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Technology and Economic Development: A Comparative Perspective

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1. Introduction

The central theme of this essay can be stated succinctly. The task of development economics and development studies more generally is to explore and explain the immense temporal and spatial diversity of the outcomes of the development process. At the core of these explanations lies an emphasis on deep structural and qualitative change and the connection between that and technological and institutional change. All economies, advanced ones included, are developing economies but each one develops in its own idiosyncratic fashion. The shifting balance of agricultural and manufacturing employment, the rise of modern manufacturing and the decline of handicraft industries, the changing distribution of economic life between town and countryside are well documented examples of how development necessarily takes place in all economies. The view I shall put forward here is premised on the claim that the connection between technology and development cannot be understood as a macroeconomic phenomenon in which the elements of creative destruction are inessential details. Whatever the other merits of explanations based on macro economic analysis, for example, with the aggregate production function and growth accounting, they are not to be found in a deep understanding of the development process. This does not mean that the accumulation of capital, human, intellectual or material, can be ignored. Rather it means that these processes of accumulation, indeed the very nature of what is being accumulated cannot be separated from the underlying processes of structural change, and structural change necessarily means that the growth rates of activities differ. Nor does this mean hat development is only to be conceived of as a 'bottom-up' process, for there are important feedback elements from higher to lower levels of activity that shape and constrain the development process. Development is a process for the generation and self-organisation of micro diversity of growth rates and it is from this micro diversity that the increase in standards of living and the broad and sustainable capacity to eliminate poverty flows. Not by accumulation alone but through the combined accumulation and assimilation of new activities, new ways of working, and new ways of using materials and energy that define the nexus of phenomena that enable development (Nelson and Pack, 1999). This is why development is an adaptive evolutionary process in the two traditional and coupled senses of that concept: as a process of the cumulative unfolding of phenomena, and as the selective retention of superior variants in a population of competing alternatives. Both aspects are central to evolutionary development for one cannot select without first creating the population of alternatives. Survival of the fittest also requires arrival of the fittest.

The perspective I explore here is based upon the economy as an evolving system, the economy as an adaptive, experimental system, a framework for enterprise and the testing of new economic conjectures. Firms are key organisations and so are markets, neither can do what the other can, and they are complementary in relation to development. Together they form the loci for experimentation and the accumulation and application of new knowledge and, at root, the problem of differential development is a problem of the differential access to practical knowledge. It is the interaction between the growth of knowledge and market processes that is the key to understanding development and innovation is the manifestation of this process. Box 1 gives a simple representation of this dynamic innovation web in which stages in the broad innovation process interact with stages in the development of different kinds of knowledge, with multiple feedback and interdependencies. However, not everything is achieved by the symbiosis between commercial firms and markets. Other organisations, typically in the public sector, are also important, particularly those concerned with the growth of knowledge, for they provide the means to separate the growth of knowledge from the context of its market application. In so doing they greatly enhance the basis for the experimental development of new technologies. This separation is not without problems but few would deny the significance either of publicly funded research and development to economic progress or, more broadly, of publicly funded education to economic development. In this regard, does the experience of a Taiwan or a South Korea differ in broad terms from that of the USA or Western Europe? Of course the detailed differences are many and matter enormously but the fact that each economy is organised as a creative, experiment-based economic system is common to them all (Lin, 1998; Kim, 1996, Hobday, 1995).

In this essay I shall explore the relation between firms, markets and public policies from a very limited perspective, that of the use and acquisition of technological knowledge (Katz, 1987). This is an immense subject and to highlight a small number of the salient issues I will use a particular lens, a comparison between two views of the firm, called the ‘neoclassical’ and the ‘evolutionary’ theories respectively. Why this emphasis on the firm? The firm matters as an organisation because the development of economies is premised on the development of firms. Firms are unique in their role of articulating technologies to productive effect, they are unique in having to combine knowledge of technology in the narrow sense with knowledge of organisation and knowledge of market, and they are unique as problem generators and locations for technological and economic learning. They must acquire, operate and further develop technology as ongoing competitive processes. If they cannot acquire the requisite levels of technological competence they will not survive in a market economy. If they do not keep up with the relevant trajectories of technological improvement they will not survive either. Economic development certainly epitomises the Red Queen effect; even standing still requires one to run rather hard.

The contrast between the two views is profound. In the first we will find the firm as a passive automaton reacting to external signals, whether market prices or the anticipated behaviours of other firms. In its most general form the firm is simply a supply correspondence between market signals and quantities. Such a firm has already solved the problem of how it acquires and uses useful knowledge. In the second we will find the firm as a creative, sentient learning organisation, actively developing the opportunities to develop profitable lines of production. In the first knowledge of opportunities is given, in the second it is purposefully created. Of course, we should not ignore the point that the two perspectives lie within the frames of different theoretical objectives, highlighting the contours and not the wider details of a particular problem. The particular problem for the traditional theory of production is that of resource allocation in a market system. The theory of production is the bridge that links together the expression of demand with the availability of the given productive agents. In this regard the theory of production plays an entirely passive role, indeed in many cases, even the idea of the firm drops from view, squeezed out of sight by the fundamentals of resources and preferences. At most the firm is a link between what is produced and the pattern of prices in the economy in the context of given knowledge of the productive arts.

Resource allocation is an important function of markets in capitalism but we err greatly if we conceive of this as the only economic question of interest. Far more significant is the question of the development of resources, the creation of new uses for the material endowment and indeed the creation of new economic resources themselves. In the evolutionary approach these questions are at the centre of the analysis and are expressed in terms of differences between firms in their innovative performance (Nelson and Winter, 1984; Nelson, 1991). In terms of economic development and the disparity in the wealth of nations this is by far the more fundamental question. The crucial role of the firm is that it is the principal agency in the economy for the creative development and practical application of technology to economic problems. If the problem is one of combining domestic knowledge with foreign knowledge it is in the firm that this combination will take place ultimately (Katz, 1987). Thus the problem explored here is the connection between the development of the firm as a productive unit and the development of the wider economy. We cannot have the latter without the former but the development of the firm cannot be understood, as it were, as a purely internal matter, it depends also on the support of a wider organisational and instituted context. The creative firm is part of a creative system, and here there is an important role for public policy, as we shall see below.

From a different angle, economic development is a question of adaptation and adaptability (Killick, 1995); of adaptation within firms and other supporting organisations and adaptation between firms in markets but not adaptation in the context of a given quantum of knowledge. Rather, as argued below, the process of adaptation in market economies depends upon the formulation of new knowledge and is itself a process for creating new knowledge. These processes are essentially evolutionary in nature and they couple together creative development processes with processes of market adjustment; they combine together variation, selection and the development of new forms of economic activity. In capitalist economies innovation and the diffusion of innovation are the primary adaptive mechanisms, and firms are the primary locus of innovative, though not necessarily inventive, activity. In Box 2 there is a simple schema to summarise the links between innovation and development in which innovation, accumulation and structural transformation are intertwined.

I take as background themes the continuing deep integration of international capital and product markets, the continued adherence to more or less liberal economic regimes and the continued development of fundamental understanding of science and technology. In relation to bioscience and the medical industries, in relation to robotics, nanotechnology and the manufacturing industries, this 21st century seems at the threshold of fundamental new developments. Whether, for example, we think of genomics and its consequences for plant and crop development or for the prevention of disease, or nanotechnology and the prospects for molecular level engineering we can imagine implications across the whole range of human activity. The way these developments are distributed around the globe, the way they contribute to further differences in development, and indeed, the way these technologies develop will depend greatly on the role of firms in translating basic knowledge into practical application. Here then lies the significance of the central theme of this essay.

I conclude this introduction by emphasising the point that the problem of development is a problem of the differential access to practical, productive knowledge. Now a caricature of modern economic theory is that it builds on the idea of a hypothetical 'fall from grace' when appraising economic institutions. The imperfections of economic organisation and the challenges for economic policy are assessed relative to a state of perfect foresight premised on perfect knowledge. I take a different view that the natural state is ignorance and that the process of economic development is the struggle to overcome our partial, imperfect understandings of the natural and human world. If private individuals must cope with the veil of ignorance so must policy makers. In this perspective, the combination of decentralised decision making in for profit firms with open, competitive markets proved to be a remarkable coupling of organisation and institution. Markets with firms make the most of imperfect understanding and provide the incentives and opportunities for ongoing creative learning. The unintended consequences of this accident of design have been profound, and it is the experimental characteristics of this system that matter in relation to knowledge and inequalities of knowledge. Capitalism is restless because knowledge is restless and while this can be uncomfortable it is also progressive, at least on average, and development is surely a synonym for economic progress (Metcalfe, 2001). The modular nature of the vast micro-array of uncoordinated attempts by firms to improve the match between needs and resources is linked with a system of selection in markets that co-ordinates the consequences of this innovative diversity and translates it into economic development. Market institutions matter enormously for development because they simultaneously generate the economic value tests that any innovation must pass, the distribution of rewards from innovation and the flow of resources to capitalise on profitable innovation. In this process much is deemed to fail, there is much that is regretted *ex post*, and there is much to be learned from mistakes but that is the unavoidable price of ignorance. The implication for development policy is considerable. The notion of policy as a corrective for market failure, an entirely negative perspective, is seen to be inappropriate. Instead, the role of policy is positive, to create the framework and opportunities that stimulate the technological learning and business experimentation that drives development.

2. Preliminaries

The foregoing is not a detailed exposition of current understanding on technology and economic development. For this is an immensely difficult topic that repeatedly tests our theoretical frameworks to their limits and no brief exposition can have much expectation of doing it justice. Nonetheless, some preliminary remarks are required to set the scene. Of particular importance is the wide diversity of development experience and potential. The technological standards achieved and the technology policies adopted in Taiwan or South Korea are far apart from those in Brazil or Tanzania or in Trinidad or Mauritius. There is no single experience, no single suite of policies that can speak for all and no single path linking the acquisition of higher levels of technological performance with economic development. Matters are even more complicated by the fact that the innovation process differs so markedly across economic sectors. The conditions relating to the accumulation of practical knowledge in machine tools or textile weaving are quite different from the circumstances in electronics or chemical fertilizer. The costs of technological exploration, the importance of basic technology and science, and the institutions supporting knowledge accumulation are different in each of these cases. Consequently, there are no simple rules for innovation policy or for science and technology policy. What works in one place at one time may be quite unproductive in different circumstances. There is a deeper, non-trivial sense that in dealing with innovation and development we are dealing with idiosyncrasies in multiple dimensions. If the following seems to the reader to be written in too broad terms these caveats should not be forgotten.

