Technological Catch-Up: Opportunities and Challenges for Developing Countries

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I Introduction

A major issue facing the world economic system is the extent to which radical global change is both creating and foreclosing opportunities for poorer developing countries to facilitate the accumulation of technological capabilities. It is an issue that received renewed attention because of the need to increase the application of environmentally-sound technologies as part of the implementation of the recommendations of the 1992 United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, particularly in relation to implementation of the technology-related provisions of the United Nations Framework Conventions on Climate Change and on Biological Diversity, both signed in 1992 during UNCED. More recently it has been given central place by the UNDP (2000) in its latest Human Development Report. Perceptions that poorer countries, especially those of Africa, could take advantage of such emerging technologies, and hence bypass the polluting vintages used by the older countries, has added to this interest, especially given risks of growing technological marginalisation in a large section of the developing world. As UNCTAD pointed out "Since new and emerging technologies increasingly affect the volume, composition and direction of world trade, countries that are unable to gain access to these new technologies, and successfully absorb them, will find themselves progressively disengaged from the global economy."[i]

But what do we mean by technological capabilities? How can they be defined? And, most importantly, how can governments operationalise the concept in policy terms? What guidance can we provide for the policy maker that will ensure that genuine technological development actually takes place in those countries that so desperately need it? The aim of this paper is to throw some light on these questions by attempting to identify the key factors (associated with technological capability) which influence the capacity of LDCs to undergo rapid technological development, a process that may result in "catching up" with aspects of economic performance in the older industrialised countries. We shall argue that such technological catch-up is closely linked to traditional decision variables such as the rate at which a country invests in human capital, invests in new technology, formulates long-term economic transformation goals, and establishes relevant institutions to implement policies. More important, however, is our perception that technological development is a systemic phenomenon in which the component parts of the economic system evolve alongside each other, and therefore for which policy interventions need to be similarly viewed. It follows that unless interventions take place within a systemic policy framework the results are likely to be less than completely successful.

Moreover, the notion of a system is also closely associated with ideas of complexity and dynamism, since economic systems are never static but on the contrary, continue to evolve in ways that are only partially predictable on the part of the analyst who wishes to intervene[ii]. It follows that policy interventions (at least those that are concerned with technological development) should not only be systemic in nature, they should also be such as to allow continued monitoring and revision on the part of relevant stakeholders, which in turn probably means that a "network" perspective is also a necessary condition for successful policy making. What all this adds up to is the proposition that policy interventions in this area cannot be viewed in traditionally "technological" terms but instead need to be seen in a wider perspective. The objective of this paper is to provide some pointers to what such a perspective might be. This paper is divided into four sections. Section I assesses the changing understanding of the relationships between technological change and economic growth. It also deals with the early ideas that shaped technical assistance policies. The second section outlines some of the main features of the accumulation of technological capacity and examines the dynamical nature of the process. Section 3 examines the sources of technological catch-up and the last section identifies three entry points into a new or emerging techno-economic paradigm. In the concluding section we emphasise finally that donor bodies ought also to take these perspectives on board and in so doing begin to think imaginatively about building technological capacity in the Third World.

II Technological Change And Economic Growth

Technology in international trade: towards non-linear approaches

Much of the literature on technology development has conventionally adopted a linear approach[iii]. The general understanding has been that technological development is a slow and cumulative process that involves the movement of knowledge from one part of the world to another in a distinctive step-by-step approach. This linear view of technological development was accompanied by the mechanistic and static outlook of much of economic theory. The outcome of the combined views of technology and economic theory gave rise to policy approaches that failed to recognise the dynamical aspects of technological development. Either technology was equated with the supply of machinery or was reduced to monetary units. The fact that technological development is part of a wider process of socio-cultural evolution was recognised only by a small sector of those interested in development. Often socio-economic factors were invoked to explain failed development projects, but not in the planning of new ones. Socio-cultural factors are still viewed as potential obstacles to technological development even though they themselves embody a set of technological solutions to local problems.

The application of these ideas to the developing countries took a number of different forms, including the mistaken belief that the mere transfer of technology defined in a narrow sense would enable developing countries to leap across the centuries and repeat the industrial revolution. It was with this false hope that the United Nations Conference on the Application of Science and Technology for the Benefit of Less Developed Areas was held in Geneva in 1963.[iv] It was believed then that the developing countries could benefit from the experiences of the industrialised countries and that there were no vested interests to undermine the success of such countries in assimilating imported technology. It was also against this background that interest grew in technical assistance programmes supported through official development assistance.

Indeed, there was a seeming relationship between technological advancement in the industrialised countries and the absence of extreme forms of poverty. Much hope was therefore placed on using technology as embodied in development projects to reduce poverty in the poorer countries. What was missed, however, was the simple fact that the reconstruction of Europe build on a well-established human capital base which could not only assimilate any imported technology, but was still at the frontier of technological innovation. Furthermore, most of the technological options available to Europe at the time were originally part of western culture and therefore were easily re-introduced in the region. The war also helped to eliminate obsolete technological vintages and create new opportunities for the use of more efficient technologies, which raise the per capita productivity of workers.

Much policy-making on development assistance was driven by compassion for the suffering and social justice but was not accompanied by a detailed understanding of the sources of economic growth. Rather attention was given to the symptoms of low levels of economic productivity in the poorer countries.[v] The sum total of such symptoms is poverty. Much attention was paid to studying poverty and trying to understand its various manifestations instead of focussing on raising productivity. One of the implications of this subtle misdirection of effort was the failure of development assistance to recognise the importance of private sector institutions in economic transformation in general, and in technological development in particular. Policies on technology development were greatly influenced by static comparative advantage models, which ascribed to developing countries the role of raw material producers and to the industrialised countries the function of exporting manufactured goods. This partly explains the emphasis donors place on rural development. These approaches were subsequently accompanied by linear and gradualist models of the diffusion of technologies as products. The initial views held that technologies in the form of products were first developed for domestic markets and they later diffused to regions at similar stages of development.[vi]

The most robust presentation of the linear model of technology transfer emerged in the mid-1960s in the form of the product cycle theory.[vii] According to this approach, new products are developed in the industrialised countries with high per capital incomes, high labour costs relative to capital and large domestic markets. A product goes through three stages: market entry; maturation and standardisation. After its introduction, other industrialised countries join in; first by importing it and then by producing it locally. It is not after the product is standardised that the developing countries start producing it. During standardisation, products are modified to suit the predominant factor prices in the developing countries.[viii] The product cycle theory ignored the fact that the notion of product maturity only held where rates of technological innovation and product improvement were slow. In situations where firms use technological innovation as a tool for competitiveness, products undergo the process of "de-maturation". Incessant technological innovation and the introduction of new design concepts, accompanied by changes in the market environment, create conditions of de-maturation. "By its very nature, epochal or disruptive innovation whatever its degree of technical novelty makes obsolete existing capital equipment, labour skills, materials, components, management expertise, and organisational capabilities. It destroys the value of present competence in various aspects of production and may alter the relative positions of competitors, attract new entrants into an industry, or even redraw an industry's competitive boundaries."[ix] The standardisation of design concepts, which is the basis of industrial maturity, makes firms more vulnerable to changes in technology, market preferences and relative prices.[x] Where changes in the external environmental are trivial, mature firms may adapt by introducing incremental innovations, but where they are substantial, "they are thrown back on a new learning process and thus brought face-to-face with the threat of de-maturity."[xi] This process of de-maturation is part of the continuous re-organisation of the global economic system that creates new techno-economic paradigms.[xii]

The catch-up hypothesis

The notion of catching up has its antecedents in historical studies on the industrial transformation of countries such as the Germany, the US and Japan. More recent studies have focussed on the newly industrialising countries (NICs) of Asia and Latin America. The process of "catching up" is often associated with technological imitation and is linked to pursuing the same path of development. Technological imitation serves a more complex function than simply pursuing the same path of development as that of the more industrialised countries. It involves a critical stage in the process of learning to industrialise and should be seen in that context. In the case of Japan, technological imitation involved recycling traditional ideas (sairiyo), exploring new ideas (tansaku), nurturing creativity (ikusei), generating breakthroughs (hassoo) and refining existing ideas (kaizen).[xiii] Catching up does not necessarily need to be viewed in a linear and unidirectional way. "As long as technology is understood as a cumulative unidirectional process, development will be seen as a race along a fixed track, where catching up will be merely a question of relative speed. Speed is no doubt a relevant aspect, but history is full of examples of how successful overtaking has been primarily based on running in a new direction."[xiv] Indeed, in new fields such as biotechnology, the developing countries are making efforts to move to the scientific frontiers but they plan to apply the acquired knowledge in developing products that are more relevant to local needs.

