must be constructed whether it is used by one train per day or fifty. The latter point means that there are scale economies in the use of indivisible capital goods, and this applies to technological information.

These problems of risk, indivisibility and inappropriability all suggest that market economies will systematically underinvest in R&D, and this will, argues Arrow (1962), ‘lead to the conclusion that for optimal allocation to invention it would be necessary for the government or some other agency not governed by profit-and-loss criteria to finance research and invention’.

But what kinds of knowledge really have the characteristics described in Arrow’s analysis? His approach points to a very narrow definition of knowledge. The first two characteristics clearly apply to the knowledge which results from fundamental scientific research, but cannot be extended unconditionally to other forms of knowledge important to innovative activity. The other classic statement of the externality problem, Nelson’s 1959 paper, speaks specifically of basic science. Implicit in the Arrow approach is the idea that technological knowledge is the same kind of knowledge as basic science, perhaps, indeed, that it is simply the application of basic science.

This ‘market failure’ approach to knowledge production leads to a relatively simple set of policy proposals. In this set-up the basic policy task is to encourage discovery-oriented activities, and then to protect the use of the results. The problems of risk and indivisibility lead to straightforward under-provision of knowledge, and suggest that the public sector should either produce knowledge directly, or provide subsidies to knowledge-producing institutions. The appropriability problem implies the existence of a major positive externality, and suggests policies either of subsidy, or the creation of property rights (via patents or other intellectual property protection). The basic problem with the approach is that it does not give any secure guide to how to identify areas of market failure, or the appropriate levels of public support which might follow from it. There appears to be a rationale for public provision, but where, and how much?

It is worth noticing that this type of approach to innovation policy accords very well with what is sometimes called the ‘linear model’ of innovation, which is frequently contrasted with systems approaches (Soete and Arundel, 1993). This is the view that the process of innovation is essentially a process of discovery, in which new knowledge is transformed into new products via a set of fixed (linear) sequence of activities or stages. There is some debate about whether the term ‘linear model’ is really appropriate for characterizing S&T policies within OECD countries over the long term, but we can outline broad characteristics of a ‘linear’ approach, and this accords with many ideas and practices in post-war research policy. These characteristics are:

- First, the technological capabilities of a society are essentially defined by the knowledge frontier; hence, technological advance depends on expansion of the frontier by a knowledge creation process based on discovery.
- Second, the knowledge which is relevant for industrial production is defined by principles which are essentially scientific, and which have in some sense been transferred, translated, or concretized from a more abstract realm.
- Third, the ‘translation’ process is basically sequential; there are temporally and institutionally discrete phases in the translation process, and these have to occur in sequence.
Fourth, the approach is technocratic, in the sense that it views technological change broadly in terms of engineering development processes and hardware creation.

However, more recent theory and applied research suggests that these characteristics are not a good guide to the nature of technological knowledge, and must therefore have limitations as a guide to the rationale and content of S&T policies. What are the alternative views, and what are their implications?

2.2. Technological Knowledge in the 'New Growth Theory'

The presence of knowledge externalities is also a key component of the so-called 'new growth theory'. The new growth theory can be characterized as an attempt to integrate the Schumpeterian notion of endogenous knowledge creation into the formal modelling approach to growth pioneered by Solow.

In these models, the basic process used to explain economic growth is the phenomenon of increasing returns to scale, flowing from the production of knowledge. These increasing returns exist because of an externality: knowledge flows to multiple users without being traded. Following from Schumpeter, new growth theory sees knowledge as partly appropriable by the firm but also, following Arrow's (1962) analysis, involving external benefits flowing to all firms within an industry or line of business. Firms thus have some limited incentives to produce knowledge, but that there will also be inter-firm spillovers which shape the stock of knowledge for all firms.

Romer (1986) models the production process of knowledge in optimization terms, as profit maximization over time. Firms generate new knowledge in their R&D departments using a 'research technology'. They must forego other forms of production today to generate knowledge that can be used to produce more tomorrow.

Romer assumes a single 'research technology' to produce knowledge, and models knowledge as something which can be measured on a single continuous scale, and which does not depreciate. The research technology is modelled as possessing constant returns to scale. The growth rate of knowledge available to the firm is thus dependent on the amount invested in further knowledge creation.

However, a firm's final output is not simply dependent on the accumulated stock of its own knowledge: it also involves all (accumulated) spillovers from all knowledge production in the economy. Romer makes a rather sharp assumption here that 'all factors other than knowledge are in fixed supply'. If the labour supply is not growing, land is in fixed supply, and there is no increase in the capital stock, investment behaviour is in effect confined to knowledge production.

If the knowledge spillover component is significant, then the wider effects of private investment decisions in knowledge will shape the overall growth of output. What is being argued here is that savings behaviour, determining the investment rate, endogenously shapes the path of output.