3. The Production Function and the Theory of the Firm

We now turn to a more detailed exposition of the idea of the firm as the locus of production and the way in which technology fits in this framework. The origin of these productive capabilities is not usually seen as an economic question and, from a developmental perspective, this is not at all helpful. No treatment of economic development can ignore the purposeful development of knowledge and skill, or avoid incorporating this within a theory of the firm and of its relations with other knowledge generating institutions. A first step to understanding these complex processes must be to ask, "What is meant by a technology?"

Technology and Transformation

The answer to this question draws together three concepts, that of activity, that of transformation and that of organisation. Every technology, including service technologies relates to some kind of productive activity, which involves the transformation of materials and energy in one form into material and energy in another form, subject to the natural laws of physical and chemical processes (Box 4a). The inputs become outputs during the process of transformation some of these outputs being the immediate purpose of the activity others being the unavoidable "waste" by-products of the activity. We usually think of these activities as producing physical transformations on materials and energy, as when chemicals are combined to product different chemicals (steel or phosphates for example) or when materials are physically reshaped or combined into new entities (forging of steel billets or assembly of ships or electronic devices). But equally important are those transformations that involve the relocation of materials and energy in space (transport or electricity distribution) or their relocation over time through storage activities (refrigeration, nuclear waste disposal or energy batteries). These later transformations are not only crucial to production in the narrow sense, they are also crucial for exchange and trade.

From this point of view, a transformation process is a technological recipe that specifies the various inputs required to produce the intended output and the order of the sequence of operations that must be carried out to effect that transformation. From this it is a short step to represent a transformation process as a set of engineering input:output coefficients for materials and energy. These coefficients embody an understanding of the transformation process that has to pass a simple test, ‘Does the recipe work?’ and if so, ‘How effectively in terms of the quality of the output?’ and ‘How efficiently in terms of the quantities of useful output relative to input?’. Important attributes of such a representation must also include the time dimension of production, and the multiplicity of separate stages and activities that must be gone through before the desired effect of the transformation is achieved. Thus the recipe is also a statement of a required division of labour. This idea of technology as transformation provides a clear framework to write the history of invention and technological change through the documentation of new transformation processes and the associated activities. This is a history of new materials (for example, steel, aluminium, plastics, antibiotics), of new uses for materials (car, television, processed food), of new sources of energy and materials (coal, oil, nuclear power, alumina) and of new kinds of energy (internal combustion, electricity). More recently it is a history of transformations in relation to data, the physical representation of information, and ways to modify, transport or store information subject to the underlying laws of the natural world. Thus, the electronic computer stores data as physical states of materials in its memory and operating systems, states that are changed by a flux of energy within the computer. Similarly, optical fibre communication relies on the encoding and decoding of data as photons, which are transported over space as a light wave. Part of the significance of these information and communication technologies is that information is a necessary element in the operation of all transformation processes. Hence the idea of an information revolution that reconfigures production activities in general.

Now while the way of thinking about technology is extremely valuable and has resulted in many major accounts of technological history (Gille, 1986; Singer, Holmyard and Hall, 1954-1958) it is not the way that economists think about technology and its impact. Indeed there is a well-established tradition in orthodox economics that has long insisted that ‘technique in relation to economics is simply so much data’. This was stated most influentially by Robbins (1932), who argued that “the technical arts of production are simply to be grouped among the given factors of production influencing the relative scarcity of different economic goods” (p. 33). Neither ends nor the ways of using means of production define the economic problem. It is this view that finds it most cogent expression in the neoclassical theory of production.

While this is helpful in defining the economic dimension of activities it has also encouraged a view that the process of change in technology is non-economic. This misconception has only recently begun seriously to be addressed, as we shall see below. If developing knowledge of any kind involves the outlay of valuable resources then an economic dimension is involved. Even if invention were not to be dominated by economic considerations that certainly cannot be said for innovation, the economic application of invention, or even less of diffusion, the spread in economic application of an innovation. Moreover, even inventions are more frequently than not a response to actual or conjectured economic problems.

Production as Economic Activity

How does the economic perspective differ from the science and engineering perspective on transformation processes that we have outlined above? The first and fundamental difference is the place given to the human element in the conduct of activities. This arises most clearly in relation to questions of purpose and organisation. Activities are carried out to meet human objectives and in a market economy these are usually taken to be equivalent to profit making, at least in a broad sense. Activities also have to be organised and the various stages and their team members co-ordinated by a unit of production that is operated in a particular location for a particular purpose. Under capitalism this unit is a firm, the business unit articulating a bundle of transformation processes to meet its objectives. Now the immediate consequence of this is that transformation processes cannot be reduced to dimensions of science and engineering. Knowledge of how to organise production, and of how to ensure the desired responses from members of the organisation becomes of great significance. How a particular transformation process operates in practice will not be independent from the people involved, the constrained imposed by organisation, and the rewards that the individuals perceive. This is the first important contribution of an economic perspective, to recognise the significance of the "technologies" of management and organisation. This management cum interpersonal knowledge is certainly not science although it has many similarities with engineering knowledge.

There is much more to useful knowledge than is encompassed in the traditional emphasis on technology as material transformation.

The second major aspect of the human element is that of “labour”, as a category of economic input. Labour implies two productive contributions, as the expenditure of human energy, and as the intelligent application of that energy to carry out specific transformations. Work and intelligence are the productive services provided by the human agent and it is these productive services that define the labour input in the transformation process. However, the application of labour need not be direct. One of the crucial achievements underpinning modern civilization is the sequence of ‘machinery’ innovations that enable roundabout methods of production to replace human energy with inanimate energy and control the application of that energy in an “automatic”, intelligent way. Since machines are typically made by labour and other kinds of machines we can see all capital goods and associated structures as so much ‘stored-up labour’ and define the services of capital goods in the same terms of energy and its intelligent application.

Hence the economic viewpoint transcends the emphasis on materials and energy inputs and outputs to focus on the intelligent work done in that transformation process through the application of labour and capital services. This intelligent work is what corresponds to the economic category “value-added”, the difference in the economic value of the inanimate energy and material inputs and their economic value as outputs. This quite different perspective on the transformation process is encompassed in the concept of the production function, a relation between a flow of output and the corresponding flows of labour and capital production services, in which the categories of energy and material input have be subsumed as non-economic attributes. Notice carefully that the inputs are the productive services, flows of intelligent effort measured by quality, intensity and time duration, not the physical agents, people and capital structures, from which those services are derived. The significance of this distinction will emerge below, since there is no necessary universal one to one correspondence between service and agent.

The last of our human dimensions is in relation to knowledge and understanding of transformation processes. As practical knowledge, indeed as any form of knowledge, technology necessarily resides in the minds of individuals and nowhere else. All change of knowledge comes from human thought. Information, a correlate of knowledge, may exist in many other inanimate forms but as such it is not knowledge itself but only a representation of knowledge of greater or lesser accuracy. Although what is known is necessarily personal in orientation what is understood is also social. The productive use of personal knowledge depends upon individuals being able to claim common understanding of a phenomena, in the sense that they can provide identical, or at worst closely correlated answers to a particular question from the viewpoint of a third party (for example, How to design an aeroplane? How to bake a cake? How to write a Word document?). Notice that common understanding is not strictly the same as common knowledge, in that the answers to the particular question may have quite different epistemological foundations in the minds of the different individuals. Moreover, in many cases there may be no underlying knowledge template and it frequently happens that technological disasters occur when devices are used beyond the bounds of comprehension, as with the thalidomide tragedy, or the Comet disasters. This important distinction between information and knowledge will emerge below in our discussion of technical change. Thus to speak of the knowledge base of any organisation is problematic. What is known is individual, what is understood is social and a matter of organisation and intercommunication. Hence the importance of the idea of social capital as a framing condition for the economic process. (See Box 3 for a brief summary.)

It is clear that we can think of the knowledge dimension of a transformation process in terms of understandings of increasing degrees of specificity. At the most detailed level is the knowledge of what to do and how to do it in a specific case. This is the practical knowledge without which transformation is impossible. We usually equate this kind of knowledge with a skill. At the most general level we find basic knowledge of the laws governing the operation of technologies (fundamental technology) and of the laws of nature that relate to them (fundamental science). In between are more amorphous levels of knowledge that bridge practice with fundamental principles such as engineering design or what is less accurately called applied science (Copp and Zanella, 1993). The relation between these categories is not straightforward. It is practical knowledge that matters for economic development and this may or may not depend on a mastery of more fundamental levels of understanding. In many technologies it does not, in many important cases transformation processes have no exact grounding in fundamental theory. Knowledge of fundamental principle will not suffice to give the recipe to design or to operate the transformation process in question. Indeed it is often the case that the creation of a transformation process has been the stimulus to search for that fundamental understanding. The development of the fundamental science of semiconductors provides only one of very many cases where the practical exploitation of the particular phenomena was far in advance of conceptual understanding and so stimulated an entire programme of scientific work. There can be no question that a scientific methodology is embedded in modern production practices and that in many technologies a deeper understanding of the relevant natural phenomena enables production methods to be improved. However, there are many methods where the processes are too complex and systemic for any insights from science to be of practical effect, or where much bridging knowledge is needed 'to make science work'. One relevant issue here is the standards that are used to judge claims to new knowledge. The standards set by scientific communities are standards of reliability in terms of the veracity of relations between facts and theoretical claims. Technological communities work to quite different criteria, the standards are expressed in terms of the workability of devices, 'Do they achieve the intended effect?' not 'Why do they achieve that effect?'. In relation to innovations, business communities set yet a third standard, namely, 'Is the method in question profitable?'. These tests are fundamentally different and in these differences lie many of the problems of interaction between scientific, technological and business communities, one of the reasons why the transfer of technologies is not straightforward.