There is a counter-intuitive aspect of the catch-up hypothesis which suggests that the further back a country is in technological development, the faster it is likely to catch up. "[T]he larger the technological and, therefore, the productivity gap between the leader and the follower, the stronger the follower's potential for growth in productivity; and, other things being equal, the faster one expects the follower's growth rate to be. Followers tend to catch up faster if they are initially backward."[xv] The explanation for this paradoxical suggestion has to do with the level of technology embodied in a country's capital stock. New introductions of capital stock embody relatively more productivity potential in less developed countries than in more industrialised ones. "When a leader discards old stock and replaces it, the accompanying productivity increase is governed and limited by the advance of knowledge between the time when the old capital was installed and the time it is replaced. Those . . . behind, however, have the potential to make a larger leap. New capital can embody the frontier of knowledge, but the capital it replaces was technological superannuated."[xvi] In other words, the economic gap between nations can also be seen as a measure of the backlog of technological opportunities that can be exploited by the poor countries.[xvii]

Expectedly, the catch-up pace decreases and the follower approaches the leader. This is mainly because the possibility for replacing superannuated technologies with best-practice technologies reduces with time. This also explains why followers start investing in basic research as they approach the leading countries, thereby reducing their dependence on imported technologies to maintain their competitiveness. The game of catching up is often played at the national level and relying on the effectiveness of the so-called national systems of innovation, described as the "network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies".[xviii] The most essential aspect of the catching-up process is the rate at which a follower is able to undertake technological imitation. It is through such imitation that a country learns to industrialise. Such imitation requires conscious and policy-guided efforts by the imitating countries. The rate of imitation is greatly influenced by existing technological capabilities, policies and institutional arrangements. This learning process, however, is also influenced by the nature of technological systems, the structure of the market for the technology and international trading rules. Also important is the emergence of competing technological options.

Catch-up and sequential development

While catching up refers mainly to the process of technological and economic competitiveness, *"catch-up"* relates mainly to the speed at which catching up is done. Of particular relevance are the stages that a country goes through to master certain technologies. The notion of catch-up deals mainly with the ability of a country to increase the rate of catching up or to omit certain stages of technology development. Interest in the time-dependent aspects of technological catch-up is emerging as a result of the frustration over the slow rate at which countries or firms assimilate or master imported technology. Part of the concern is associated with the fact that time and sequencing are often confused. As a result, reference to the cumulative aspects of technological development are mistaken as the slow rate at which countries accumulate basic technological competence. Furthermore, sequencing is not necessarily associated with the linear progression of technological development. In many cases, technological change is not a linear process and involves patterns that can be characterised as punctuated equilibria. The concept of techno-economic paradigms has been derived from non-linear view of technological change.[xix]

Indeed, innovation by its very nature carries elements of non-linear change mainly because change results from the introduction of new information in an evolving system. Often such introductions result in non-trivial departures from a seemingly non-linear path. Such non-trivial departures are associated with far-from-equilibrium situations created by the clustering of technological as well as institutional innovations.[xx] This aspect of change does not, however, contradict the cumulative nature of technological development. The point is that such cumulative change is often influenced by the internal characteristics of the technologies in use as well as related learning sequences. This cumulative process is often disrupted by at least three factors. First, the dominant design concepts may be superseded by new technological solutions resulting in new processes and products. Second, the economic environment may select for other design concepts and configurations, thereby rendering the dominant ones irrelevant. Third, other social factors such as environmental regulations may force certain design concepts out of the market without providing for their immediate replacement. Political pressures make this option less common unless the technologies are associated with major social liabilities. The more common scenario is where environmental governance promotes the development of new design concepts as in the case of substitutes for ozone-depleting substances.

Industrial learning entails a set of sequential steps until such a stage that a particular technological trajectory of techno-economic paradigm is flung far from equilibrium. "An 'evolutionary' sequence seems to obtain as far as in-house knowledge generation is concerned. Such sequence involves search, and learning, in a much more fundamental way than the one presently contained in the received theory. Product design capabilities, followed by process engineering and production development skills, seem to develop in a sequential order, absorbing the best part of one (or even two) decades of company technical history."[xxi] The existence of rigid sequences involved in technology development raises concern over the ability of a country or firm to omit any of the stages. "Seven steps can be identified in the course of adopting an imported technology. Briefly stated, they are: determining the needs; surveying the alternative technologies and the alternative supplies; choosing a particular combination of technology and supplier; absorbing the techniques in their first application in the importing country; disseminating the techniques throughout the economy; improving upon them; and developing new and superior techniques through research and development in the importing country itself."[xxii]

These stages take time and are often repeated because of aborted efforts. Technology development efforts are then abandoned when one of the stages is not successfully completed. The successful implementation of any of the stages must be anticipated in the original planning and its execution provided for in every proceeding stage. Such planning, however, has to take into account the fact that much of the progress will depend largely on in-situ experimentation and the accumulation of site-specific knowledge and experience. It is notable that many of the technology transfer efforts in developing countries, especially in Africa, were designed to produce certain commodities and not to promote technological development.[xxiii] As a result, the step-by-step approach outlined above is often not part of the project implementation process. Equally the issue of time is often taken for granted when dealing with technological development. In South Korea, for example, engineering firms took nearly 20 years to emerge from industrial infancy and to compete in international markets without needing extensive protection.[xxiv] The removal of protection does not necessarily mean that a firm has fully mastered technological competence. Such long time horizons are not unique to the developing countries. It "often takes more than a decade for an industry to create competitive advantage; the process entails the long upgrading of human skills, building clusters and penetrating foreign markets. In the case of the Japanese auto industry . . . companies made their first faltering steps towards exporting in the 1950s yet did not achieve strong international positions until the 1970s."[xxv] At the level of product development, similar time horizons apply. In the pharmaceutical sector, for example, it often takes over a decade to develop a new drug, with typical capital outlays of hundreds of $US million.

Another important feature is changing parameters for market entry. Because of the dynamic nature of the process of technological innovation, entry barriers keep changing and raising the costs of learning. For example, the price of a state-of-the-art integrated circuit plant was US$0.5 million in 1972 and rose to US$400 million in 1990, making it more difficult for latecomers to join the field. This change in costs was also accompanied by the growing complexity of the knowledge base needed to enter the microelectronics race. The complexity of the required knowledge has become a more critical entry barrier than the financial requirements involved. This is partly because such knowledge requirements also demand a more sophisticated institutional set-up at the national level. Technological learning in thus time-dependent and involves a series of discrete steps which cannot be easily avoided. In this respect, the main issue is therefore the ability of a country to facilitate the accumulation of technological capability and build industrial dynamism. It is this rapid rate of technological development manifested through local industrial activities or international competitiveness that is the main concern for the poorer developing countries.

Technological niches

One of the features of technological evolution is the creation of specialised market niches that utilise variants of dominant technologies or design concepts. Much of reverse engineering is aimed at understanding the principles behind dominant designs and applying these to the development of technological variants. This process takes place when certain design concepts start to dominate the market and show their viability. It is also at this stage that intellectual property rights are of particular importance because firms find it necessary to use legal and other means to maintain their leadership in the market. It is also at this stage that interest in knowing the basic principles behind certain design concepts is highest. Much of the discussion over the protection of intellectual property rights relates to this stage of technological evolution.

Technology niches are important for a number of reasons. First, they enable the lesser-developed countries to enter the technology market without being required to move and compete at the frontier of its development. Niches can therefore be used to buy time and acquire the requisite technological knowledge without being subjected to the demands of market competition. Second, market niches can in themselves be a significant activity by developing country firms. In the field of biotechnology, for example, creating technology niches may be an important way of applying new techniques to local problems for which there is little interest among multinational corporations. Third, countries that are explicit about their interest in operating in specific niches are more likely to benefit from technological co-operation with larger firms in the industrialised countries. This is mainly because such market niches are unlikely to threaten the major firms but at the same time provide market information of relevance to the larger corporations. Finally, technological niches may be in themselves an important step in the sequence of technological development. For example, those developing countries that have built capacity in certain areas of tissue culture technology have a greater potential to move into genetic manipulation than those that start from scratch. In many countries, tissue culture capabilities have been built because of conservation or quarantine needs but have now been extended to commercial applications.