What we have in this type of theory is the explicit introduction of knowledge into growth theory with very little consideration of the real characteristics of the knowledge-creation process. We turn now to consider more extensively the realities of knowledge creation and its systemic features.
2.3. Learning and Technological Knowledge in Modern Innovation Theory

The question of the nature of learning is approached here via consideration of the nature of technological knowledge, or more particularly the nature of the knowledge bases which are generated by learning.

Clearly all firms operate with some kind of technological knowledge base. Such knowledge bases tend to be complex, in the sense that they involve the articulation of many elements. Here we distinguish between three areas of production-relevant knowledge, namely firm-specific knowledge, sector product-field specific knowledge, and generally applicable knowledge (Salter, 1969). Against this background we make three further distinctions, namely between the form of knowledge, the object of knowledge, and the institutional structure of production of knowledge.

At the firm level, the first area of production specific knowledge, the knowledge base is highly localized and specific to product characteristics. The specific character of these knowledge bases is not simply technical: it is also social, concerning the way in which technical processes can be integrated with skills, production routines, use of equipment, explicit or tacit training, management systems and so on. In terms of the form of knowledge, the relevant technological knowledge base is likely to be informal and uncodified, taking the form of skills specific to individuals or to groups of co-operating individuals. The tacit and localized character of firm-level knowledge means that although individual firms may be highly competent in specific area, their competence has definite limits. This means, firstly, that they may easily run into problems in innovation which lie outside their area of competence, and secondly that their ability to carry out search processes relevant to problems can also be limited; when creating technologies they must be able to access and use knowledge from outside the area of the firm.

The key characteristic of knowledge at this level is that it is bounded. Firms have a relatively restricted knowledge-base and a relatively restricted set of technological capabilities: their technological performance at any point in time is shaped by their history, and by the niches which they have been able to occupy. Typically, they have a limited range of products and processes which they understand well, and where they can compete.

The notion of bounded rationality – limits to knowledge, cognition and therefore calculation at the level of individual economic actors – deriving from the work of Herbert Simon, has played an important role in the evolutionary analyses of Richard Nelson and Sidney Winter (1982) which have in turn been central to modern innovation analysis. The concept refers to two things: firstly, that only a narrow band of technological solutions or possibilities are known to any particular firm and that, secondly, following from this there are constraints in the firm’s ability to calculate or compute the results of particular decisions or choices. This helps to explain the strong uncertainty attached to decision-making.

The idea of bounded knowledge is also useful in explaining the focused character of technological advance. Fransman (1990, p. 3) speaks of ‘bounded vision’ at the firm level:

... 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 areas 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 case 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.

There are also knowledge-bases at the level of the industry or product-field. Modern innovation analysis emphasizes the fact that industries often share particular scientific and technological parameters; there are shared intellectual understandings concerning the technical functions, performance characteristics, use of materials and so on of products. Nelson (1987, pp. 75–76) calls this the ‘generic’ level of a technology:

On the one hand a technology consists of a body of knowledge, which I shall call generic, in the form of a number of generalisations about how thinks work, key variables influencing performance, the nature of the currently binding constraints and approaches to pushing these back, widely applicable problem-solving heuristics, etc. I have called this the ‘logy’ of technology ... Generic knowledge tends to be codified in applied scientific fields like electrical engineering, or materials science, or pharmacology, which are ‘about’ technology.

Generic knowledge bases are highly structured, and tend to evolve along structured trajectories (Dosi, 1982). This part of the industrial knowledge base is public (not in the sense that it is produced by the public sector, but public in the sense that it is accessible knowledge which in principle available to all firms): it is a body of knowledge and practice which shapes the performance of all firms in an industry. Of course this knowledge base does not exist in a vacuum. It is developed, maintained and disseminated by institutions of various kinds, and it requires resources (often on a large scale). Tassey (1991, p. 347) has defined the combination of knowledge and institutional base as the ‘technology infrastructure’, in the following way:

The technology infrastructure consists of science, engineering and technological knowledge available to private industry. Such knowledge can be embodied in human, institutional or facility forms. More specifically, technology infrastructure includes generic technologies, infratechnologies, technical information, and research and test facilities, as well as less technically-explicit areas including information relevant for strategic planning and market development, forums for joint industry-government planning and collaboration, and assignment of intellectual property rights.

Finally, there are widely applicable knowledge bases, of which the most important technically is the general scientific knowledge base. This is itself highly differentiated internally and of widely varying relevance for industrial production; but some fields – such as molecular biology, solid-state physics, genetics or inorganic chemistry – have close connections with major industrial sectors. It is important not to overemphasize the role of scientific knowledge in modern industrial development by presuming a one-way connection between science and technology: organized science does not evolve simply according to some internal dynamic,
but is also shaped by policy or funding decisions which usually have economic, industrial or military objectives.