Thus what we mean by technology opens up a range of possibilities. At the most concrete level is the idea of technology as artefacts or services and the way that they are produced. Paralleling this is the idea of technology as useful knowledge, including knowledge of organisation, and at its most practical level this become inseparable from the idea of technology as personal skill and organised routine. Further distinct is the idea of technology as science applied. When we come to the question of technological change and its link with the development process all four notions play a role in our understanding.

Yet a further distinction has played a role in recent discussion, that between codifiable and tacit knowledge. This is a deeply difficult area but the issue at stake is whether or not personal knowledge can be translated into a symbolic information format that permits its encoding/decoding and so facilitates easy transmission between individuals. When this is not possible, or equally important not economic, we say that the relevant knowledge resides in a tacit domain and that it can only be transmitted through a combination of personal observation and experience of others expressing their knowledge in some act. Quite obviously the development of codes and symbolic forms of representation is central to the possibility of shared understanding. Economic development in general is paralleled by the growth of transmissible and therefore codified information. Notice though that a code may be precise or loose, it may be complete or partial, it may be local to a particular community or it may be universal (Senker, 1995; Cohendet and Steinmueller, 2000). Consequently, as Polanyi insisted, all information is absorbed with the help of a tacit background. Now this turns out to be particularly important when we consider how technological knowledge is transmitted between individuals and firms. As the old expression due to Polanyi (1962) has it, “we know more than we can say, we can say more than we can write”. These are immensely important reasons why flows of information are not equivalent to flows of knowledge.

With these observations in mind we now turn to a comparison of the contrasting neoclassical and evolutionary views of technology and more importantly technical change. Inevitably, in the space available these are partial caricatures but they will serve their purpose well enough.

Technology and Innovation: The Neoclassical Viewpoint

In the neoclassical theory of markets the problem to be highlighted is that of economic choice and the role of relative prices in guiding economic choice concerning the allocation of the services of production agents between different activities. For this problem, as Robbins argued, the technical arts of production are data. Technology from this perspective can be viewed as a set of fully known blueprints, codified knowledge available from the “universal blueprint library”. Each blueprint is the recipe for producing a given question of output, fully and unambiguously specifying the inputs required, that is to say the factor services, and the steps to be followed for that particular transformation process in a particular unit of production. This leads to a familiar suite of diagrammatic representations of a particular recipe or technique. It is defined by a point in economic input:output space in Box 4b.

Now suppose that the firm has knowledge of number of alternative techniques at its disposal, labelled $a-e$ in the diagram, each producing the same quantum of output. These alternatives define the production set of the firm or, if preferred, the production function. All that is then required is a knowledge of the relative prices of the factor services to establish which of these options, coexisting simultaneously in the knowledge base of the firm, is the most economic in the sense of producing the particular level of output at minimum cost. Now as relative factor prices change, thresholds will be passed successively at which the most economic technique alters and always in the direction of the technique that uses relative less of, economises on the use of, the factor input that has become relatively more expensive, Box 4c. Of course, a different level of output could define a new set of coefficients, but if constant returns to scale are assumed, all the information in the production set is contained in the techniques for any one level of output. Now suppose further that the techniques are divisible in that they may be operated at different scales. If these graduations are infinitely small it follows that the space between two techniques is also part of the production set. Thus any point in the line segment connecting $a-b$, or $b-c$ and so on, is a viable production point obtained by operating a and b simultaneously with an appropriate mix of the inputs allocated to the two boundary recipes, point a', for example. It is but a short step to remove the angular steps by assuming an infinity of available techniques so that the set boundary becomes a smooth isoquant with every factor price ratio coinciding with a unique most economic technical choice. But nothing in the economic theory of production requires that we take this step and I do not intend to do so.

A series of attributes of the production set may be defined in relation even to this minimal specification of the recipe set. The orthodox theory of production develops this idea by establishing economic measures of technology that explore this link between technical opportunities and economic choices (Brown, 1966). Distinctions are made between the efficiency with which individual inputs or groups of inputs are employed (productivity measures); the sensitivity of the choice of technique to changes in factor prices (the elasticity of substitution); the extent to which the levels and proportions of inputs vary with output (the degree of scale economy); and, the relative proportions that factor services are employed in different techniques (factor intensity). While the technical properties of a particular activity greatly influence these attributes, their purpose is solely economic, to characterise the most economically appropriate choice of method and how this varies with market signals.

While from an economic perspective it is appropriate to take the production set as a given, from a development perspective this is wholly inadequate. What is it then that determines the production set the spectrum of available blueprints if they are not contained in a universal library? The answer is that it is specified by the knowledge contained within the firm. However, this seemingly innocuous statement opens up a whole range of difficult questions, some of them alluded to above, that help locate the issues to be dealt with in our treatment of the evolutionary theory of the firm. By knowledge we might simply mean the set of alternatives of which the firm has had experience of using over and above the technique currently in operation. But economists have typically sort a greater generality by assuming that the production set is defined by a much wider set of potential techniques, that determined by the state of more fundamental scientific and technological knowledge (Salter, 1960), knowledge that is assumed to be available freely in the public domain. The objections to this broad definition are twofold. First, it ignores the 'non-fundamental' knowledge that is necessary to turn principle into practice. Too much weight can be given to formal knowledge of the scientific kind to the detriment of the many different kinds of practical knowledge of technique and organisation required to operate a transformation process (Rosenberg, 1976). Secondly, it is clearly open to a fatal objection in that moving to a new technique, say from 'a' to 'c' is not possible unless new knowledge is acquired in the process of transition, and this knowledge cannot be specified in full specified in advance of the change. In short, outside of a narrow range of possibilities, any changes of technique necessarily leads too, indeed require, learning and the growth of new knowledge. Choice of technique with knowledge given is a very limited concept.

Consider now a second issue in relation to the knowledge of the firm. The production set or function clearly defines a boundary between methods that are unavailable, unknown to the firm, and those that are inefficient. Thus in relation to technique b, b' is beyond its capabilities to articulate, while b'' is simply an inefficient way to produce the specified quantum of output. However, this does not establish that b'' will not be chosen over b. Technical knowledge is not sufficient, the firm must also possess the organisational ability to identify and to implement b, and not a less efficient alternative (Nelson and Winter, 1984). Thus the neoclassical postulate that all firms operating the same activity, anywhere, will have access to and be able to implement choices from a single, well-defined, best practice production set is a step too far. This is reflected on a daily basis not only by efficiency differences between countries but even more strikingly by differences between firms within an activity in a given country. If this were not so, it would be difficult in the extreme to understand what might be meant by a problem of knowledge and economic development. How has this notion of the universal technological option, the ubiquitous blueprint and its hypothetical library, come about?

The simple answer is that economics for long found it easier to work with the idea that the state of the technical arts is, as it were, "manna from heaven". This is the logical outcome of the Robbinsian perspective, technology or any other form of knowledge is not an economic problem. The more complex answer is that when economists came to develop an economy of knowledge they did so from a particular perspective. Their key postulate highlighted the idea of knowledge as a non-rival good, arguing that any item of knowledge could be used any number of times by any number of firms to produce any quantum of output or indeed to develop new knowledge. This is unexceptional but it is also the source of our difficulties. That knowledge is non-rival in use does not mean it is freely available to all whom might find productive use for it. At the core of the matter is the point dealt with above that information does not equate to a flow of knowledge. Information is a representation of knowledge and while it may, as a matter of empirical fact, be virtually costless to transmit between individuals, whether directly or indirectly, this does not mean that it is costless to absorb. What the "transmitter" transmits and what the "receiver" receives may not be the same. What is understood will depend on the recipient's present state of accumulated knowledge and this is necessarily individual, idiosyncratic and a typical consequence of personal specialisation in relation to productive activity. This is why education is so important to development, it is a principal determinant of individual capacities in general to absorb knowledge. But these capacities are not unlimited. The division of labour results in all of us acquiring a well defined ability to absorb certain specific kinds of knowledge while casting a veil of ignorance in regard to knowledge in other domains. Information flow results in neither uncontested nor uniform knowledge states and indeed on this hangs the very possibility of progress in relation to knowledge. Thus from an economic viewpoint, new knowledge is not only "costly" to produce it is costly to absorb and absorptive capacity depends on prior acquisition of knowledge (Cohen and Levinthal, 1989). This helps explain why some firms carry out fundamental scientific and technological research out of their own resources (Rosenberg, 1990). They need to build their own basic knowledge to be able to interact with the external research communities, to be able to understand the relevant knowledge frontiers, and to be able to engage in the 'gift exchange' practices that permit entry to the networks of researchers (Hicks, 1995). But the point is more general, the decision to absorb external knowledge is a positive step the success of which depends on the deployment of resources and the outcome of which depends on what is known already.

Consequently, the deeper reasons why the production sets of firms are idiosyncratic rests on the fact that the accumulation of knowledge requires the disposition of real resources and is always contingent upon the current knowledge base of the firm. To capture this idea economic analysis usually proceeds with the help of an innovation possibility frontier, an analogue of the production function connecting innovative effort to innovative output. In its more advanced treatments this sees the issue as a matter of investment subject to uncertainty (Machlup, 1962). More effort leads to more innovation but subject to diminishing returns, for the additional effort is always conditioned by the 'fixed state' of our prevailing knowledge. This concept is wholly sensible but the idea that all countries and indeed all firms in any narrowly defined activity face a common innovation possibility frontier is not tenable. The idiosyncrasy of innovation possibilities is beyond doubt, and once different they will remain different such that even if two firms devoted the same effort to innovation they would not produce identical innovations. Indeed the very notion of innovation is synonymous with idiosyncratic behaviour, to innovate is to act in a way that is unique. Even the concept of 'equal innovative efforts' is difficult to define and it certainly cannot be measured accurately by expenditures on R&D, for example. But then differences in innovation possibility sets become the most powerful rationale of different production possibility sets, and the non-zero costs of absorbing external knowledge prevent the transfer of technology eliminating those deeply founded differences. That the innovation possibility set will differ across firms is also a clue to its fuzzy nature. To know what the boundary is, is to know exactly which innovations will follow from inventive effort, a contradiction in terms, for the future cannot be known. The history of technology speaks otherwise, the unintended consequence, the serendipitous outcome is ever present. Innovation is a non-predictable discovery process in which new artefacts and new knowledge are joint products. It is not obviously encompassed by the idea of optimising over probabilistic outcomes, since to write down the probability distribution requires that all the possible innovations be known in advance.