Technology niches, especially where they are likened directly to production capability building, may be an important way of acquiring technology. This approach, which would involve working closely with the private sector, would be more beneficial to the developing countries than to rely on direct support for basic research in public institutions. The creation of technology niches, however, will place equally critical demands on the national system of innovation to provide the necessary support and inputs. Developing countries could use such technology niches, not only to learn about specific technologies, but also to identify optimal institutional configurations for technological development. It is through such niches that the limits and potentials of a country to promote technological innovation can be tested. The knowledge about institutional organisation acquired through such a process is vital in the design of other technology development programmes. Technology niche creation, if effectively carried out, would provide a basis for future industrial advancement.

III Technological Capabilities

Technological capabilities, firms and networks

The term "technological capabilities" encompasses the wide range of knowledge and skills required to acquire, assimilate, utilise, adapt, change and create technology. It includes knowledge on organisational structures and procedures as well as behavioural patterns of workers and customers. For such capabilities to generate the necessary economic dynamism, they require certain complementary inputs that include organisational flexibility, finance, quality of human resources, support services and information management and co-ordination competence. It is the synergistic relationship between technological and other capabilities that lead to economic dynamism. It is such interaction that results in catching up or catch-up. One of the most critical aspects of technological change is its cumulative nature, especially in the form of skills and as part of the overall human development of a country. This cumulative view implies that prior capabilities are crucial in determining future rates and directions of technical change. "Previous capital is needed to produce new capital, previous knowledge is needed to absorb new knowledge, skills must be available to acquire new skills and a certain level of development is required to create the agglomeration economies that make development possible."[xxvi]

The main locus of the accumulation of technological capacity is the firm. "Below the level of the state, the agent of expansion in all late-industrialising countries is the modern industrial enterprise."[xxvii] One of the main reasons why firms are the locus of technological accumulation is that they need to build the necessary capability to maintain their competitiveness. Firms, for example, will provide the training necessary to enable them to absorb the available technology and to maintain their competitiveness. Firms are in a better position to determine their training needs than public institutions. In this regard, firms serve as a more suitable locus for the acquisition of imported technology than public enterprises. In the past, firms were viewed in the economics literature as discrete entities operating in isolation and preoccupied mainly with making choices between a set of constraints to meet their profit maximisation objectives. The challenge was seen mainly in the context of getting prices right. This static view of the firm also assumes that technological development is exogenous to the process of economic growth. Technological options are presumed to exist on a shelf and can be acquired easily provided that a firm can determine its factor endowments and make the relevant choices. Countries with abundant cheap labour, for example, need not invest in capital-intensive technologies. This view of the firm, fortunately, is losing ground and giving way to more dynamic approaches to the role of technology in the economy.

Management literature, however, treats firms as "complex organisms, but with management having considerable discretionary authority over broad firm policies."[xxviii] This provides a relatively dynamic view of the firm. In recent studies, especially by evolutionary economists, the firm is viewed as the locus of the accumulation of technological capabilities necessary for competition. "Indeed most students of technical change . . . [see] technical advance as the most important problem over the long run, and in seeing the process of technical advance as an evolutionary one, with many new departures competing with each other and prevailing practice, with winners and losers determined in actual context."[xxix] It is therefore through the firm that the competitive advantage of a nation is asserted. It is also through the firm that meaningful approaches to the accumulation of technological capability can be undertaken. It is not, however, sufficient to view firms in the narrow context of organisms with organisational and technological capabilities. Firms operate as organisms in a "market ecology" in which they are linked through the exchange of information, knowledge, finance, materials, personnel, equipment and ownership. The ability for a firm to accumulate technological capability is influenced greatly by its exchange relationships with other actors. Firms operate in a complex industrial network marked by competition and co-operation.[xxx] The innovative capabilities of firms may be limited by the extent to which they participate in trading and knowledge networks. The main reason for this is that innovation is an interactive process involving the recombination and validation of a wide range of pieces of information.[xxxi]

Innovation is also a social process resulting from informal and formal communication networks. "Such networks are social facts; they provide the channels over which information moves. Some of them are long-lived, serve as organised command and control systems, and are coterminous with formal organisations . . . But many are not. They may be highly informal and evanescent . . . Some networks serve not as the control systems of organisations but rather to interconnect organisations and individuals."[xxxii] In the absence of increased networking between enterprises and knowledge bodies, technological catch-up would be unlikely. Enterprises are increasingly becoming knowledge-intensive agencies; their existence involves the effective acquisition, accumulation and use of knowledge for competitiveness. The emergence and growth of the private sector in itself extends the complexity of knowledge networks, which in turn, creates a knowledge base for the emergence of new enterprises. There is therefore a co-evolutionary process between the emergence of firms and the growth in the complexity of knowledge networks. Industrial networks tend to co-evolve with the overall growth of an industrial sector or through the emergence of industrial districts. An industrial district has been defined as a productive system characterised by a large number of enterprises involved in producing a homogenous product. A large proportion of these firms is small or very small.[xxxiii] An industrial district is different from an industrial estate or export processing zone in that firms in such a district are linked to each other in an organic manner and form a complex network of innovative relationship. Industrial districts are not planned, but they are self-organising and quasi-spontaneous. "Innovativeness and adaptability are hallmarks of industrial districts; flexible productive networks mean that the enterprise can satisfy rapidly increasing demand."[xxxiv]

One of the main aspects of the innovativeness of industrial districts in the cultural and social integration that makes it a technological community. This integration facilitates the flow of information that is vital to the process of innovation. Such integration is also linked to the emergence of flexible specialisation that is essential for rapid response to changing market conditions. The footwear industry in Agra (India), for example, has been slow to respond to market changes because of the lack of effective communication between the high caste (involved in international trade) and the lower caste (working as artisanal shoemakers).[xxxv] Many of the characteristics of industrial districts are shared with the informal sector in the developing countries.[xxxvi] But unlike industrial districts, these sectors are often a means of survival under conditions of limited economic opportunity and low levels of technological innovation. But with the emergence of the relevant institutional support systems and the provision of infrastructure, it is possible to provide conditions that would facilitate the transformation of the informal sector into innovative industrial districts.

Attempts to merely bring the firms together without looking at the intricate networking arrangements that promote innovation are likely to fail. For example, the garment export industry of Okhla in South Delhi has exhibited little technological innovation despite the agglomeration of

1,500 firms. "Most firms in the cluster show little sign of technological change. The main competitive strength of the firms is not their ability to innovate, but the possibility of using low-cost labour."[xxxvii] This is the case partly because the garment industry is based on mature technologies and the competitive edge is determined by the price of labour. Technological innovations such as motorising sewing machines will also be limited by levels of investment as a proportion of installed machinery. Where such proportions are large, as in the case of sewing technologies, it does not pay to innovate unless competitors are installing more efficient technologies. It is clear from this case that technological innovation is influenced by the convergence of economic, social and technological factors in an evolutionary manner. There would be no reason to innovate unless there was an evolutionary strategy to respond to both internal and external factors.

Incremental innovation and industrial learning

Much of the discussion on technology transfer has focused on the importation of new technologies. This has led to arguments that place excessive emphasis on issues such as intellectual property protection and international financial flows. While these issues are important, it is vital to stress the value of incremental technological innovations, especially at firm level, in the overall technological development of a country. Studies on industry in the NICs show that much of what constitutes industrial dynamism is a result of cumulative technological innovations introduced at the enterprise level. Such innovations are critical in the field of energy conservation where retrofitting and adjustments in energy use can result in more immediate savings than the installation of new equipment. Variations in the intensity of energy use indicate where possibilities for incremental technical innovations to improve energy efficiency may lie. Over the 1970-90 period, energy intensity (or energy use per unit of GDP) declined by 29% in the industrialised countries while it rose by 30% in the developing countries.

