OPPORTUNITIES FOR AND LIMITATIONS TO TECHNOLOGICAL LEAPFROGGING

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INTRODUCTION

There is a long-standing tradition of research in UNCTAD and other international organizations into the relationship between technology transfer and economic development. That well-established tradition has brought to the forefront the complexity of technology transfer within a development process and the often limited contribution of such technology transfer to development and economic growth. Such emphasis was particularly worthwhile in providing a counterweight to the dominant view, popular in the 1950s and early 1960s, about the industrialization "short-cut" that the import of foreign technology could provide to developing countries. The importance of ‘foreign’ technology and its international diffusion for economic growth was and still is a historically well recognized factor in the industrialization of both Europe and the United States in the nineteenth century, and even more strikingly of Japan in the twentieth century.

The resurgence of interest in international technology diffusion, technological ‘catching up’ and even technological ‘leapfrogging’ is undoubtedly inspired by the rapid industrialization of a number of newly industrializing countries over the last two decades, and by the historical analogy that apparently can be drawn with previous industrialization processes of now industrialized countries (Soete, 1981 and 1985). How common such rapid technological accumulation processes could be for industrializing countries is the main issue addressed in this paper.

Clearly, the enormous difficulties experienced by the great majority of developing countries in their efforts to industrialize do not lend great support to a set of arguments based at first sight on simple historical analogy and a relatively simple, ‘mechanistic’ view of the process.

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of economic growth and development. The present paper hopes, however, to illustrate how a richer approach, focusing directly on the technological issues that underlie the process of development, rather than just the transfer, can provide insights into how technologies evolve and are diffused and under what ‘exceptional’ conditions a process of ‘effective’ technological catching-up and possibly leapfrogging can take place.

There exists, of course, a voluminous literature on the subject of international technology diffusion and technological ‘catching up’ which has been a focal point of research for both development economists and economic historians. It is not intended to review this literature here. Suffice it to say that some ‘convergence’ appears to emerge between particularly these latter contributions, based on in-depth case studies of the emergence and taking over of countries in the production and use of particular technologies (see, in particular, Ames and Rosenberg, 1963, Habakkuk, 1962, and von Tunzelmann, 1978) and some of the more recent international trade and growth models based on imitation and ‘catching up’.

That convergence puts, as will be seen, the emphasis clearly back on the historical institution framework within which the process of imitation/technological catching up took place, including the role of historical accidents, the importance of ‘developmental’ constraints, be they primarily economic (such as the lack of natural resources) or more political in nature, the role of immigration and other “germ carriers”, and the crucial role of Governments.

From such a perspective, the diversity in growth performance of countries provides an illustration of the historical and institutional complexity of economic development. The latter, in line with many recent contributions in the field of evolutionary economics (see, in particular, Arthur, 1989, Silverberg, Dosi and Orsenigo, 1988, and the contributions therein of Arthur, Allen, Metcalfe, Freeman and Perez) needs more and more to be viewed as a path-dependent, increasing-returns development process, with many bifurcations and possibilities of ‘locked-in’ development. In such an interpretation, some industrialization locations got “selected” early on and exercised by appropriating the available agglomeration economies - “competitive exclusion”, to use again a term developed by Arthur (1986) - on other
locations. Indeed, it is the increasing returns associated with industrialization and development that make the conditions of development so paradoxical. 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.

All development policies have in one way or another been geared to breaking out of this vicious circle. Most have concentrated on tackling the investment and infrastructure locational questions, with some, but relatively less direct, attention to the knowledge and skills constraint. It is obvious that the international diffusion of technology provides a crucial ingredient to the technological 'locking out' of underdevelopment. This was the implicit argument in some of the neo-technology accounts of international trade, where comparative advantage would shift with the further international diffusion of the technology to 'less developed' countries. These countries would, through the 'use' of imported technologies, acquire some comparative industrialization advantage in mature products and industries. At first sight, the choice of mature products as a point of entry seemed indeed the only one to initiate a development process and start on a path of economic growth. However (and leaving aside for the moment all aspects of technological 'blending' and other user-initiated technological change), in so far as mature products are precisely those that have exhausted their technological dynamism, there would be a clear risk of getting 'fixed' in a low-wage, low-growth, development pattern.

Perez and Soete (1988) have discussed in detail the question whether the development constraints mentioned above are always equally formidable or whether their intensity varies in time, with some increasing and some decreasing, thereby providing opportunities to escape from the vicious circle. They emphasized how technological catching up could only be achieved through acquiring the capacity for, as opposed to the simple 'use' of, technology. This meant being able to enter either as imitators or as innovators of new products of processes.