None of this, of course, means that economic considerations, in the shape of profit expectations, are irrelevant to the innovation process. Relative factor prices, relative consumer valuations of product attributes, the scale of demand in relation to the market for a new technology, the relative costs of following different patterns of enquiry, the difficulty of maintaining intellectual property in new devices all play a well understood role. When these factors change we must expect the pattern of innovation to change in an economising direction. The changes, however, will be idiosyncratic in their origins, essentially unpredictable in form and often in unintended areas of application but almost invariably capable of an economic rationalisation after the event. In short what is transparent ex post is surely opaque ex ante.

One other aspect of idiosyncrasy needs mention. It is still the case that most formulations of technical change treat it is a phenomenon spread more of less uniformly over the entire production set. As shown in box 4d, all the techniques might be shifted towards the origin by some change in available knowledge irrespective of whether those techniques are in use or not. There is however a compelling argument that improvements will tend to be localised in the production set around current practice that they are stimulated by problems and problems are generated by current activities. Costly R&D, for example, will typically be deployed in support of a process of search in the vicinity of current production (Atkinson and Stiglitz, 1969; David, 1975; Nelson and Winter, 1984; Stiglitz, 1987; Lundvall, 1992; Antonelli, 1999). More tellingly, learning frequently depends on experience, in doing and using, so that reliable changes in knowledge depend on problems generated by operating the current technique, not some hypothetical alternative technique. This is quite a compelling argument about the incremental, locally bounded pattern of technical development. It would explain how firms in the same line of activity but operating in the different factor price environments of different economies would experience different foci for innovation and create further technological idiosyncrasies in the process. Thus, in Box 4e, the firm operates technique ‘c’ and only improves this technique over time. The current technique is precisely the searchlight shining the light by which to discover improvements to practice.

However, incremental local innovation does not cover all the possibilities. There must always be room for creativity untrammelled by current activities, room for radical innovation that transcends current practice. Here we have reached the key issue. Economic development depends upon, indeed might be equated with, sustained creative activity, incremental and radical. As soon as we consider radical innovation we must confront the importance of knowledge arising outside a particular constellation of firms. If relevant knowledge arises in many contexts (universities for one) how is it to be incorporated into firms? To answer this question we need a different approach to the firm and its technological knowledge.

4. <u>Capabilities and the Growth of Knowledge</u>

In any explanation of economic development a central role must be given to a treatment of the development of productive capacities and thus the development of the organisations taking that responsibility, namely, firms. Following Bell and Pavitt (1993) we shall distinguish between productive capabilities and innovative capabilities, the ability to change productive capabilities. In recent writings these latter have been subsumed under the category of dynamic capabilities. (Teece, Pisano and Shuen, 2000). At stake here is not simply the quantitative growth of the firm but its qualitative transformation in relation to methods of production employed and selection of what is to be produced and how these change over time. What makes firms different from markets is that it is the firm that decides what is to be produced and how. Firms are not substitutes for markets they achieve what markets cannot achieve, in the sense that interactions between individuals and teams depend on administrative authority and purpose not on exchange of exactly specified factor services. Within the evolutionary tradition the key questions become ‘How and why do firms differ in their productive capabilities?’ and ‘How and why do these capabilities develop at different rates over time for different firms?'. It is on these differences that an evolutionary dynamic if development is based. Like all theories of the firm the focus is on adaptation but this is not the passive adaptation to external signals in the context of well defined production and innovation choice sets. Rather the adaptive response is a creative response that always requires the acquisition of some new elements of knowledge (Shackle, 1961). Economic incentives are always important but not all change is a pre-programmed response to market stimuli in automaton fashion. Moreover, not all stimuli can be seen as external to the firm, many of the relevant pressures and opportunities for change will arise from within its operation. More importantly still is the kind of development that is an imaginative step and involves the creation of activities hitherto unthought of rather than the adjustment to prevailing experience. Consequently, how firms develop and manage their cognitive and imaginative processes, how they accumulate and articulate new knowledge are at the core of the evolutionary approach. We might also insist that they are at the core of the problem of disparities in economic development. Much of our understanding of these processes is tied up with what I shall call the capabilities theory of the firm but before turning to this representation of the firm a brief comment is necessary, on rationality.

On Rationality

The question of rationality as the basis for action has always been a problem in the social sciences. All thinking must accept that economic action is based on the purposeful adjustment of means to ends, but this claim is not exhausted by the view that this adjustment is Olympian, with all possible options being evaluated fully in the light of all the available constraints. It is Olympian rationality that underpins the idea that firms in the same line of activity have the same productive and innovative choice sets and thus eliminates idiosyncrasy at source. The reasons for stepping back from this position need only be rehearsed briefly. They include, manifest limits on human cognitive and evaluative powers, the fuzzy nature of the relation between information and knowledge, and the multiplicity of goals that arise in any organisation. These have all been discussed intensively within the literature on the theory of the firm (Cyert and March, 1963; Nelson and Winter, 1984; Langlois and Robertson, 1996). The important point for us is that they all contribute to an understanding of why technological differences between firms are sustained over time. The evolutionary story is perfectly compatible with the idea of local rationality that decisions make the best of circumstances as they are perceived. What it does not accept is the uniformity of circumstance and perception. Indeed if Olympian uniform behaviour were the norm it is not possible to see how innovation, imitation and technology transfer could arise, for each of these is contingent on sustained difference and variety. Thus what has to be understood is how the objectives of firms differ (the problem of strategy) and how the characteristics relevant to competitive selection differ (the problem of performance).

Moreover the rationality of markets is a quite separate question from the rationality of firms. If selection is for profitability it does not follow that the more profitable firm is more rational in its adjustment of means to ends. The firm that is only 50% efficient will still have lower costs than a rival that is 100% efficient but operates a transformation process that is 51% less productive. There is nothing in the competitive process argument that suggests that selection is for rationality. Selection works with what is on offer in the market not what might be on offer in different circumstances. Notice though that while selection is myopic in this sense, it does not mean that expectations of the future are irrelevant: only that their influence on selection is mediated by how those expectations influence current behaviours.

Thus for the evolutionary approach a firm is not a passive automaton acting out the solution to a rational plan. Rather it is a creative, imaginative entity, the outcome of an ongoing and unfinished process of organisational design (Bausor, 1994). It is a framework for generating new knowledge, for encapsulating a restless process of discovery. It is this combination of creative firms and open adaptive markets in which any position is open to challenge that makes capitalism an ongoing development process.

The theory of the developing firm that underpins this view is one that puts knowledge and change of knowledge as its central explanatory challenge. The firm is the totality of what is known within it and this depends on the individual members and the way in which they interact. To this capability based approach we now turn.

Knowledge and the Development of the Firm.

A number of important ideas can be brought together as the foundations of this developmental perspective on the firm (Knudson, 1996). A convenient starting point is provided by Penrose (1959) and her view of the firm as an administrative unit that generates productive services from bundles of physical and human productive agents. This perspective presupposes organisation and purpose. The administrative unit is operated in the context of a particular theory of business held by the top management team (Castanias and Helfat, 1991; Eliasson, 1990). Or, as other writers put it, a dominant logic underpinning the operations of the firm (Prahalad and Bettis, 1995) or a vision of its purpose (Fransman, 1994). In distinguishing between purpose, resources and agents in this way, Penrose provides the foundation for what is now called the capability theory of the firm. A central feature of this theory is the explanation it provides for why each firm writes with its own signature in the commercial world.

To understand this approach it is helpful to distinguish between agents of production, productive services or resources, capabilities and competence. Agreement in terminology in this literature is not exact but the categories involved are transparent enough (Foss, 1996; Dosi *et al*, 2000). The agents of production are the employees, the land and the various kinds of produced means of production, machines, buildings etc, which firms can obtain 'in the market'. There is nothing about these agents in general that prevents their being deployed by any other firm operating the same or any other transformation process. Each of these agents embodies the skill or knowledge that is a potential to provide productive services but how this potential is realised depends on the nature of the firm under whose control the agents fall. Thus the productive services that are extracted are idiosyncratic and peculiar to each firm. The same individual may when working in different firms produce different flows of productive services depending on motivation, instruction and the services of other complementary agents in the firms. As Winter (1987) has emphasised, productive resources are qualities not things, and these qualities are not entirely properties of the productive agents. Not only is the production function idiosyncratic so are the factors deployed to operate it and the same agent operated by different firms will not usually generate the same flow of resource. Moreover, what a firm is able to extract in the form of productive service is not only idiosyncratic it is also necessarily non-marketable, unlike the underlying physical agents. Consequently, the mere acquisition of productive agents does not, of itself, provide any basis for competitive advantage. Nelson and Winter (1984) quote Michael Polanyi on this theme in a way that makes the development related point perfectly,

> "The attempt to analyse scientifically the established industrial arts has everywhere led to similar results, …., I have myself watched in Hungary, a new imported machine for blowing electric lamp bulbs, the exact counterpart of which was operating successfully in Germany, failing for a whole year to produce a single flawless bulb" (Polanyi, 1962, p. 52).

The machines were the same, the ability of the respective organisations to elicit the necessary productive services was radically different, a phenomena which any development scholar will recognise many times over. Kim (1996), for example, provides a telling discussion of the same problem in relation to the efforts of South Korea to establish an automobile industry. Fine technological and organisational details matter and the flow of productive services cannot be taken for granted. In the light of this the firm is clearly an organisation of overwhelming importance for development, for it is within the firm that the fine details are attended to. Its capabilities not only determine the technological level of an economy, its internal management processes also determine the resources available to the economy. Thus technology in a narrow sense is not enough. That knowledge and skill must be embedded in an organisation working for a purpose. Quite clearly, knowledge of management must play a key role in this perspective, and managerial knowledge is like engineering knowledge, it is accepted because it works not because it reflects some deeper sense of truth.