Such innovations need to be distinguished from "radical" or "major" innovations, which are often associated with the introduction of new capital goods. Incremental technical innovations are introduced during the regular operations of plants and their cumulative effect over time may be more important than introducing new equipment. Such innovations could play an important role, not only in improving energy efficiency, but also in re-designing plants so that they use alternative raw materials or reduce emissions of harmful gases. Incremental innovations are often associated with technological capacity building at firm level and emerge from training programmes as well as organisational change. Incremental technical change results from conscious policy efforts to enhance the capacity of workers to improve their performance as well as the efficiency and output of equipment. This process is slow and cumulative because firms cannot build technological and managerial competence that tend to co-evolve. Firm-level learning is often slowed down because of unbalanced growth between technology and management. Changes in technology may require adjustments in management systems which takes time.

Given the central role of firms in incremental innovation, on-the-job-training is an important aspect of the accumulation of technological capacity. The ability of firms to undertake such innovative activities depends on the external market environment and the incentives provided for such activities. In Kenya, for examples, firms tend to undertake incremental innovation when faced foreign exchange constraints and cannot easily import spare parts. National policies that assist on-the-job-training and provide incentives for related activities would facilitate the rate at which technological capability is accumulated. Unfortunately, government-industry relations are generally poor and are limited to regulatory controls in most developing countries. The rapid accumulation of technological capability at firm-level will require major changes in the way government and industry intact. Responding to market signals alone, especially under conditions that allow firms to pass on higher production costs to the consumers, will not be sufficient in promoting technological innovation in enterprises. Neither will they assist in forging closer relations between firms and research institutions.

III Sources Of Technological Catch-Up

Policy environment and institutional setting

One of the key aspects of technological catch-up is the overall national policy towards technology, the institutional setting in the particular country and how the policies are implemented. The relationship between public policy and technological dynamism is starting to attract attention, especially in light of evidence from South Asia. Previously, Japanese experiences had indicated alternative policy approaches but had been ignored or dismissed on the account that Japan was unique and offered little that could be emulated by the developing countries. More recent studies, however, have shown that the Japanese experiences were applied successfully in a number of South Asian countries. One of the central policy features of the Japanese model and other South Asian countries has been the promotion of shared growth. Conventional economic models have tended to suggest that rapid economic growth could not be achieved under conditions of shared growth. In other cases it has been argued that growth programmes needed to be pursued first before wealth redistribution could be effected. The South Asian experiences show that shared growth was possible and rapid capital formation including the accumulation of technological capability was essential. "To ensure that its population supports development, the benefits of growth should be widely spread. The more equally such benefits are diffused, the longer will support in favour of development last."[xxxviii]

This overall policy framework was critical in providing for a growth-oriented development strategy that placed emphasis on capital formation in general and the accumulation of technological capacity in particular. In addition to gaining legitimacy through shared growth, South Asian governments created a cadre of economic technocrats whose operations were insulated from political pressures to a substantial extent. This insulation involved "the ability of economic technocrats to formulate and implement policies in keeping with politically formulated national goals with a minimum of lobbying for special favours from politicians and interest groups."[xxxix] The technocrats were not only able to carry through specific plans and programmes, but they also had the space to experiment with new ideas and maintain flexibility in their operations. It is through such insulation of the technocrats that vested interested can be prevented from undermining new policy initiatives. Under a wealth-sharing system, the costs of lobbying are relatively high and the return low. This reduces the need for those with partisan interests to interfere with the policy process. The insulation of the technocrats was accompanied by increased competence and integrity in the civil service. Such changes may require major governmental efforts to reduce social problems such a corruption while at the same time encouraging reciprocity between the government and the business community.[xl] It calls for innovative approaches to the relationships between the government and other sectors of society; it is essentially an issue of governance.

A key aspect of technological development is the creation of institutions and institutional arrangements that facilitate the process. Institutions that search for technology, carry out assessments, undertake evaluations and perform policy analysis are essential for promoting rapid accumulation of technology capability. The presence of such institutions is not enough unless accompanied by measures that promote their interaction and co-operation. Consultative processes are essential in promoting the flow of information, building consensus and arriving at collective decision-making[xli]. At a technical level, institutional co-operation is an essential aspect of the national systems of innovation. The final aspect of the public policy is the manner in which the state "intervenes with subsidies deliberately to distort relative prices in order to stimulate economic activity. This was as true in Korea, Japan, and Taiwan as it was in Brazil, India, and Turkey. In Korea, Japan, and Taiwan, however, the state exercised discipline over subsidy recipients. In exchange for subsidies, the state imposed performance standards on private firms. Subsidies were not give-aways, but instead were dispensed on the principle of reciprocity."[xlii] The management of such reciprocity requires a professional and technically competent civil service in general, and a sophisticated and responsive scheme of governance in particular. In the absence of a technically competent civil service and responsive governance, it is not possible to maintain the discipline needed to carry through with long-term programmes such as industrialisation.

Investing in human capital

The role of human resource development in economic development is starting to receive careful attention. Education, which is central to the process of development, is gradually being recognised as a critical aspect of economic transformation in general and the accumulation of technological capability in particular.[xliii] Evidence from the developing countries is showing a close relationship between investment in education and overall economic transformation. This relationship had previously been documented in sectors such as agriculture but it is now being recognised to be central to the overall process of development. "Development is all its forms economic, social, and cultural will depend increasingly on knowledge-based industries, agriculture, and services. Education is a key to development that knowledge and the sense of personal efficacy needed to adjust to rapid change."[xliv] The educational needs of countries differ depending on their level of development. While the industrialised countries are reforming their educational systems to provide for greater training in technical subjects, poor countries are focussing on primary education, especially for girls, as a central aspect of human development.[xlv] Evidence from the South Asian countries suggests that those countries that invest in primary education have a greater chance of improving their economic performance than the ones that invest less in this sub-sector. By 1965 Hong Kong, Korea, and Singapore had achieved universal primary education and Indonesia with its large population had primary enrolment of 70%. Investment per pupil is also high in these countries. For example, Korea's real expenditures per pupil rose by 355% over the 1970-89 period. The increase in Kenya was only 38% over the same period. Children in South East Asian perform better than children in other developing countries in standardised tests of cognitive skills.[xlvi] On the whole, education policies in South Asian countries were designed to facilitate the acquisition, assimilation and mastery of technology.

In most developing countries, however, there is no direct link between education policies and technological development. Education is designed generally for providing basic knowledge in the hope that such knowledge will enable individuals to deal with the real world. An education policy that puts emphasis on technical subjects is the most effective way of laying the foundation for rapid development of human capital in general and technological advancement in particular. While primary education is essential, there is also the danger that these countries may ignore the importance of higher education, especially when it comes to mastering science-intensive technologies. The overall prospects for catch-up will depend largely on how countries balance between primary education for all and higher education with emphasis on strategic subjects. It is unlikely, for example that developing countries will effectively participate in the biotechnology market unless they build considerable fundamental knowledge in fields such as molecular biology, biochemistry and genetics. The creation of the requisite capacity in such fields will be critical to the ability of the developing countries to make significant and sustained advances in emerging fields such as biotechnology.[xlvii]

For effective technological advancement, developing countries will need to devote much of their energy to technical tertiary education. Emphasis should be given to natural science, mathematics, information technology, and engineering. In Singapore, for example, over 50% of tertiary level students are in these fields; the shares are 39% for Taiwan and 36% for Hong Kong. In Korea, there are 50 scientists and technical personnel for every 1,000 people, compared with an average of less than 10 in the developing world. Such numbers are not in themselves important except in the context of their application in industrial development. Training programmes in these countries are linked to the specific needs of industry. In addition, on-the-job-training is an important part of the creation of technical competence. Investment in education is costly for most developing countries. In Kenya, for example, over 35% of national recurrent expenditure is devoted to education. This level of expenditure may not leave much funding for research. One of the incentives that could be provided for countries that invest heavily in education could be to supplement their budgets for specialised research and development programmes. Educational levels, therefore, could be used as an indicator of future possibilities for catch-up and additional support for technology development would be a strategic investment.