These different types of knowledge base are not separate but integrated with one another, often in complex ways. Moreover they evolve over time: that is to say, technological knowledge tends not to result from generalized processes of search, but rather builds on past achievements. This gives an evolutionary character both to artefacts and knowledge, but it also implies that knowledges are both structured and cumulative over time. The capabilities of any knowledge producing institution, at a point in time, tends therefore to be a product of its past history. This introduces a process of path dependence both into institutions and to the system as a whole.

Against this background, forms of innovation and learning can be classified along three main dimensions. These concern the following characteristics of innovation:

- Firstly, the focus of innovation in terms of the broad types of change which are sought or undertaken at any particular time.
- Secondly, a dimension concerning the degree of change in the underlying knowledge bases, and the extent to which knowledge bases evolve on the basis of existing capabilities or are fundamentally changed.
- Thirdly, dimensions concerning the modes of learning through which innovation occurs.

2.4. Characteristics and Form of Search Processes

What are the basic constraints and modes of search and learning processes? Firms, and other actors involved in technological change, do not generally have good knowledge either of all available technical possibilities, or of how to search for solutions to technical problems. Rather, economic dynamics rest on highly differentiated search processes and technology development efforts by firms under conditions of serious technological and economic uncertainty. Such technological learning processes result in the creation of a great deal of technological variety, and the selection of specific technologies by market and non-market processes. The selection process narrows down the overall amount of technological variety and leads to the cumulative development of technological knowledge along more or less well-defined ‘trajectories’.

These highly incomplete forms of knowledge are usually specialized around areas of previous experience, and involve substantial tacit dimensions. This has a number of implications. An absolutely central point here is that tacit knowledge is person-embodied; any firm-level strategy for the development of knowledge must therefore be an employment strategy. The bounded and relatively limited character of firm-based knowledge means that firms seeks to innovate on the basis of the cumulatively-development knowledge which they already possess; they seek to learn along the trajectory they are familiar with (Kline and Rosenberg, 1986). This means that firms rarely use scientific discovery as the basis of innovation, and depend heavily on the skills portfolio which they have built over time. But it also implies that they are always likely to confront technological problems which lie outside their existing boundaries of competence.

What is it which firms must learn and know about in order to innovate and survive? Lundvall and Johnson (1994) define relevant economic knowledge along four main dimensions as follows:
Specific factual information (‘know-what’). This type of knowledge tends to be relevant in specialized areas of expertise, such as law and medicine, but it can be also vital to innovation activities: knowledge of relevant regulatory issues, for example. Such knowledge can be stored and supplied from outside the firm, via consulting companies, databases, and so on.

Knowledge of basic scientific principles (‘know-why’). Scientific knowledge is increasingly important in the solution of particular innovative efforts, both in terms of specific results and in terms of search heuristics. Although there is no direct connection between scientific capabilities and innovative performance, such knowledge is increasingly important as a problem-solving input.

Specific and selective social knowledge (‘know-who’). In the context of human-embodied knowledge and interactive learning and interactive problem solving, access to key personnel is a new resource. A range of studies have demonstrated the role of such human contacts in innovative earning (von Hippel, 1989).

Practical skills and capabilities (‘know-how’). This covers skills, and all aspects of production capabilities and marketing.

These types of learning and knowledge must cover at least three distinct areas: technological competences and capabilities, organizational capabilities, and ‘system’ capabilities in terms of interactive links.

2.5. Degree of Change in Underlying Knowledge Bases: From Incremental Innovation to Changes in Technological Regime

Learning implies change in knowledge bases, but the degree of such change may vary considerably over time. On the one hand, there are continual small changes in design, components, materials and so on, which are made on the basis of existing skills, and which over a period add up to very fundamental changes in technical characteristics, productivity and so on. On the other hand, there are from time to time very radical changes in underlying knowledge bases, which force major changes both on firms, sectors and whole economies. These are sometimes referred to as ‘paradigm shifts’, a term which will be more extensively discussed below.

Abernathy and Clark (1985) have distinguished a number of areas of such change, and the degrees of change which might be involved. They remark that it is important to note that the product features themselves, and the firm’s position within them, are not in and of themselves the fundamental source of advantage. Such a position is the immediate, outward manifestation of a more fundamental, internal reality. The foundation of a firm’s position rests on a set of material resources, human skills and relationships, and relevant knowledge. These are the competencies or competitive ingredients from which the firm builds the product features that appeal to the marketplace. Table 1 shows their division of competitive components, along a scale showing the potential range of impacts of innovation.