Capabilities take us one step further up the hierarchy of the firm. They are defined as the combinations of resources and organisation structures that enable a transformation process to be articulated. They may be defined in relation to a particular stage of production, or some other function necessary for the operation of the firm, marketing, logistics or personnel management, for example. Capabilities are the organisational analogue of personal skills in executing a task or set of complementary tasks. Here lie the importance of teamwork, of trust and of experience, all the elements, which lead to the idea of the social and organisational capital, contained in a particular firm. To support this view, Box 5, illustrates the many influences on the capabilities of a technically progressive firm, as derived from one of the pioneering studies of innovation in UK industry. One of the major findings of this study is the strong positive association between these indicators and innovative performance. Notice also how much these indicators relate to the growth of knowledge and its embodiment in the managers and routines of a company.

Firms then are bundles of different capabilities articulated for a strategic purpose, and this bundle, we call the competence of the firm. The competence defines the set of comparative advantages enjoyed by the firm relative to its rivals and it is these that underpin its relative performance. The sense of purpose, the logic of the business, identifies the productive opportunity, guides actions and decisions, provides tests of performance and acts as a filter in relation to the accumulation of critical knowledge and the absorption of external knowledge. It will be clear that organisation is of vital importance to this view. It is the organisation that extracts and combines the resource flows into the various capabilities and integrates those capabilities into a business competence. The organisation is an operator that transforms individual knowledge into a pattern of collective understanding, and if the operator changes so will that understanding.

Capabilities and Routines

Now, from a developmental perspective, the central feature of the capabilities perspective lies in its link with the creation and exploitation of valuable knowledge, the firm becomes a framework for creating and combining many different kinds of knowledge for a purpose. (Kogut and Zander, 1992). It is clear that this framework must possess a considerable degree of stability, the functions to be performed cannot be continually questioned and renegotiated. Indeed to do so would be to forego the economies of scale and scope which come from having invested in a competence that can now be exploited through extended repetitions of the relevant tasks. Scholars have approached this element of stability essentially by claiming that the recipes for action are embodied in standard operating rules (Cyert and March, 1963) or in behaviour routines (Nelson and Winter, 1984). Routines are the templates, the instructions to guide action, they reflect lines of communication and reporting, they specify tasks, and they embody the organisation's self-knowledge of its operating procedures. As patterns of practice, routine bundles are the carriers of the firm's know–how. They are practices instituted they are the embodiment of shared understandings. Clearly, routines involve much more than technical knowledge in the sense of the traditional theory of production discussed above. Some routines are very precise templates, they brook no deviations from the specified repetition of actions by individuals and teams. Others, typically related to higher order tasks in the organisation, are more deliberative and exercise the use of judgement, they are frameworks for solving problems not the answers to problems. Clearly, the more creative is an organisation the more important are the higher level routines.

However, in specifying routines as stable combinations of rules, directions and organisational patterns of communication we must confront a paradox, the paradox of innovation in the presence of inertia. A central task of management is to stabilise the routines that define a particular firm. However, total stability would imply that no new knowledge is ever acquired and absorbed into the firm. This cannot be so, for firms are restless organisations as Penrose pointed out. Indeed, it is the central insight deployed by Penrose that the development of the firm depends on the continual development of capabilities and on the elicitation of new productive services. Thus the firm is not only the frame for combining multiple kinds of knowledge to practical effect it is also the framework for learning. In capitalist economies no other organisation has these dual roles.

Once again the combinatorial nature of the link between routines and capabilities is important. From this comes interdependence so that an improvement in one routine may be passed over because its adoption would be contingent on changes in other complementary routines and these wider ‘costs’ may be barriers to change. From this also comes the dynamics of imbalance. Thus improvements in some capabilities trigger the need for improvements in related capabilities. Equally, expertise can be acquired that cannot be turned into capability, and this slack provides an incentive for complementary development. This developmental potential is what is meant by the idea of dynamic capabilities. The rate at which the organisation identifies and generates competing solutions to internal problems, the rate and direction in which it explores the potential contained in its particular theory of business are the outcomes of the exercise of dynamic capabilities. How opportunities for innovation in technology and organisation are identified, how resources are allocated to problem solving, and how the change processes are managed are each sets of dynamic capabilities that shape the development of the firm. There is no guarantee that sets of capabilities that are effective in relation to existing activities will be coexist with correspondingly effective sets of dynamic capabilities. Excellent firms are not always creative firms, and observers have often pointed to the transient nature of excellence.

To summarise, the developmental firm is a modular construct. Agents are hired and complementary resources are extracted from them through the deployment of organisational routines that embody the capability to perform sets of related tasks. Combined together the capabilities constitute the competence of a firm, a concept that depends on the overarching theory of business. However, while resources, routines and capabilities are defined within the firm, its competence is clearly a comparative concept for it reflects the performance of a firm relative to its rivals. If rivals improve their capabilities or develop more fruitful theories of business then the competence of our firm must necessarily decline. Hence the importance of dynamic capabilities to maintain the momentum of competitive advantage. These ideas are just as applicable to developing economies as they are to the advanced nations. The search for competitive advantage can never be relaxed for no advantage is permanent or free from challenge as many firms in developed and developing nations alike have found to their cost.

5. Technical Change and Development from an Evolutionary Perspective

How does the evolutionary perspective help reach an understanding of the complex linkages between the mastery of technology and the development process? Part of our answer already is that technological knowledge has to be combined with complementary organisational and business capabilities to good economic effect. Moreover, that the outcomes in terms of technological performance and innovation cannot be presented as if they are underpinned by passive choice made from well-defined, common decision sets. It is the idiosyncratic nature of firm performance in respect to current technologies and the development of innovations that provides the link to evolution.

A deeper answer to the question is gained by enquiring into the conditions for a country to gain share in world markets for a particular product or closely related group of products. A number of economic tests must be passed that map onto the development problem. First the national firms in question must be viable, they must not make losses at the ruling world prices and local efficiency wages relative to foreign efficiency wages. This requires not only a level of technological mastery but also the translation of this into a sufficient level of business competence. But viability at ruling international prices is not enough, development requires much more. It requires the capacity to grow on the foundations set by viability and it requires a capacity to adapt as market circumstances change. For example, if the national firms can export profitably they must also increase their output to at least the world average rate if they are to maintain their share of world markets. Obviously they must grow more rapidly than the world average if their export shares are to increase. They must be able to attract the necessary productive agents and manage the process of investment and expansion to achieve this. But growth of capacity is only part of the dynamic challenge, the firms must also increase their level of technological mastery to prevent their technological performance falling behind the world average for the firms competing in that sector. They do not need to be world best practice but they must be good enough to maintain at least an average position in relation to the quality of the products and the efficiency of the methods of production. These twin dynamic challenges in relation to accumulation and innovation are formidable. Why is this an evolutionary problem? For three reasons, it requires variation in performance relative to international competitors, it requires structural change in the domestic and international economies and it requires the ongoing generation of innovation to keep pace with world developments. These concepts, variation, selection and generation are the building blocks of economic evolution.

By ‘variation’, we mean the differences between firms in their economic performance with a substantial portion of this traceable to the differences in their technological and organisational capabilities. At one broad level variation is the difference between the capabilities of traditional and modern sectors (Nelson and Pack, 2000), more specifically there are the differences within sectors, the ever present distribution of performance between best and worst practice, both nationally and internationally. This is the idiosyncratic dimension of firms emphasised above, founded upon their continual differential discovery of innovations, mutations, in their respective transformation processes. However what is crucial to development is that superior methods are spread within the economy so as to increase the average efficiency with which resources are used and that better practices always displace inferior practices in terms of resource utilisation. In this way development is a question of re-mixing the proportions in which alternative technologies are used, it is inherently a question of structural change (Lall and Teubal, 1998). Two broad processes facilitate this spread of better technology and organisation practices. The first is imitation, rival firms acquire the capability to operate the transformation process either by their own innovative efforts, or by licensing or other technology transfer arrangement if appropriate, or by reverse engineering if possible. In each case, as with all learning processes, the imitation is not likely to be exact and can often lead to many improvements and variations not seen by the innovator. The second process is the evolutionary equivalent of dynamic competition, what evolutionary analysis calls selection. By 'selection' is meant the competitive processes by which the different technological capabilities acquire different levels of economic significance over time. Firms and markets play complementary roles in this variation-selection framework. Each firm is a variation and selective device in itself, in which inventions are conjectured and subjected to internal mechanisms of choice and articulation. It is a trial and error generator in which firms differ greatly in their creativity. The ensuing differences across rival firms results in further market-based selection. Depending upon its product price quality profile relative to competing products, a firm will lose or gain custom and a share of total market revenue. According to the relative efficiency of its production processes, it will also generate a level of profit and a share of the aggregate profit generated in the sector. In this process the way markets work is crucial to a development-oriented outcome. The prices established in markets for products and inputs value the activities of the rival firms, they determine the margins of economic viability for a particular activity and they determine the distribution of profits or economic rents across rival activities (Winter, 1995). If they do not reflect accurately the underlying quality and cost profiles of the rivals, selection will be distorted. Profits are in turn the basis for further investment and growth at the expense of rivals. But profits alone are not sufficient. Firms that are selected to be more profitable must be willing and able to translate that superiority into a higher rate of output growth than less profitable rivals. If this is not the case then the balance of resource utilisation will not flow in favour of the better production methods. Moreover, it is the open, adaptive aspects of markets that permit the entry of new technologies and firms and eliminate those activities that have fallen below the margins of economic viability.

Restrictions on entry and the continued use of non-viable technologies are very effective ways to limit the development process.