National systems of innovation and knowledge networks

The emergence of firms and industrial advance support institutions form part of the national system of innovation. These systems, which evolve over time, provide the context in which knowledge is created, transmitted and embodied into products and processes. The robustness and diversity of a national innovation system is an indicator of the ability of a country to facilitate the accumulation of technological capability. "Generally . . . diversity affects innovation because it affects technical, organisational and institutional learning and contributes to the knowledge base of the economy . . . . Diminishing this diversity means destroying parts of the economy's stock of knowledge and reducing the number of technical options. It also means decreased possibilities for communication and interaction between different kinds of skills, knowledge, and competence and, and thus, reducing learning possibilities."[xlviii] In essence, the competitiveness of a country is to a large extent determined by its institutional diversity and interactions. Countries often formulate policies to promote technological innovation in certain fields such as microelectronics and biotechnology. The impact of such policies is often the creation of "technological communities" which are linked through competition and co-operation. Such technological communities and related institutional arrangements become the central locus for the generation of innovations. Technological advance is therefore understood as "proceeding through the work of a community of actors."[xlix]

One of the main features of the developing countries has been the heavy involvement of the public sector in industrial development at the expense of private enterprises. "The failure to recognise the firm as the central player in the accumulation of technology has been a major shortcoming of technology policy."[l] Firms are not simply commercial entities but important nodes in the global knowledge system. They are also the institutional locus in which industrial learning takes place. Firms not only emerge from the accumulation of technological capabilities, but they influence the rate and direction of accumulation. Policies that ignore the central role of firms in industrial learning are not likely to be effective in promoting the rapid accumulation of technological capability. The failure to recognise the role of firms has resulted in the poor recognition of firms as important agents in the transfer of technology. The central role of firms in technological development provides a basis upon which to assess the role of foreign direct investment in industrial development.[li]

International trade and foreign investment

International trade policies have had a variety of impacts on technological development. It appears that technological development has been faster in countries, which have linked international trade to industrial advancement. Countries such as South Korea have had a strong outward policy while maintaining regulatory controls over direct foreign investment and foreign technology licensing. India, on the other hand, protected local industries, provided only limited export incentives and restricted the importation of foreign technology. The overall impact was a slow pace of technological transformation. Singapore, on the other hand, has maintain an open policy for both technology and capital imports. The result has been a dynamic export market dominated by foreign firms. The changing policy environment in most developing countries, especially in relation to economic liberalisation measures, will make it difficult for them to use regulatory controls to shape the direction of technological innovation. Market incentives will continue to play an important role in promoting technological innovation. Although instruments such as subsidies for technological innovation are unpopular, it is obvious that other forms of state intervention will need to be devised to promote technological innovation in the poorer developing countries. Such intervention measures will need to be more closely linked to trade liberalisation measures.

Also related to the issue of international trade is the role of direct foreign investment in technological development. There is ample evidence that foreign investment is a most important vehicle for technology transfer. It is through such investment that the technological landscape of most NICs has been transformed.[lii] But the ability of the countries to derive maximum benefits from direct foreign investment is dependent on the available human capital. In Korea, for example, the technical sophistication of the labour force and the commitment of the government to industrialisation enabled the country to extract other conditions which ensured faster and more effective acquisition of technology. The main conditions included large-scale training programmes, which facilitated the transfer of tacit knowledge from foreign experts to nationals. This enabled the country to systematically replace expatriates with qualified Koreans. But in many developing countries, training has not been organised as a strategic measure to enhance national technological capability. Although foreign firms are normally required to train nationals, there is little monitoring of this process to ensure that the requirements are met. International trade in technology, especially through foreign investment, provides opportunities for creating strategic alliances between foreign and domestic firms. Such alliances could be an important source of research co-operation as well as technology development. There is, however, the view that such alliances could restrict the flow of technology. It is feared that strategic alliances may create monopolies, which restrict trade in technology and the flow of scientific knowledge into the public domain, especially where basic research is carried out through such alliances. The critical point here is that alliances between firms in the industrialised and developing countries can be designed in such a way that they promote technological development in the host country.

IV Entry Points

Technological maturity and late entry

The rapid rate of technological innovation in the industrialised countries is reducing the time that mature technologies stay on the market. This process of de-maturation erodes much of the prior technological competence built by firms in the developing countries and makes it difficult for them to accumulate the technological capability needed for catching up. In other words, the imitation efforts of many countries are not rapid enough to enable them to close the technological gaps created by new innovations. The use of knowledge that is already in the public domain may not be a suitable way to facilitate catching up or catch-up. Relatively recent technological knowledge, however, may not be easily accessible to the poorer developing countries because of cost and other restrictions such as intellectual property protection. Another important aspect of technological innovation is that products and processes are becoming more sophisticated thereby complicating industrial learning. For example, technologies which previously relied entirely on mechanical parts now contain microelectronic components. The use of reverse engineering is such situations is limited by the ability of the importing countries to acquire competence in the field of microelectronics.

One way of the using mature technologies as a basis for building technological capability is to link production more closely with educational processes. This will ensure that a large section of the population is able to acquire practical skills and basic knowledge that can be used widely in society, especially in small and medium-scale enterprises.[liii] Unfortunately, most poorer developing countries have not recognised the fact that industrialisation is a learning process which requires approaches that are specific to the prevailing conditions in the country. The need for economic transformation requires that new approaches to industrial learning be put in place in light of the changing patterns of technological innovation. Other factors such as quality requirements in international trade militate against the use of mature technologies for catching up. The pressure to diversify products and meet new quality and environmental standards will require that the developing countries upgrade their productive capability. Those able to do so will be forced onto the catching up path while others will fall by the wayside. In some countries, especially in Africa, the pressure to export is already putting pressure of firms to raise product quality in order to remain in the international market.[liv]

Early entry

For countries with the requisite technological competence, early entry into the technology market is the most viable option for technological catch-up. In the early stages of the emergence of new techno-economic paradigms, entry barriers are relatively low and information is more easily accessible. Developments in biotechnology are currently at this stage. Countries with basic competence is related disciplines can easily enter the field. However, this stage is also risky. As design concepts start to stabilise and products reach the market, the market tends to concentrate, favouring large-scale manufacturers or highly innovative firms. This is where most developing countries fail. Much of the knowledge "required to enter a technology system in its early phase is in fact public knowledge available at universities. Many of the skills required must be invented in practice. It is only as the system evolves that it generates the new knowledge and skills which become increasingly of a private nature and are not willingly sold to competitors anywhere. With time, as . . . the system approaches maturity, and again both the knowledge and the skills tend to become public or are willingly sold at a price."[lv]

Developing countries with the relevant human capital base are always presented with new windows of opportunity for entering new technological systems. But doing so requires other skills such as the capacity to monitor international trends, formulate long-term strategies and determine the locational as well as infrastructure advantages of the country. Most African countries, for example, do not have the capacity or the requisite institutional arrangements for monitoring technological advantages. Planning efforts are usually of a short-term nature and therefore unable to accommodate technological requirements for long-term growth. In more recent years, most countries have been forced to adopt short-term planning strategies to enable them to implement macro-economic stabilisation programmes. However, the challenge now is to put in place long-term structural adjustment programmes which are based on industrial transformation.