In terms of public policy, the most important of these learning effects are probably those on the radical dimension:

instead of enhancing and strengthening, innovation of this sort disrupts and destroys. It changes the technology of process and product in a way that imposes requirements that the existing resources, skills and knowl-
Table 1. Innovation and changes in firm competence

<table>
<thead>
<tr>
<th>Domain of innovative activity</th>
<th>Range of impact of innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology/production</strong></td>
<td></td>
</tr>
<tr>
<td>Design/embodiment of technology</td>
<td>improves/perfects existing skills</td>
</tr>
<tr>
<td>Production systems/organization</td>
<td>strengthens existing structure</td>
</tr>
<tr>
<td>Skills (labour, managerial, technical)</td>
<td>extends variability of existing skills</td>
</tr>
<tr>
<td>Materials/supplier relations</td>
<td>reinforces application of current materials/suppliers</td>
</tr>
<tr>
<td>Capital equipment</td>
<td>extends existing capital</td>
</tr>
<tr>
<td>Knowledge and experience base</td>
<td>builds on and reinforces applicability of existing knowledge</td>
</tr>
<tr>
<td><strong>Market/customer</strong></td>
<td></td>
</tr>
<tr>
<td>Relationship with customer base</td>
<td>strengthens ties with established customers</td>
</tr>
<tr>
<td>Customer applications</td>
<td>improves service in established application</td>
</tr>
<tr>
<td>Channels of distribution and service</td>
<td>builds on and enhances the effectiveness of established distribution network/service organi-</td>
</tr>
<tr>
<td>Customer knowledge</td>
<td>uses and extends customer knowledge and experience</td>
</tr>
<tr>
<td>Modes of customer communication</td>
<td>reinforce existing modes/methods of communication</td>
</tr>
</tbody>
</table>

edge satisfy poorly or not at all. The effect is to reduce existing competence, and in the extreme case to render it obsolete. (Abernathy and Clark, 1985, p. 6)

Such change is usually understood through the concept of change in a ‘technological paradigm’ of ‘technological regime’. As noted above, the basis of this notion is that just as firms have a definite set of technological capabilities, so do industries. As Dosi (1988b, p. 1128) puts it, ‘a crucial implication of the general paradigmatic form of technological knowledge is that innovative activities are strongly selective, finalized in quite precise directions, cumulative in the acquisition of problem-solving activities. This accounts for the relatively ordered patterns of innovation’ (Dosi, 1988b).

The concept of technological paradigm refers to the common features of the technology shared by the firms in an industry, or even a group of industries. Most firms in an industry share a core set of approaches to the technological problems they face (although this does not define a unique approach to solving those problems).

This idea of a core technological framework for industries has been widely used in modern innovation theory. On the one hand, this shared framework can be
thought of in terms of shared knowledge, and a shared understanding of problems. It is this approach which underlies Dosi’s concept of ‘technological paradigm’. However, for reasons which are developed later, we prefer to use the notion of ‘technological regime’ because we want to go beyond an approach which focuses on shared ideas, towards one which places more emphasis on real technological and economic factors. In a study of Georghiou et al. (1986) on post-innovation improvements and competition the concept of a technological regime is also used. A technology regime is defined as a set of design parameters which embody the principles which will generate both the physical configuration of the product and the process and materials from which it is to be constructed. The basic design parameters are the heart of the technological regime, and they constitute a framework of knowledge which is shared by the firms in the industry.

In a similar way, Sahal (1985) speaks of ‘technological guideposts’ charting the course of innovation activities and ‘innovation avenues’ that designate pathways of technological evolution. We would emphasize that the ways in which a technology can develop are constrained: constrained by more than the consensus of engineering ideas about how to approach problems. They are constrained by available methods and techniques, by the specific characteristics of technologies, by patterns of infrastructure and consumer demand, and so on. Accordingly we define a technological regime in the following way:

A technological regime is the overall complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, institutions and infrastructure which make up the totality of a technology.

When it comes to dynamics, most technological change theorists use the concept of a ‘technological trajectory’ to describe the continuous process of change along typical paths. These trajectories can be defined as the activity of technological progress limited by the economic and technological trade-offs born of the technological paradigm or regime (Dosi, 1988). Shifts in technological regimes clearly involve both major shifts in underlying technological knowledge, but also a wide range of managerial, organizational and even social changes. A more fruitful line of approach is the Freeman and Perez concept of techno-economic paradigm, which refers . . . to a combination of interrelated product and process, technical, organizational and managerial innovations, embodying a quantum jump in potential productivity for all or more of the economy and opening up an unusually wide range of investment and profit opportunities. Such a paradigm change implies a unique new combination of decisive technical and economic advantages.

Such change is by no means rare, although these forms of very radical change are often much slower than is commonly represented. However, they do involve fundamental changes in learning modes and functions and are usually associated with major changes also in the organization and management of firms.