Variation and selection alone are not complete explanations of the evolutionary dynamic. An account is needed of how variations are generated and how this creative capacity is nurtured, distributed and sustained in an economy. Selection is best seen as selection across a population of behaviours that are developing over time and this provides a different dimension on the symbiosis between firms and markets. How innovations, variations, occur in relation to technology and organisation is not independent of the market process. Whether we consider the awareness of innovation opportunities, the resources available to innovate, the incentives to innovate, or even the capabilities to innovate each of these interacts with the market selection process. Problems that are the stimulus to learning arise from the experience of production and use of products and services as a continuous process. The profits generated in the selection process are a principal determinant of the resources available to invest in innovation. Competitive pressures in open markets are sufficient incentive to stimulate innovation in search of competitive advantage. The capabilities to innovate depend greatly on prior market experience of trial and error developments. In each of these ways innovative variation is contingent on the market process in which variation, selection and the generation of further variation discover new resources and uses of resources, the outcome of which is economic development.

Thus the nature of the firm as an experimental agency embedded in market processes, as well as its nature as a productive agency, is at the forefront of the evolutionary analyses of technological change (Lall and Teubal, 1998, Lall, 2000). How a firm is to be organised to be efficient in relation to current activities and creative in relation to variations in activities is one of the central management problems within the capability approach to the firm. It is only partly a question of technology management. There is no particular reason why a firm, which has well developed production capabilities with a particular technology directed at particular markets, will have similarly well-developed capabilities in relation to any other relevant technology or market opportunity. Indeed, one of the themes in the capabilities literature is that already developed capabilities are not plastic, they contain within themselves a considerable degree of inertia constraining the kinds of variations that will be considered and selected in a given firm.

Particularly in relation to more radical innovations the key steps are often associated with firms outside of a given sector. It is precisely because of the limitations to the innovative capability of any one firm that the broader development of technology depends on the contributions of many firms. Capitalism adapts in the way it does largely because of its modular structure. Resistance to radical technological development in established forms is overcome by the creation of new firms and open competitive processes permit new firms to acquire customers and resources at the expense of established firms. Such systems are extremely competitive but not in terms of the notion of perfect competition. It is not a competitive economic structure that matters but rather a competitive economic process in which there is a high rate of business experimentation. The distributed nature of innovation processes turns out to be one of the experimental strengths of market capitalism as a system. The ability to de-couple the generation of innovation from existing contexts is an extremely powerful but also highly uncertain route to economic adaptation. For this reason, adaptation in the economy requires a consideration of more than firms and markets.

It is my contention that the newly industrialising economies such as Taiwan and South Korea have achieved an internationally competitive mastery of relevant technologies in a remarkably short span of time through processes of variation, selection and generation of technological capabilities, albeit with important differences in approach between them. Moreover it is their ability to continually improve that mastery that has been the feature of their success. Yet other economies show little capacity to become technologically self-sustaining. These discrepancies in performance raise the question of their dependence on policy and the contribution that innovation policy can make to development. To this we now turn.

6. The Policy Dimension

In this final section I briefly explore some of the policy implications of the foregoing. This is too large a topic for other than a superficial treatment of important issues identified by a rich and growing literature (Katz, 1987; Lall, 1995, 2000, Lall and Teubal, 1998). Questions of priority setting in relation to technologies and firms and of incentives for innovation I will not explore, rather my focus is on knowledge, organisations and innovation infrastructures. To begin it is useful to distinguish science and technology policy from innovation policy more generally. The former is relatively narrow in scope concerned as it is with the organisation of and resource commitment to the accumulation of particular kinds of relatively abstract knowledge. Innovation policy is much broader; it is concerned with the economic exploitation of practical knowledge, with the flow of resources to support knowledge accumulation within and between firms, with the openness of markets and with the supply of entrepreneurs. There is much more to innovation than science and technology or R&D activity (Teubal *et al*, 1996). Indeed, the whole tenor of our analysis is that technology has to be combined with complementary business capabilities to create economic development, and that these business capabilities must be accumulated as well. Many policy instruments impinge on the accumulation and application of business capabilities, including competition policy, exchange rate and tariff policy and macro policy in general. We must take this as read. I shall not deal with the details of science, technology and innovation policy in relation to specific sectors or firms but rather focus on the general principles that follow from the previous discussion.

The traditional perspective on innovation policy implies that the fundamental problems of accumulating knowledge are solved. Production sets and innovation possibilities are already clearly defined and largely common to firms in a sector. Firms know of an extended range of opportunities conditional upon the wider state of science and technology but fail to exploit them effectively because of market failure induced divergences in the private and social rates of return to investments in knowledge and innovation (Arrow, 1962; Stoneman, 1984). The role of the optimising policy maker is to correct these divergent incentives by suitable fiscal arrangements and grants conceived as stimuli to innovative activity. Knowledge is indistinguishable from information and both are ‘in the ether’ there to be absorbed if only the incentives are correctly aligned.

This incentive aspect of policy is not irrelevant in developing economies but it pales into insignificance beside the fundamental gaps in practical knowledge across countries. Correcting this gap is not only a question of catching up in established areas of world production but of building the internal capacity for the independent development of technology and business knowledge, dynamic capabilities as we termed them above. At first this can be directed at the modification of imported technology and business capability, to match local conditions in relation to the supply of inputs or consumer needs but there is not the slightest reason to prevent a more ambitious attitude emerging with time. Learning to learn takes time and resource but opens up an ever-richer range of innovation possibilities, as demonstrated by experience in Taiwan and South Korea. Furthermore, opportunities for significant innovation don't just occur in so-called high-tech sectors, traditional technologies associated with mature markets are quite capable of deep technological transformation.

In contrast we have insisted that information does not map readily into knowledge nor is it accessible without investments in absorptive capability. From the evolutionary perspective technology is not simply knowledge embodied in material agents. It is also a matter of the knowledge and skill to define a space of possibilities. A space that can be explored for commercial advantage: so that the history of many technologies is reflected in a cumulative stream of related innovations that explored regions of the technology opportunity space (Georghiou *et al*, 1984). No technology is ever created without the potential for further improvement. Dahlman *et al* (1987), for example, provide an interesting and wholly typical example of a ceramics technology first used in the USA and then improved in large successive steps as it is transferred to new economic environments in Mexico and then Brazil. In this sense every technology is an opportunity for discovery, for the progressive elimination of ignorance.

It is this that takes us to a different view of innovation policy and its correlates in respect of science and technology. This sees the central task of policy to create a rich ecology of organisational and institutional support for knowledge absorption and generation and to support the development of the associated innovative capabilities in firms. In advanced economies the innovation process is exactly reflected in systems of interconnected organisations that store, produce and disseminate information for productive purposes. They constitute a complex set of innovation systems distributed across sectors, jointly involving public and private activity and open to the international exchange and development of new knowledge (Nelson, 1993; Edquist, 1997; Carlsson, 1995). Few firms, if any, even the largest in a sector, can find it economic to innovate entirely on the basis of internally generated knowledge. The modern innovation process is embedded in a detailed division of knowledge creating activity, an increasingly roundabout system for generating and applying practical knowledge, that has the characteristic of being distributed across many organisations, not only firms. Innovation typically requires mastery of multiple technologies generated by different organisations. This raises two innovation policy problems. 'How does the firm gain access to access external knowledge?' and 'How does it combine external knowledge with that generated by its internal innovation processes?'. In short, 'How is this extended division of innovative labour to be co-ordinated?'. For the developing economy this extended ecology of innovation systems cannot be taken for granted. Indeed it does not arise automatically in advanced economies. It is the primary purpose of the adaptive policy maker to establish the framework of organisation and institution that connects the economy both internally and with the wider world of technology (Lall and Teubal, 1998, Teubal, 1996).

The point is that the innovative capabilities of a firm depend on active links to the knowledge held by users (knowledge of market) and by suppliers (knowledge of materials and machinery) and by non-firm organisations such as public research laboratories and universities whether national or foreign. These are non-trivial tasks and require of management an outward orientation to valuable knowledge. The ability of firms to absorb external knowledge is vital to their development and absorption is itself an active, creative process (Bell and Pavitt, 1993). There is, for example, no purpose in establishing powerful public research institutes in particular technologies, if the national firms do not possess the background knowledge to absorb what is made available. Learning processes are simultaneously individual and collective, and so what one organisation can learn is dependent on learning in collaborating organisations. In this regard there is an immensely important role for public policy in creating and supporting a range of national and sector specific knowledge based organisations to support dynamic capability formation in local firms. In a broad sense this is the problem of social capital formation to facilitate the range and depth of interactions between individuals, groups and organisations in the pursuit of innovation (Box 3).

Rather than focus on the idea of market incentive failure in relation to innovation, this suggests that a far more appropriate notion for developmental policy is that of innovation system failure (Metcalfe, 1994a, 1994b; Lall and Teubal, 1998). The role of policy is to ensure that the appropriate range of knowledge organisations exists nationally and that they interact to productive effect. The problem, in brief, is to create a working innovation ecology that evolves over time as national capabilities and ambitions grow. Information does not flow easily within or between organisations and yet the widespread diffusion of information can bring great benefit to firms (David and Foray, 1996). Even when proprietary issues are absent, the acquisition of information depends on knowing where to look, who to ask, and on the ability to comprehend the answers. The assumption that knowledge flows naturally like water would on a frictionless level surface is simply wrong. Hence the emphasis on the innovation infrastructure as the key to the purposeful articulation of link between technology and development (Teubal *et al*, 1996). A broad set of policies accepted to be consistent with this view would include:

- Education policies to increase the knowledge absorbing and creating potential of nationals at all levels from primary to higher education;
- Establishment of problem solving agencies, whether public or private in relation to the technologies of specific sectors (Dahlman *et al*, 1987);
- Establishment of a national technological infrastructure, including the patent system, training activities including management training, organisations for the conduct of basic scientific and technological research and for the establishment of standards and metrology services (Tassey, 1992; Teubal *et al*, 1996)
- The stimulation of networks of firms and other organisations in collaborative support of innovation to build on the complementarities between different technologies;
- An active policy of searching for and acquiring foreign technologies, whether through licensing, imitative reverse engineering, development contracts or inward foreign investment;
- A commitment to outward oriented trade policies that set international standards for performance and encourage interaction with demanding foreign customers.