Path-dependence and technological niches

Early entry into a technological system carried with it the risk of being on a doomed path or technological dead-end. It is not possible to predict the future direction of technological change. However, historical studies have shown that technological change occurs in an evolutionary fashion, generating a wide range of technological options which are shaped and in turn shape the character of the market. It has been argued that the "stock of technological available at any time can only be understood by a systematic examination of the earlier history out of which it emerged."[lvi] And the "future growth in knowledge can only be understood within the context of the particular sequence of events which constitute the history of the system." Technological evolution, like other forms of evolution, is path-dependent. A path-dependent sequence of events is one in major future outcomes can be influenced by remote, trivial or chance events at moments that do not necessarily seem significant.[lvii] In the early stages of technological development, a wide range of innovation pathways are usually open and it is often difficult which one will emerge as the winner. In the area of photovoltaic technology, for example, the range of materials for making cells have been the key determining factor. "If one technology gains an advantage over its competitors, there are strong incentives for resources to be drawn away from trying to advance its rivals, since major advances may be needed to make them competitive. And once resources come to be largely focused on the leader, further improvements may soon make it and its further development the only economic way to proceed because competing designs are left so far behind."[lviii]

When products based on dominant designs reach the market, they create their own supporting set of institutional mechanisms which influence other related technological development. Operating standards may be established in line with the dominant designs, which makes it difficult for new designs to diffuse. In addition to standards, marketing and servicing networks and related competence emerge to which the buyers get "locked in". This "lock-in" effect means that it may be difficult for developing countries to enter the technology market during period of rapid diffusion when the winners are shaping the new technological trajectory. Windows of opportunity tend to close at this stage unless a country has the technological competence to develop variants of the dominant designs which do not violate the intellectual property rights of the original designers. "[A]fter a dominant design becomes established, firms that do not produce a variant of it tend to drop out of the industry, or into small niche markets. With product design more stabilised, learning by incumbent firms become more cumulative, and potential entrants are increasingly at a disadvantage."[lix]

The idea of settling into market niches may be of relevance to the developing countries because they accord an opportunity for learning. In the case of biotechnology, for example, this trend is already emerging. Many developing countries are acquiring the technology and applying it to limited areas of national interest. They are not planning to enter mass markets. Biotechnology, though, lends itself to such niche applications because of its problem-specific nature.[lx] The scope for exploiting market niches to facilitate industrial learning needs to be given greater attention. Firms in specialised fields could be supported to acquire certain technologies and diffuse them in the economy and to build the requisite knowledge for future technological development. This approach would be superior to the notion of science parks which have little linkage with the productive sector.

V Conclusion

This paper has reviewed the main issues related to the concept of "technological catch-up" which is understood to mean the rapid accumulation of technological capacity to levels which enable a country to become a technological leader or competitor with the leading countries. Technological catch-up may also involve the use of advanced technologies to deliver new products and services that do not necessarily compete with those developed in the industrialised countries. Many of the products of biotechnology, for example, may be relevant to certain locales and of little interest to the major firms. Their technological requirements, however, may be just as high as those for the products of the leading firms. The paper has shown that there are three points of entry into the game of technological competition. The first relates to the accumulation of basic technological competence in society. This is related to human capital formation. A country without the requisite technical competence is unlikely to make sustained advances in technological development. The second issue is the ability of a country to make an early entry into a particular technological system. This step can only be achieved where the first one has been accomplished. The last issue is the potential for a country to occupy particular technological niches as part of a strategy for industrial learning. With the widening range of technological trajectories and systems, the opportunities for the developing adopting any of the three strategies or combinations thereof are relatively high.

What can the international community do to speed the process along? It is the view of this paper that the aim must be one of helping the developing world to help itself through appropriate forms of capacity building. Part of this must clearly be in the area of education and this effectively means radical help for university and related systems in many parts of the Third World. However, it is important to stress that such help is not reducible to formal training, laboratory equipment and related resources on their own. This has tended to be the accepted solution in the past but it does not help to create viable national systems of innovation. In other words it does not *in and of itself* create the connectivity and institutional reform necessary to link education and research directly to poverty reduction and sustainable development. For that to happen, we believe, aid programmes should focus more on building up links with Northern institutions, many of whom have been struggling themselves in recent years to integrate better into sustainable development. There are many examples of such organic linkages that have appeared in recent years[lxi] (usually with much success) but with few exceptions donor agencies have not made such "learning relationships" an integral part of their aid policies.

At the same time, however, the process of catch-up is a manifestation of the degree to which a country exhibits the political will to organise itself to facilitate industrial learning; it is fundamentally an institutional question. Unfortunately, there is still little known about the way nations learn. A more detailed assessment of national innovation systems may give us an idea of why some countries learn faster than others. The rate at which technological communities and the associated novel institutional formations emerge may be an indicator of the potential for rapid industrial development. Such communities, however, can only be effective at achieving their goals if they participate in the global knowledge networks. But many of them are not, or are often blinded by nationalistic prejudices and are therefore suffer from the self-induced "lock-out" effect. Nevertheless it is the view of this paper that possibilities are certainly present. To change these possibilities to reality, however, means imaginative action on the part of (national and international) political and scientific elites. It remains to be seen what will happen.

References

Abernathy, W.J., K.B. Clark and A.M. Kantrow. 1983. ***Industrial Renaissance: Producing a Competitive Future for America.*** (New York: Basic Books).

Abramovitz, M. 1989. ***Thinking About Growth: And Other Essay on Economic Growth and Welfare.*** (Cambridge, UK: Cambridge University Press).

Aitken, H. 1985. ***The Continuous Wave: Technology and American Radio, 1900-1932.*** Princeton, NJ: Princeton University Press.

Alam, G. 1994. "Industrial Districts and Technological Change: A Study of the Garment Industry in Delhi." UNCTAD. ***Technological Dynamism in Industrial Districts: An Alternative Approach to Industrialisation in Developing Countries?*** United Nations Conference on Trade and Development. New York: United Nations

Amin, A. 1994. "The Potential for Turning Informal Economies into Marshallian Industrial Districts." In UNCTAD. ***Technological Dynamism in Industrial Districts: An Alternative Approach to Industrialisation in Developing Countries?*** United Nations Conference on Trade and Development. New York: United Nations.

Amsden, A. 1989. ***Asia's Next Giant: South Korea and Late Industrialisation***. New York: Oxford University Press.

Arthur, B. 1989. "Competing Technologies, Increasing Returns, and Lock-In by Historically Small Events," ***Economic Journal, Vol. 99***, pp. 116131.

Bell, M., and K. Pavitt. 1992. "Accumulation of Technological Capability in Developing Countries." In Summers, L., and S. Shah. eds***. Proceedings of the World Bank Annual Conference on Development Economics 1992. Supplement to the World Bank Economic Review and the World Bank Economic Observer.*** Washington, DC: World Bank.

Bhagavan, M. 1992. ***The SAREC Model: Institutional Co-operation and the Strengthening of National Research Capability in Developing Countries.*** Stockholm: Swedish Agency for Research Co-operation with Developing Countries.

Bhattacharya, A., and M. Pangestu. 1993. ***Indonesia: Development Transformation and Public Policy.*** Washington, DC: World Bank.

Burenstam-Linder, S.B. 1961. ***An Essay on Trade and Transformation***. New York: John Wiley.

Chau, L.C. 1993. ***Hong Kong: A Unique Case of Development.*** Washington, DC: World Bank.

Chowdhury, A, and I. Islam. 1993. ***The News Industrialising Countries of East Asia***. London: Routledge.

Christensen, S., D. Dollar, A. Siamwalla and P. Vichyanond. 1993. ***Thailand: The Institutional and Political Underpinnings of Growth.*** Washington, DC: World Bank.

Clark, N., and C. Juma. 1991. ***Biotechnology for Sustainable Development: Policy Options for Developing Countries.*** Nairobi: Acts Press.

Clark, N G & C Juma. 1992. ***Long-Run Economics: An Evolutionary Approach to Economic Change.*** London: Pinter Publishers.

Clark, N G 1987 “Similarities and Differences Between Scientific and Technological Paradigms”, ***Futures 19*** (1), February.

Clark N G, P M Allen and F Perez-Trejo ***Evolutionary Dynamics and Sustainable Development; a Systems Approach***, (Aldershot; Edward Elgar, 1995)

Clark N G, 2000 "Public Policy and Tertiary Education in Africa: Aspects of Institutions and Management Capacity", ***Journal of Economic Studies 27*** (1/2)

Clark, N G 2002 "Innovation Systems, Technology Assessment and the New Knowledge Market: Implication for Third World Development" ***Journal of the Economics of Innovation and New Technology, (4)*** July.

Constant, E.W., 1980. ***The Origin of the Turbojet Revolution.*** Baltimore, Maryland: The Johns Hopkins University Press.

DFID 1997. ***Eliminating World Poverty.*** White Paper, Department for International Development, London, UK

Dahlman, C. 1991. "The Role of Government: Education Policy, Technical Change, R&D, and Competitive Advantage." In Haque, I. ed. ***International Competitiveness: Interaction of the Public and the Private Sectors***. Washington, DC: World Bank.

Dijk, M.P. Van. 1994. "The Interrelationship Between Industrial Districts and Technological Capabilities Development: Concepts and Issues." In UNCTAD. ***Technological Dynamism in Industrial Districts: An Alternative Approach to Industrialisation in Developing Countries?*** United Nations Conference on Trade and Development. New York: United Nations, pp. 349.