2.6. Modes of Learning: From Individual to Interactive to Systemic

It has been argued above that innovation should not be seen in terms of individual acts of learning or discovery. Recent theory instead sees such learning as interactive. Within a firm, for example, successful innovation results from multi-directional feedbacks between the various forms of competence and skill on which a business relies: between marketing, finance, and product-process development, for instance. Innovation is thus a process of interactive knowledge-creation, in which, for
example, skills in marketing are used to channel relevant information about user needs into the development processes which shape the technical and performance attributes of products. In this context, innovation is far from being simply the ‘transfer’ of knowledge which has been developed elsewhere.

A second interactive dimension follows from the boundedness of firms’ knowledge bases, referred to above. Successful innovative firms are usually those which are open to their environments. That is, they engage in interactive learning involving other institutions: partners, rivals, and a wide range of other knowledge-creating and knowledge-holding institutions.

The ability of firms to engage in the interactive learning described above is shaped by the structure, types, scale and communication processes between relevant knowledge-creating or knowledge-holding institutions. Such institutions have a tangible location in specific regional or national spaces, and are thus shaped by regional or national political cultures, legal systems, modes of corporate governance, or wider social values. Among the most important of these institutions are those which create or maintain scientific knowledge. These institutional underpinnings lead to the idea that innovation involves systemic interactions. Hence we have the idea of ‘innovation systems’ as the basic context for innovation performance.

To summarize this discussion, we can argue that both the learning processes and the knowledge bases of industrial firms have the following characteristics:

- They are differentiated, multi-layered, involving the systemic integration of many different types of knowledge.
- They are highly specific, organized around a relatively limited set of functions which firms understand well, and the system is thus characterized by boundedness, bounded rationality and ‘bounded vision’.
- They involve significant tacit components, embodied in the skills of engineers, R&D staff, workers and managers.
- They are cumulative, developing through times as firms build up experience with particular technologies; this in turn implies that technological knowledge is path dependent.
- They are developed through costly processes of search, through processes of learning and adaptation.
- They are internally systemic in the sense of being part of an overall production and marketing system which has many components.
- They are externally systemic, relying on interactions between firms and other agents, and relying also on infrastructural support.

A primary foundation of system phenomena therefore lies in the nature of technological knowledge itself. This view of learning and knowledge is radically different from that of the neo-classical approach, both in the long-standing Arrow formulation, and the newer formulations found in the new growth theory. We turn now to a discussion of the implications for public policy.

3. Policy Issues

We now turn to some of the policy issues arising from these complexities concerning the nature of innovation and underlying learning processes. The discussion here focuses on the implications of systems approaches for two broad issues:
The rationale for policy action. What is the underlying justification for policy intervention, and do these justifications throw any light of the general scope, objectives and methods of policy?

Policy capabilities. In a system context, what competences, skills and resources do policy-makers need; to what extent do these differ from current views?

3.1. The Rationale(s) for Policy Action

The standard rationale for policy action with respect to learning and innovation follows from the market failure analysis of Arrow (1962). It simply argues that a completely competitive, decentralized market system will provide a sub-optimal level of knowledge, and that this leads to a case for either public subsidies to knowledge creation, or to creation of intellectual property rights. This links up with 'linear model' approaches, and leads in practice to policies consisting of subsidies to R&D (although the market failure approach is particularly weak in identifying where those subsidies should go, and what their level should be).

Systems approaches would not necessarily drop such policies: as noted above, they certainly recognize the existence of generic knowledge bases, and would make provision for the supply of non-appropriable generic knowledge. In addition, as we shall indicate below, systems approaches have a greater potential for identifying where public support should go. The most important distinction between the standard rationale for policy intervention and the systems approach is that market-based systems not only suffer from an under-supply of knowledge, but are likely to actually generate areas of systematically weak performance. These areas of 'systemic failure' may call for actions contrary to conditions of perfect competition, for example, cooperation and collaboration between firms to facilitate knowledge flows, government regulation and the creation of incentives. Areas of systemic failure include:

- failures in infrastructural provision and investment;
- 'transition failures';
- lock-in failures; and
- institutional failures.

3.2. Failures in Infrastructural Provision and Investment

We have emphasized above that systems theories often stress the importance of infrastructures, a concept very prevalent in the systems literature, but more or less absent from the neo-classical mainstream. Two types of interaction between firms and infrastructures seem to be important: firstly, with physical infrastructures usually related to energy and communications, and secondly with science-technology infrastructures such as universities, publicly-supported technical institutes, regulatory agencies, libraries and databanks, or even government ministries.

The author has argued elsewhere that these infrastructures have a number of specific technical characteristics which lead to serious problems of investment appraisal (Smith, 2000). The features include very large scale, indivisibilities, and very long time horizons of operation; they lead to major problems in the financing of infrastructural investment, and are very unlikely to produce adequate returns within the context of standard ROI investment appraisal techniques. This is a serious problem, since virtually all studies of major technology creation, or of the nature of
industry knowledge bases, indicate an important role for knowledge developed within the kinds of infrastructure developed above.