The ways in which the systemic and infrastructural aspects of the innovation process are revealed in practice reflect a wide variety of mechanisms. Markets in problem solving services play an important role, through the work of technical consultancies and higher education institutions. A firm specifies an idiosyncratic problem and the agency applies its generic capability to find a solution. At a second level, firms can engage in a wide range of collaborative arrangements aimed at synthesising idiosyncratic knowledge or in jointly developing new knowledge. Again these collaborations may include Universities and public or private research institutes as well as other firms, domestic or overseas. At a third level are a multitude of innovation stimulating supply chain interactions between firms their suppliers of equipment, materials and components and their customers that embed a firm's innovation system in the matrix of its market relations.

All of these ways of taking advantage of external knowledge and skills can be viewed in terms of collaboration in the pursuit of competitive advantage and they all rely on the combinatorial capabilities of the firm to integrate and reconfigure the different kinds of knowledge in pursuit of innovation. The kind of collaboration that is appropriate, for how long, and how it is organised depend greatly on the type knowledge concerned and on the scale of advance that is involved relative to current capabilities. The larger the step, the more basic the knowledge, and the greater the uncertainties, the more likely will the arrangements involve reciprocal collaborative commitments, for example, in the form of a club arrangement for R&D. Even in advanced economies the state also plays a fundamental role in the operation of these distributed innovation processes. The funding of basic science and technology in Universities, the funding of R&D to meet the missions of government agencies, and the public procurement of innovation in relation to defence and health all fit under this heading (Mowery and Rosenberg, 1998). Innovation systems that are successful appear to depend on the combination of complementary public and private investments in knowledge.

One of the most important aspects of these distributed innovation systems is their modular nature, and modularity is essential to all adaptive, evolutionary processes. No firm can be free from internally generated constraints on its innovative activities. This is an elementary consequence of the division of intellectual labour: specialist knowledge necessarily generates more general ignorance so that sunk investments in knowledge and capabilities constitute constraints as well as a framework for defining opportunities for exploration. Bygones might be bygones for the economist but in reality they define the experiences from which the future is imagined and the development of all firms has this history dependent quality. Moreover, as argued above, there is no automatic rule that stipulates that today's leader at innovation will deliver the same performance tomorrow. There is even more diversity in relation to innovative performance than there is in relation to production and business in general. Hence the importance of new firm formation and of cross entry from firms in other sectors to overall innovation performance. The idea is more general. While the final stages of innovative activity necessarily lie in firms and are directed at perceived market opportunities, the ability to de-couple innovation from the market context has proved to be very fruitful. Publicly funded investments in fundamental science and technology have proved to be been a very important underpinning for subsequent innovation in firms. A wider range of understanding is developed that is exploited in quite unpredictable ways. Ideas are kept alive even though the innovative link is not apparent. However, for this de-coupling to work the knowledge bridges between firms and other research organisations must be instituted and crossed, thus the importance of the innovation infrastructure to a creative experimental economy. Notice also that innovation directed discovery processes are inherently wasteful in the narrow sense that many innovative activities end in failure. This is the consequence problem of ignorance, since the future is not knowable there is no alternative to the trial and error process. What does matter is that failures are learnt from that they are seen as the discovery of pathways not yet to be followed. That is to say all new knowledge can be useful in an experimentally organised economy.

7. Concluding Remarks

The link between economic development and technological knowledge is difficult to unravel. Pace much thinking in economics, technology is not reducible to knowledge that is easily appropriated and absorbed by firms. It does not flow freely, it is not fully codifiable and the capacity to understand is heavily dependent on past investments in knowledge acquisition. Neither production sets nor innovation possibilities are well defined and the technology of the individual firm is largely idiosyncratic as a consequence. We have argued that the acquisition of technological mastery is not trivial and that it depends on the nature of the supporting national innovation infrastructure as much as it does on the capabilities of individual firms. Yet firms are crucial and unique in their role of articulating and combining the many different kinds of knowledge underpinning development. The ability of a firm to develop competitive advantage in international terms depends on the complementary exploitation of technological capabilities in the narrow sense with a range of broader business capabilities. It is the experimental manner in which these distinct capabilities are accumulated and combined and the adaptive evolutionary process in which they are exploited and translated into development that makes the process a matter of compound collaborative learning. The role of innovation policy is to support this learning framework and in this process the policy maker too is adaptive not optimising.

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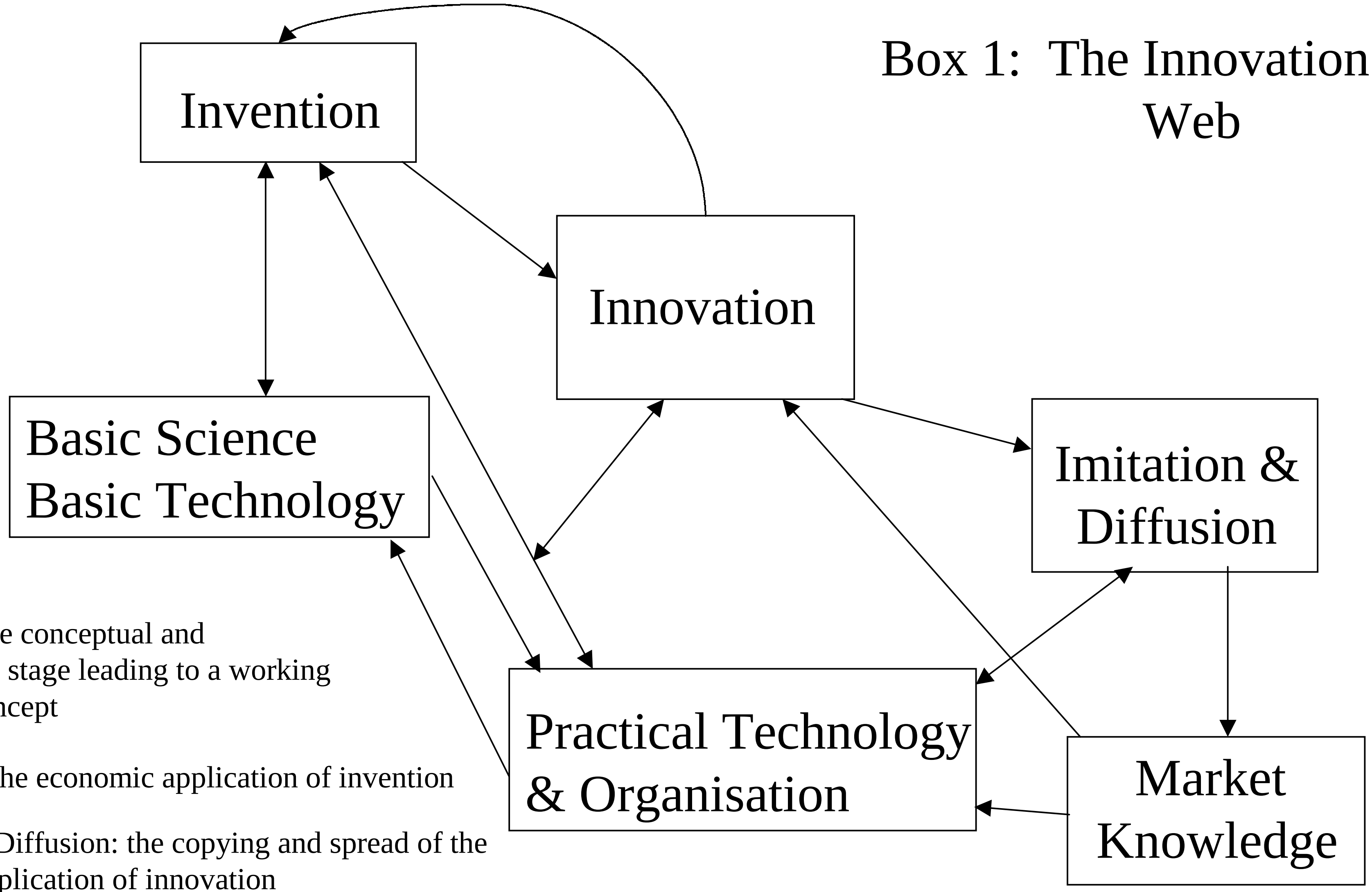
Box 1: The Innovation Web



Invention: the conceptual and development stage leading to a working device or concept