Dosi, G. 1982. "Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change." ***Research Policy, Vol. 11***, pp. 147-162.

Edquist, C, (ed.), 1997 ***Systems of Innovation Approaches – Their Emergence and Characteristics***. Cassell Academic, London.

Enos, J.L. 1991. ***The Creation of Technological Capability in Developing Countries***. London: Pinter Publishers.

Enos, J.L., and W.H. Park. 1988. ***Adoption and Diffusion of Imported Technology: The Case of Korea***. London: Croom Helm.

Fransman, M., and K. King. eds. 1984. ***Technological Capability in the Third World***. London: Macmillan.

Freeman, C. 1987. ***Technology Policy and Economic Performance: Lessons from Japan***. London: Pinter Publishers.

Freeman, C., and C. Perez. 1988. "Structural Crisis of Adjustment, Business Cycles and Investment Behaviour." In Dosi, G. et al. eds., ***Technical Change and Economic Theory***. London: Pinter Publishers.

Fritsch, W., and G. Franco. 1991. ***Foreign Direct Investment in Brazil: Its Impact on Industrial Restructuring.*** Paris: Organisation for Economic Co-operation and Development.

Frohling, P. ed. 1986. ***Swedish Development Aid in Perspective: Policies, Problems and Results Since 1952***. Stockholm: Almqvist & Wiksell International.

Gomulka, S. 1990. ***The Theory of Technological Change and Economic Growth.*** London: Routledge.

Griffin, K., and J. Knight. eds., 1990. ***Human Development and International Development Strategy for the 1990s.*** London: Macmillan.

Haddad, W.D., M. Carnoy, R. Rinaldi and O. Regel. 1990. ***Education and Development: Evidence for New Priorities.*** World Bank Discussion Paper No. 95. Washington, DC: World Bank.

Hakansson, H. 1987. ***Industrial Technology Development: A Network Approach.*** London: Croom Helm.

Jacobsson, S. Undated. ***The Length of the Infant Industry Period: Evidence from the Korean Engineering Industry. Department of Industrial Management and Economics.*** Mimeo. Guteborg, Sweden: Chalmers University.

Johnson, B. 1992. "Institutional Learning." In Lundvall, B.-A ed***. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning.*** London: Pinter Publishers, pp. 2344.

Juma, C. 1991. "Investment Strategy and Technology Policy: Empirical Lessons from Power Alcohol Development." In Coughlin, P. and G. Ikiaria. ***Kenya's Industrialisation Dilemma.*** Nairobi: Heinemann Kenya.

Juma, C., C. Torori and C.C.M. Kirima. 1993. ***The Adaptive Economy: Economic Crisis and Technological Change.*** Nairobi: ACTS Press.

Juma, C., J. Mugabe and P. Kameri-Mbote. eds. 1994. ***Coming to Life: Biotechnology in African Economic Recovery.*** Nairobi: Acts Press and London: Zed Books.

Katz, J.M. 1987. "Domestic Technology Generation in LDCs: A Review of Research Findings." In Katz, J.M. ed. ***Technology Generation in Latin American Manufacturing Industries: Theory and Case Studies Concerning its Nature, Magnitude and Consequences.*** London: Macmillan.

Kim, K., and D.M. Leipziger. 1993. ***Korea: A Case of Government-led Development.*** Washington, DC: World Bank.

Kameri-Mbote P, D Wambugu and N G Clark, 2001 “Public/Private Partnerships For Biotechnology In Africa: The Future Agenda” ” ***SUPRA Paper No. 12***, Research Centre for the Social Sciences, University of Edinburgh, January

Kravis, I. 1956. "'Availability', and Other Influences on the Commodity Composition of Trade," ***Review of Economics and Statistics. Vol. 38***, pp. 1430.

Leipziger, D.M. and V. Thomas. 1993. ***The Lessons of East Asia: An Overview of Country Experience.*** Washington, DC: World Bank.

Lundvall, B.-A. 1988. "Innovation as an Interactive Process: From User-Producer Interaction to the National System of Innovation." In Dosi, G. et al. eds., ***Technical Change and Economic Theory.*** London: Pinter Publishers, pp. 349-369.

Lundvall, B.-A ed. 1992. ***National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning***. London: Pinter Publishers.

Martin B and R Johnston, 1999 "Technology Foresight for Wiring up the national Innovation System: Experiences in Britain, Australia and New Zealand" ***Technological Forecasting and Social Change 60*** (1), pp 37-54.

Nelson, R. 1991. "The Role of Firm Differences in an Evolutionary Theory of Technical Change," ***Science and Public Policy, Vol. 18***, No. 6, pp. 347-352.

Nelson, R. 1994. "Economic Growth via the Co-evolution of Technology and Institutions." In Leyesdorff, L., and Peter Van den Besselaar. eds. ***Evolutionary Economics and Chaos Theory: New Directions in Technology Studies.*** London: Pinter Publishers, pp. 21-32.

Nelson, R., and N. Rosenberg. 1993. "Technical Innovation and National Systems." In Nelson, R. ed. ***National Innovation Systems: A Comparative Analysis.*** New York: Oxford University Press, pp. 3-21.

Perez, C., and L. Soete. 1988. "Catching Up in Technology: Entry Barriers and Windows of Opportunity." In Dosi, G. et al. eds., ***Technical Change and Economic Theory***. London: Pinter

Petri, P.A. 1993. Common Foundations of East Asian Success. Washington, DC: World Bank.

Porter, M. 1990. ***The Competitive Advantage of Nations.*** London: Macmillan.

Prigogine, I. and Stengers, I. 1985. ***Order Out of Chaos: Man's New Dialogue with Nature.*** London: Flamingo.

Pyke, F., and W. Wengenberger. eds. 1992. ***Industrial Districts and Local Economic Regeneration***. Geneva: International Institute for Labour Studies.

Rosenberg, N. 1982. In***side the Black Box: Technology and Economics.*** Cambridge, UK: Cambridge University Press.

Rosenberg, N. 1994. ***Exploring the Black Box: Technology, Economics and History***. Cambridge, UK: Cambridge University Press.

Rosenberg, N., and E. Birdzell. 1986. ***How the West Grew Rich..*** London: I.B. Tauris and Co.

Rostow, W.W. 1960. ***The Stages of Economic Growth.*** London: Cambridge University Press.

Salleh, I.M., and S.D. Meyanathan. 1993. ***Malaysia: Growth, Equity, and Structural Transformation***. Washington, DC: World Bank.

Soete, L. 1990. "Opportunities for and Limitations to Technological Catch-up." In United Nations. ***Technology, Trade Policy and the Uruguay Round***. New York: United Nations.

Soon, T.-W. 1993. ***Singapore: Public Policy and Economic Development.*** Washington, DC: World Bank.

Stewart, F., H. Thomas and T. de Wilde. eds. 1990. ***The Other Path: The Influence of Policies on Technology Choice and Small Enterprise Development.*** London: Intermediate Technology Publications.

Tatsuno, S.M. 1989. ***Created in Japan: From Imitators to World-Class Innovators.*** London: Harper & Row.

Thomas, V., and Y. Wang. 1993. ***Government Policy and Productivity Growth: Is East Asia an Exception?.*** Washington, DC: World Bank.

Thomson, R. ed. 1993. ***Learning and Technological Change***. London: Macmillan.

Tiffin, S., F. Osotimehin with R. Saunders. 1992. ***New Technologies and Enterprise Development in Africa***. Paris: Organisation for Economic Co-operation and Development.

UNDP, 1999 ***Human Development Report,*** New York: United Nations.

UNCTAD 1990. ***Transfer and Development of Technology in Developing Countries: A Compendium of Policy Issues.*** United Nations Conference on Trade and Development. New York: United Nations.

UNCTAD 1993. ***Trade Policies, Structural Adjustment and Economic Growth: Trade Policy Reforms in Developing Countries and the International Support Required.*** Geneva: United Nations Conference on Trade and Development.

UNCTAD 1994. ***Technological Dynamism in Industrial Districts: An Alternative Approach to Industrialisation in Developing Countries?*** United Nations Conference on Trade and Development. New York: United Nations.