These problems indicate a role for public sector supports, for which there are three basic modes – regulation to set up incentives and controls for private provision; subsidies to private provision; or direct public provision. This entire area is problematic at the present time, since increasing pressures on public expenditure have led to strategies of privatization and/or marketization which have serious implications for infrastructural operations. From a systems perspective, the problem of infrastructural investment failure becomes a significant justification for public sector actions.

3.3. ‘Transition Failures’

Transitions and dynamics are an important part of any innovation-based theory of the economic process, and this is especially true of systems theories. At the same time the notions of firm-level knowledge and learning underlying systems theories imply serious problems for firms and sectors in adapting to transitions.

It has been emphasized that in adjusting to technological change an important consideration is the fact that firms, especially small firms, are necessarily quite limited in their technological horizons. Firms almost always concentrate on what they know best: they focus on products and technologies where they have experience and skills, and they try to bring a high level of expertise to the technologies which exploit those skills. This produces a situation in which firms have strong competence within their area of technological knowledge, but relatively limited capabilities even in closely related areas. Three kinds of problems arise as a result:

Firstly, even in the normal course of innovative activity it is almost certain that firms will frequently encounter technological problems outside their existing capabilities. Secondly, there may be changes in technological opportunities or patterns of demand which push the market into new areas of technology: that is to say, there may be discontinuous shifts in technology. There is considerable evidence to suggest that even relatively minor shifts can provide serious problems for firms who have no background in the new technology. This is particularly a problem for small economies which possess relatively small numbers of players in many sectors; relatively minor discontinuous shifts can provoke major changes in the industrial structure. Finally, there can be major shifts in technological regimes or paradigms. These transitions can be particularly difficult since they often imply development of or adaptation to completely new generic technologies, where the relevant capabilities (which are usually not technical but organizational) lie quite outside the existing structure of capabilities.

There are thus likely to be what we might call transition failures; many public policies are in fact aimed at these issues, frequently without any explicit rationale. This rationale should be made more explicit, since it has important implications for policy capabilities and objectives.

3.4. Lock-in Failures

A strong feature of systems theories is the notion of path dependence, or ‘lock-in’ to existing technologies. One of the basic reasons for path dependence is the existence of system or network externalities, combined with the fact that technologies exist in close links with their social and economic environment. This means that
technological alternatives must compete not only with components of an existing technology, but with the overall system in which it is embedded. Technological regimes or paradigms persist because they are a complex of scientific knowledge, engineering practices, process technologies, infrastructure, product characteristics, skills and procedures which make up the totality of a technology and which are exceptionally difficult to change in their entirety.

Just as firms are not able to switch away from their existing technologies, so industries and indeed the whole socio-economic system can be ‘locked-in’ to a particular technological paradigm. It is very unlikely that movement away from such a paradigm can be induced by, for example, tax policies on a particular input. The elements of a technological paradigm interlock with each other, and with a social and technical infrastructure built up over a long period. A change in a technological paradigm must involve a complex and integrated process of change in science, engineering practice, physical infrastructure, social organization, plant design and so on.

This does not mean that regimes never change, but it does lead to serious problems of lock-in. Perhaps the most important case at the present time concerns the role of the hydrocarbon-based energy system in greenhouse gas emissions and global warming. The problem lies firstly in the ubiquity of these technologies: hydrocarbon-using energy technologies are used as inputs to virtually all economic and indeed social activities throughout the world. Secondly there is the complexity of the relevant energy technologies. We are not discussing here a single technology, but rather an exceptionally complex system of integrated technologies for the production, distribution and use of energy.

The question then arises: how can technological change happen? The question of systemic change seems central to any transition away from hydrocarbon-based energy technologies, yet the system is unlikely to be changed by such initiatives as carbon taxes, or the development of individual alternative techniques. That is to say, actions at the level of individual agents are unlikely to overcome lock-in. External agencies, with powers to generate incentives, to develop technological alternatives, and to nurture emerging technological systems are required. This is therefore an important rationale for public action in a systems context; it is by no means a rationale which is likely to be frequently used, but on the occasions it is relevant it is likely to be of exceptional importance.