Innovation: the economic application of invention

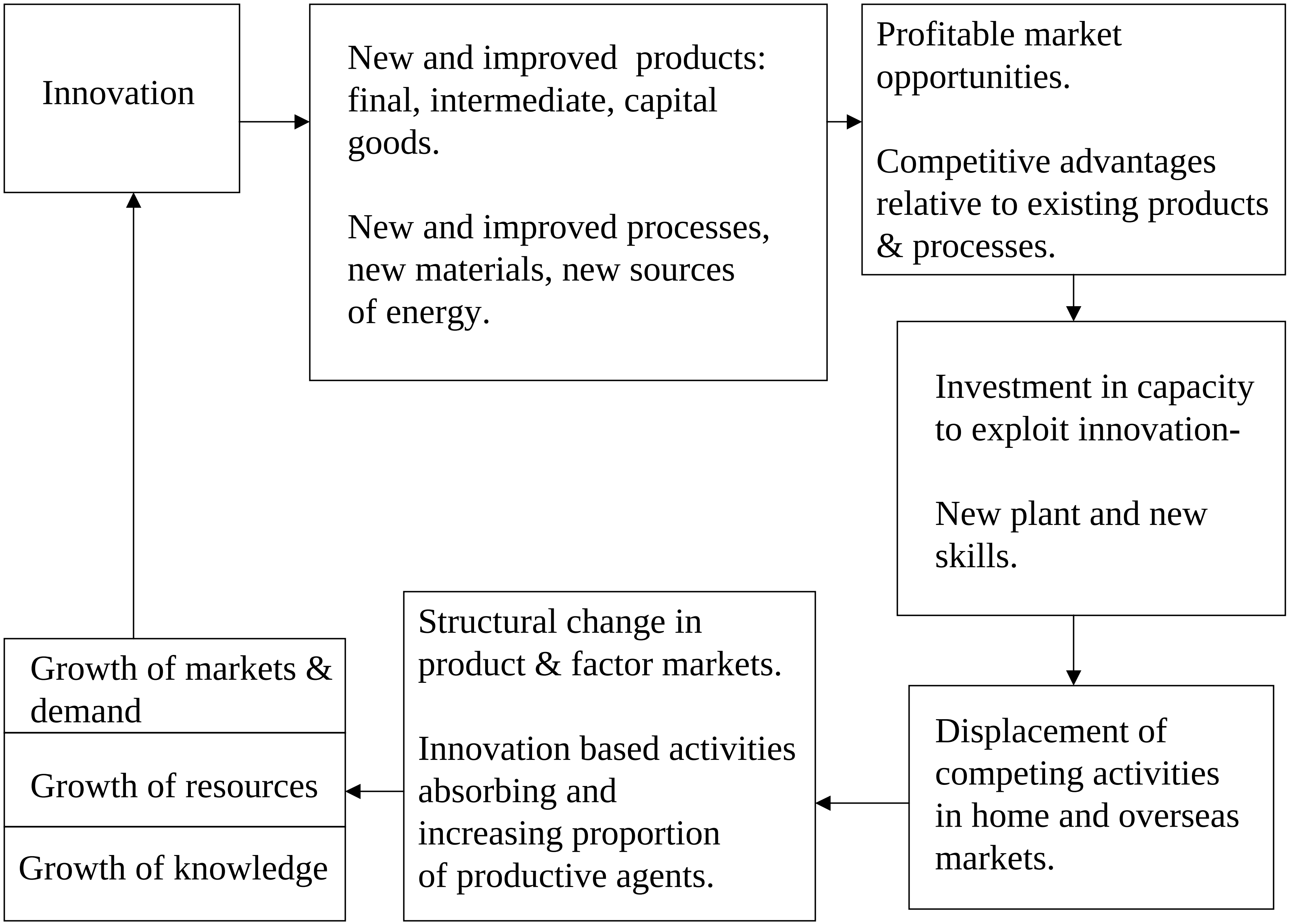
Imitation & Diffusion: the copying and spread of the economic application of innovation

Basic Science: the systematic search for the law-like properties of natural phenomena
Basic Technology: the systematic search for the law-like properties of man-made phenomena

Practical Technology & Organisation: the knowledge to translate basic science and technology into inventions and innovations

Market Knowledge: knowledge of the applications, uses and the valuations placed by consumers

Box 2: Innovation, Competition and Development



Box 3

Social Capital

Definition: The complex of durable arrangements that shape and condition social interaction in society at all levels and thereby provide the framing conditions for economic activity and the accumulation of knowledge and understanding.

The "capital" nature of this formal and informal institutional framework is reflected in the facts that:

- The set of normal arrangements is to a substantial degree durable, and accumulates through the acquisition of experience and the expenditure of resources and time.
- Although durable the social arrangements will decay if not activated with sufficient frequency and are subject to obsolescence if superior arrangements are formed.
- As framing conditions, social capital enhances the streams of future material income.

The concept of social capital is difficult to separate from that of cultural capital as the following examples illustrate:

Cultural Capital to Social Capital

- The rules governing legal and political activity
- The rules governing the permitted domain of market activity or the areas when technology can be developed
- The rules governing the generation and exploitation of intellectual property rights
- The rules governing patterns of social interaction, the networks of "who talks to whom, on what topics with what authority and what frequency"
- The rules for the establishment of trust in contractual arrangements whether formal or informal

"Units" of social capital are constructed at many different locations within one economy, and it is relevant to distinguish:

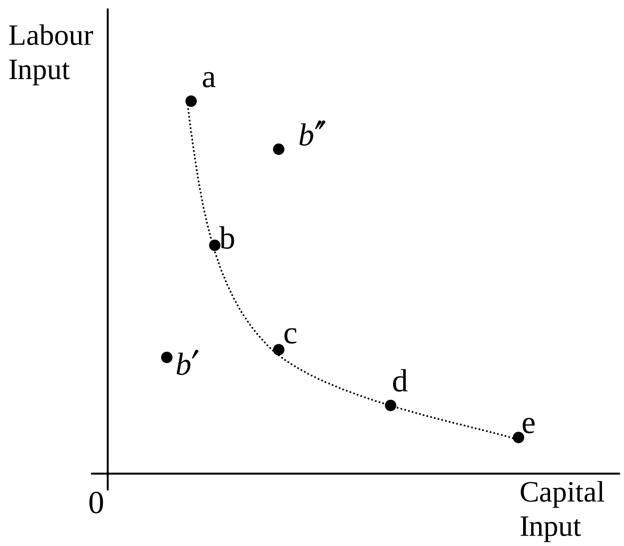
- Social capital accumulated within organisations, which shapes and conditions the way they work.
- Social capital accumulated between organisations, which shapes and conditions the way industries in markets and innovation systems work.

Box 4

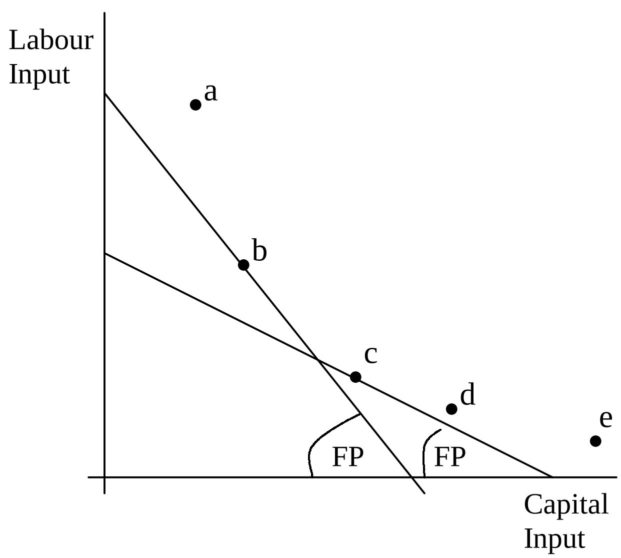
4a The Transformation Process

Energy ⊕ Materials Inputs → Energy ⊕ Materials Outputs
- Proper outputs
- "Wastes"

4b The Production Set

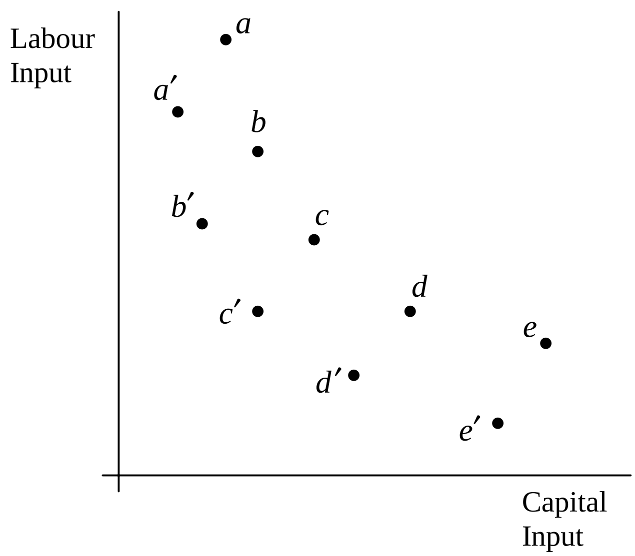


4c

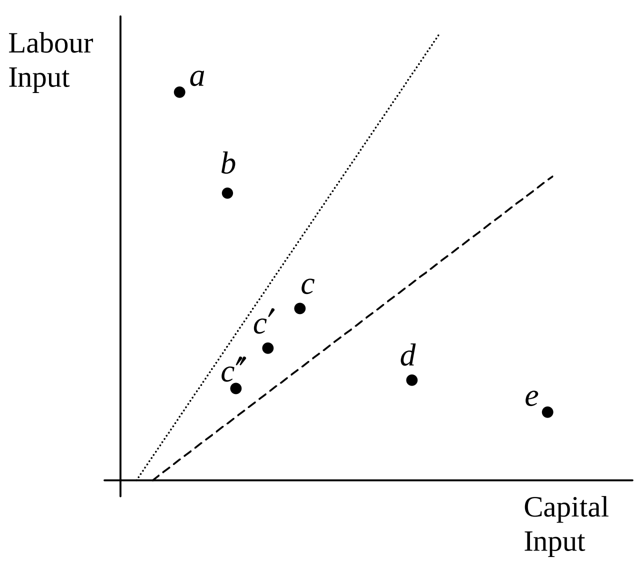


FP. Factor Price Ratio

4d


Labour
Input
a
a′
b
b′
c
c′
d
d′
e
e′
Capital
Input

4e


Labour
Input
a
b
c
c′
c″
d
e
Capital
Input

Box 5

The Technically Progressive Firm

The range of factors identified in one of the pioneering studies of innovation in industry. The 24 factors are:

1. High quality of incoming communication
2. A deliberate survey of potential ideas
3. A willingness to share knowledge with other firms
4. A willingness to take new knowledge on licence or enter joint ventures
5. A readiness to look outside the firm
6. Effective internal communication and co-ordination
7. High status of science and technology inside the firm
8. Consciousness of costs and profits of R&D
9. Rapid replacement of machines
10. Sound policy of recruitment for management
11. An ability to attract talented people
12. A willingness to arrange for effective training of staff
13. Use of management techniques
14. Identifying the outcome of investment decisions
15. High general quality in the chief executive
16. Adequate provision of intermediate managers
17. Good quality in intermediate management
18. An ability to bring the best out of managers
19. Use of scientists and technologists on the Board of Directors
20. A readiness to look ahead
21. A high rate of expansion of assets
22. Ingenuity in coping with material and equipment shortages
23. An effective selling policy
24. Good technical service to customers

Source: Carter, C.F. and Williams, B.R., 1957, Industry and Technical Progress, Oxford University Press.