United Nations. 1963. ***Science and Technology for Development: Report on the United Nations Conference on the Applications of Science and Technology for the Benefit of the Less Developed Areas.*** New York: United Nations.

Vernon, R. 1966. "International Investment and International Trade in the Product Cycle," ***Quarterly Journal of Economics. Vol. 80***, pp. 190-207.

Vestal, J. 1993. ***Planning for Change: Industrial Policy and Japanese Economic Development, 1945-1990.*** Oxford, UK: Oxford University Press.

World Bank. 1993. ***The East Asian Miracle: Economic Growth and Public Policy.*** New York: Oxford University Press.

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[i]UNCTAD (1993), p. 26. The text goes on; "It is important to recognised that frontier technology not only dominates new and exotic processes and products; they also penetrate traditional economic activity as well. Therefore, comparative advantage resting on inexpensive labour is no longer immune from international competition,"

[ii] For a detailed discussion of this see Clark, Allen and Perez-Trejo (1995), especially Chapters 2 and 6.
[iii] See Clark and Juma, 1992 and Clark 1995 for an exploration of this point.
[iv] United Nations, 1963. The United Nations Conference on Science and Technology for Development held in Vienna in 1979 was a follow-up to this event. The institutions that were created to implement the agenda of the Vienna conference were recently reduced to programmes within the United Nations system as part of the rationalisation of the United Nations system.
[v] Rosenberg and Birdzell, 1986. There has been a return to this position on the part of some bilateral aid agencies recently, particularly DFID. See DFID, 1997
[vi] One of the most articulate presentations of this view is Burenstam-Linder, 1961.
[vii] Antecedents of the product cycle theory can be traced to Kravis, 1956. For the macroeconomic equivalent of the product cycle theory, see Rostow, 1960.
[viii] Vernon, 1966.
[ix] Abernathy, Clark and Kantrow, 1983, p. 28.
[x] "As does a biological species that has become perfectly adapted to a particular environmental niche, mature industries carry with them the implicit threat of extinction or, at least, catastrophe if environmental conditions should suddenly or radically shift," Abernathy, Clark and Kantrow, 1983, pp. 2829.
[xi] Ibid. p. 29.
[xii] Techno-economic paradigms can be defined as "a combination of interrelated product and process, technical and organisational and managerial innovations, embodying a quantum jump in potential productivity for all or most of the economy and opening up an unusually wide range of investment and profit opportunities. Such a paradigm change implies a unique new combination of decisive technical and economic advantages," Freeman and Perez, 1988, p. 47, 48.
[xiii] Tatsuno, 1989.
[xiv] Perez and Soete, 1988, p. 460.
[xv] Abramovitz, 1989, p. 221
[xvi] Ibid. p. 221
[xvii] Gomulka, 1990, 159.
[xviii] Freeman, 1987, p. 1.
[xix] Constant, 1980, Dosi, 1982. Clark, 1987
[xx] Prigogine and Stengers, 1985. For a discussion on the isomorphism between technological and institutional change, see Clark (2002) in press.
[xxi] Katz, 1987, p. 44.
[xxii] Enos, and Park, 1988, p. 11.
[xxiii] Juma, 1991
[xxiv] Jacobsson, Undated
[xxv] Porter, 1990.
[xxvi] Soete, 1990, p. 5. This point is underscored by Rosenberg: "Perhaps the most distinctive single factor determining the success of technology transfer is the early emergence of an indigenous technological capacity. In the absence of such a capacity, foreign technologies have not usually flourished. Countries that have had successful experiences usually learned at an early stage that the importation of foreign technologies required some minimum level of technological skill not only to modify and adapt the foreign technology to local needs, once it had been imported, but to provide the basis for an intelligent selection among the wide range of potential foreign suppliers. Intelligent choice among the alternative technologies available presupposes considerable technical knowledge. Such knowledge, in turn, is difficult to acquire in the absence of any domestic experience or capacity," Rosenberg, 1982, p. 271.
[xxvii] Amsden, 1989, p. 8.
[xxviii] Nelson, 1991, p. 347.
[xxix] Ibid., p. 348.
[xxx] Hakansson, 1987.
[xxxi] Lundvall, 1992 and Edquist,1997.
[xxxii] Aitken, 1985, p. 15. He adds: "If we ask how inventions come into being, a sound operational rule is to examine the flows of information that converged at the point and at the time when the new combinations came into existence. A hypothesis worth testing is that the points of confluence of information flows define the social locations where there is a high probability of new combinations being made. And a derivative hypothesis is that the most interesting and striking of new combinations are likely to occur when

information flows meet by chance or by design, that have not met before. In such a case a new node is formed and the possibility exists, at least as long as the interconnection lasts, that networks previously disconnected will be able to exchange information with each other," pp. 1516.

[xxxiii] Pyke and Sengenberger, 1992.

[xxxiv] Dijk, 1994, p. 28.

[xxxv] Ibid., p. 29.

[xxxvi] "Both types of economy have clusters of small firms in the same industry, strong artisanal traditions, similar technologies, and embedded knowledge-base and ability to invent and adapt, informal market arrangements, strong family and kinship ties, and a marked sense of local identification," Amin, 1994, p. 66, 67.

[xxxvii] Ibid., p. 261.

[xxxviii] Vestal, 1993, p. 161.

[xxxix] World Bank, 1993, p. 167.

[xl] In South Korea, for example, the government introduced a law for dealing with illicit wealth accumulation in 1961. "The government exempted most businessmen from criminal prosecution and eschewed confiscating their property. In exchange, businessmen were required to pay off their assessed obligation by establishing new industrial firms in basic industries and by donating the shares to the government. . . Within days, however, an alliance had been formed between business and government that laid the basis for subsequent industrialisation," Amsden, 1989, p. 72.

[xli] As may be seen for example with the development of “foresight” exercises in many industrialised countries. See, for example, Martin and Johnston, 1999.

[xlii] Op. cit., p. 8.

[xliii] "Technological capability is essentially embodied in people, not machinery. In the process of acquiring, using, diffusing, and improving technology, a key input is a technical human capital base able to assess and decide on technology matters. This requires a well-developed education system that lays the necessary foundations at all levels. Because of the rapidly changing nature of technology and competition, on-the-job-training to upgrade workers' skills is also needed," Dahlman, 1991, pp. 53, 54.

[xliv] Haddad, Carnoy, Rinaldi, and Regel, 1990, p. 1.

[xlv] Griffin and Knight, 1990. "At the primary and secondary levels good basic education, including a strong concentration in technical and engineering-related areas, is necessary to speed the diffusion and adoption of new technologies, to make local adaptations and improvements on the shop floor, and more generally to increase the awareness and ability to take advantage of technological opportunities," Dahlman, 1991, p. 54.

[xlvi] World Bank, 1993, p. 43.

[xlvii] Clark and Juma, 1991. "At the university level, it is necessary to have qualified personnel who can monitor technological trends, assess their relevance to the prospects for the country and individual firms, and help to develop a strategy for reacting to and taking advantage of the trends. In addition, high-level technical human resources are necessary to assimilate, adapt, improve, and develop local technology that may be more appropriate or otherwise superior to what may be obtained from abroad," Dahlman, 1991, p. 54.

[xlviii] Johnson, 1992, p. 37.

[xlix] Nelson and Rosenberg, 1993, p. 15.

[l] Bell and Pavitt, 1992, p. 271.

[li] Fritsch and Franco, 1991.

[lii] Chowdhury and Islam, 1993.

[liii] Stewart, Thomas, and de Wilde, 1990.

[liv] Juma, Torori and Kirima, 1993.

[lv] Perez and Soete, 1988, p. 476. "This implies that, given the availability of well-qualified university personnel, a window of opportunity opens for relatively autonomous entry into new products in a new technology system in its early phases," Perez and Soete, 1988, p. 476.

[lvi] Rosenberg, 1994, p. 10.

[lvii] See, for example, Arthur, 1989.

[lviii] Nelson, 1994, p. 24.

[lix] Nelson, 1994, p. 25.

[lx] Juma, Mugabe and Kameri-Mbote, 1994.

[lxi] Good examples may be found in Clark, 2000; Kameri-Mbote et al. 2001 and Clark, 2002.