3.5. Institutional Failures

Systems approaches emphasize the institutional context as a defining and structuring element in the system. A key aspect of this is the framework of regulation: at a national level this involves technical standards, risk-management rules, health and safety regulations, and so on. The regulatory system also includes the general legal system relating to contracts, employment, intellectual property rights (patent and copyright law) within which firms operate. Finally there is the wider context of political culture and social values, which shapes public policy objectives and particularly the macroeconomic policy environment. Taken together, this integrated set of public and private institutions, regulatory systems and the policy system makes up an overall context of economic and technical behaviour which shapes the technological opportunities and capabilities of firms. It thereby shapes firms’ economic performance and the macroeconomic evolution of the economy as a whole.
Whether or not these institutions/regulatory processes develop through conscious choice or through the evolution of cooperation, they are invariably discussed and implemented through policy agencies. The operation of this system ought to be itself a responsibility of policy makers. An example is the operation of markets for corporate control, which are shaped by a major part of the regulatory environment, namely the corporate governance system. Given that corporate take-overs appear to have impacts on overall R&D performance, they also impact on the innovation system. There are powerful arguments to suggest that regulatory differences indeed shape innovation and economic performance. The need for monitoring and assessment of regulatory performance, and if necessary changes in regulatory systems, provides a rationale therefore public action.

3.6. Policy Capabilities and Knowledge Bases

What competences or capabilities must policy-makers possess, what do they need to know, if they are to develop and implement policy actions within the overall framework suggested in this paper? Operating policies within a system framework would seem to imply new demands for knowledge and assessment for policy-makers themselves. Here we look at five problem areas:

- the assessment of system specificities;
- understanding of relevant knowledge bases;
- assessment of system dynamics;
- system co-ordination; and
- identification of untraded knowledge flows.

3.7. Identifying System Specificities

It follows from the analysis presented above that systems are likely to be quite specific in terms of institutional frameworks, industrial structures and technological bases. Empirical analysis seems to support this, both at national levels and regional levels: technological specialization is a pervasive phenomenon, and wide variations exists between systems. Archibugi and Pianta’s work is especially important with respect to national systems; they show the existence of substantial specialization patterns with respect to R&D investments, technological fields of patent grants, and scientific publication (Archibugi and Pianta, 1992). The CIS survey has clearly suggested major ‘innovation structure’ differences across Europe. We know also that there are significant institutional differences with respect to governance of firms and sectors (Hollingsworth, 1994). Finally, the regional literature also shows that specialization and diversity are pervasive at regional levels—according to Storper and Scott (1995, p. 513) ‘a new “heterodox” economic policy framework has emerged in which significant dimensions of economic policy at large are being reformulated in terms of regional policies’. This is partly the result of the economic success stories of territorially agglomerated clusters of SMEs and partly the result of the new political initiatives towards a ‘Europe of regions’. Carlsson and Stankiewicz (1991, p. 115) have gone so far as to argue that sometimes it seems more accurate to refer to a regional technological system (in their words) than to a national one ‘as high technological density and diversity are properties of regions rather than countries. They are the results of local agglomeration of industrial, technological and scientific activities’.
These specificities must be taken account of in policy design. Their existence seems to suggest that ‘neutral’ policies are likely to be so abstract that they have little effect within the distinct structures of specific systems. Policies therefore should be designed with system specificities in mind. This imposes fairly substantial analytical demands (both statistical and otherwise), regardless of whether policies are being made at central level or at regional level. There are a range of attempts to develop this kind of system knowledge base at the present time, for a number of countries, mainly through the OECD’s National Innovation Systems project, which is an attempt to produce quantitative analyses of systems which go beyond a primary focus on the R&D system (Chaminade, 1995; den Hertog et al., 1995; Laursen and Christensen, 1996; Numminen, 1996; Smith and Nas, 1995). Certainly there are many methodological problems here, but possibilities clearly exist to improve knowledge bases for systems structures.

3.8. Identifying and Mapping the Technological Knowledge Bases of Systems

There is clearly a need for policy-relevant knowledge concerning the broad knowledge inputs which are relevant for a system. Central to the systems approach is the view that the key resource of a firm, or an industry, is the knowledge base from which it draws its competence in refining, developing, creating and selling new products. Knowledge in specific areas underpins the capabilities and specific competences of the firm, and may hence be seen as the competitive basis of firms and industries and one of the major factors that creates firm differences and hence firm competitiveness. As well as diversity between systems, there is considerable structural differentiation within systems. Policies in support of innovation and technological change need rather precise identification of how system knowledge bases are actually constructed. This is not at all a simple matter: even the knowledge bases of apparently simple industries rest on the articulation of quite different knowledges, and interactions between quite different institutional forms. Apparently simple industries such as fishing or timber products can have very complex scientific knowledges underlying them, and an important part of the policy problem is to identify these knowledges and provide support for their development: many such knowledge fields (such as wave dynamics or GPS in fishing, or algorithms for optimal cuts in timber) fulfil classic criteria for public provision – they are codified, non-appropriable and have public-good properties. How can these interactive knowledge bases be mapped and understood by policy-makers?

It seems in principle possible to map the complexity of sectoral knowledge bases by identifying the following:

(1) The key activities in the industry and key personnel performing these kinds of activities. What are the main technical components of production activity within the sector concerned? What must a firm do to be a viable operator in the industry?

(2) The key techniques – meaning capital inputs, equipment, instruments and production routines – being utilized to perform these activities. What are the techniques which the firm must master in order to be able to undertake the activities described above?

(3) The knowledge bases – in terms of engineering and scientific knowledges – supporting these techniques. What are the codified knowledges with which the technical operations are designed, analysed, and produced? Note of course that
the knowledge bases behind capital and intermediate inputs are likely to be considerably more complex than those which are produced directly within most industries.

(4) What are the organizational forms – in terms of companies, research institutes, universities and so on – through which these knowledges are produced and disseminated? Concretely, who develops the relevant knowledge inputs, and on what resource basis?

Here are identifying the level at which knowledge is shared among firms, or is common to them; that is, the level which policy can address. Although there also exists a dimension of knowledge which is firm specific, there is clearly a need for an approach of this type, which identifies both the direct and indirect knowledge inputs for a sector in a specific country or region, an approach which is necessary since policy makers are likely to need a much enhanced view of both the depth and complexity of knowledge bases used in sectors and activities which are relevant in their economies (Balconi, 1993).

3.9. Assessing System Dynamics

Systems are dynamic; it might even be claimed that they are turbulent. We have already indicated one dimension of this above, namely pervasive product innovation, but various other quantitative indicators could be mentioned. We have also outlined a number of potential ‘systemic failures’ which call for policy intervention. ‘Lock-in’ failures, for example, imply a role for policy in adapting to or generating shifts in technological regimes, the question is, how can we identify when such shifts are happening? When should policy-makers be attempting to support the existing system – with its historically accumulated advantages – and when should they be helping to create a new system? Similarly, how can transitions which may be occurring anyway be identified within the ‘noise’ of the normal dynamics of the system? It is clearly difficult to answer these questions in a practical way, but solving them is an important part of generating knowledge bases for systems-oriented policies.

3.10. System Co-ordination

A key policy issue arising from systems approaches is the need to identify and perhaps support nodal points in the creation and distribution systems, keeping in mind that these are likely to be changing over time: the innovation system is not a structure, but a dynamic process. At the simplest level, the task would be to identify key points or functions within the system where public support would improve the overall distribution capability. Since knowledge systems are complex in practice (even in small societies), and usually managed by quite separate institutions, there is a need for policy co-ordination and for adequate information systems to ensure that such co-ordination is possible. Actually, this problem is present even when a linear approach to policy is adopted. Although such policies are fundamentally discovery-oriented, they tend in practice also to involve other elements: to combine basic research policies with policies aimed at developing commercial applications, at diffusion, at training, and so on. The general question of policy co-ordination is a long-standing one in all advanced economies, and more or less unresolved. A systems approach suggests that developing information systems for policy co-ordination is a core priority.
3.11. Identifying Externalities: Untraded Flows of Knowledge

The basic rationale for public policy is that there are necessary activities and functions which are insufficiently fulfilled by private initiative: this usually implies an externality, and much public policy is concerned with externalities. The characteristics of knowledge described above have a number of implications for the externality question. On the one hand they imply that the externality effects emphasized by Arrow are not a significant obstacle to the production of knowledge in that knowledge is not always cheap to transmit or easily appropriated (Carlsson and Jacobsen, 1993). On the other hand, the knowledge system approach emphasizes a wide range of interactions, some of which will take the form of non-traded flows of economically useful knowledge. There are potentially large externalities, the identification of which might be central to policy formation and operation. What forms can such externalities take? Given the general characteristics of industry-specific and firm-specific knowledge bases sketched above, we can suggest a range of forms of external knowledge. These certainly include generic ‘public domain’ sources of scientific technological information, but they could also include knowledge from other firms in an industry (through marketing relationships, co-operative knowledge exchange, trade literature etc.); acquisition of skilled personnel; acquisition of process technologies; regulations and standards, and so on. Any identification of externalities requires some form of overall system mapping, with particular reference to ‘intangible’ knowledge flows.

4. Conclusion

As we suggested in the first section of this paper, systemic approaches have established a powerful case for thinking about economic performance in terms of ‘systems’. However, at this stage discussion of policy in the context of innovation systems can only be conducted at a rather abstract and general level. There is nothing particularly coherent about systems approaches at the present time, and there remains much to be done in refining the theory and giving it empirical relevance. Even then, it is in the nature of systemic approaches that the details of policy must vary widely to suit particular national, regional, and local needs. Having said this, it remains clear that public policies have had a central role in the evolution of national systems, both in development of underlying knowledge bases, and in provision of the physical and knowledge infrastructures on which technological regimes rest. It is also clear that observation and analysis of the dynamics of particular systems will be necessary to identify the places for policy action. Conceptualizing the appropriate rationales for and tasks of policy are precursors to the much more demanding question of policy instruments and implementation methods.

References