To answer this question, they stressed the role of technological change as a disruptive process with changes in direction and deep
structural transformations, in contrast to the notion of technological change as a global and more or less continuous process. It is this latter notion which still underlies in many ways the traditional way development is viewed: a cumulative unidirectional process, a race along a fixed track, where catching up is merely a question of relative speed. Speed no doubt is a relevant aspect, but history is full of examples of how successful overtaking has been primarily based on running in a new direction.

In this paper an attempt is made to integrate some of these technological catching-up and leapfrogging views into a more global, dynamic view of economic growth and international trade. The first section attempts to distinguish two different theoretical ‘bifurcations’: the first in the area of international trade, technology accumulation and growth and the second in the area of technology diffusion. This leads to a third section, where some general arguments on catching up and leapfrogging are put forward. A final section discusses policy implications. Throughout the analysis no reference is made to any particular group of countries.

I. TRADE, TECHNOLOGICAL ACCUMULATION AND ECONOMIC GROWTH

One of the fundamental premises of classical and neo-classical trade theory is that trade (or the notional transition from autarky to trade) affects the intersectoral and international allocation of inputs, quantities, and prices, but does not affect the rate of utilization of the stocks of inputs themselves and, thus, the rate of macroeconomic activity. This is straightforward in modern general equilibrium analysis, where full employment of all factors is assumed. It is equally true for that part of Ricardo’s Principles concerned with international trade, based, as it was, on the assumption that:

"no extension of foreign trade will immediately increase the amount of value in a country, although it will very powerfully contribute to increase the mass of commodities, and therefore the sum of enjoyments. As the value of all foreign goods is measured by the quantity of the produce of our land and labour, which is given in exchange for them, we should have no greater value if, by the discovery of new markets, we obtained double the quantity of foreign goods in exchange of a given quantity of ours."
Since in Ricardo's model production techniques are given, the assumption concerning an unchanged "amount of value in a country" is equivalent to an assumption of constancy of the rates of macroeconomic activity throughout the notional transition from autarky to trade.

Opposed to this mainstream view, many contributions, both in the early classical and in the more recent technology gap tradition, have tended to emphasize the dynamic link between trade, growth and technological accumulation. In this group of contributions, highly heterogeneous in scope and nature, but seldom thoroughly formalized and often coming from outsiders to the dominant economic tradition, one may include early economists from the eighteenth and nineteenth centuries, such as Ferrier, List, and Hamilton, as well as more recent contributions from some technology-gap and product-cycle authors (Posner, Freeman, Vernon, Hirsch); post-Keynesian writers such as Kaldor, Cornwall and Thirlwall; "structuralist" writers in development economics, especially within the Latin American tradition; economic historians, such as Gerschenkron, Kuznets and Balogh; and some modern French writers, such as Bye, de Bernis, Lafay and Mistral.

Obviously, these contributions are highly different in nature and scope. However, one may state that they have in common, explicitly or implicitly, one or several of the following assumptions (Dosi and Soete, 1988):

- Differences in technological levels and innovative capabilities are a fundamental factor in explaining differences among countries in both levels and trends in exports, imports and income;
- General equilibrium mechanisms of international and intersectoral adjustment are relatively weak, so that trade has important effects upon the rates of macroeconomic activity of each economy. In other words, the growth of each economy is often balance-of-payments constrained and this constraint becomes tighter or looser according to the levels and composition of the participation of each country in world trade flows. The weakness of price/quantity adjustments between sectors and between countries has to do partly with the nature of technology (fixed coefficients, irreversibilities, etc.) and partly with the nature of demand (sticky baskets of consumption, etc.). As a result, what adjusts in the
international arena is world market shares within each sector and, in consequence, the levels of macroeconomic activity generated by foreign demand;

- That same weakness of general equilibrium adjustments is such that the intra-sectoral distribution of trade shares among countries and its evolution through time can be explained by a set of country-specific absolute advantages and without explicit reference, at least as a first approximation, to price/quantity adjustments between sectors and between factors' returns;

- Technology is not a free good;

- The allocative patterns induced by international trade have dynamic implications which may either yield "virtuous" or "pervasive" feedbacks in the long term.

These assumptions have generally been stated in a rather confused way by the early writers, who did not share the rigour and depth of a Ricardo or Samuelson, and were often motivated simply by policy issues such as protection versus free trade. None the less, they had precious, if confused, insights into complex problems of economic dynamics which were neglected in the cleaner but more restrictive formalizations of modern trade theory. For example, Tucker (1774) assumed that there is a macroeconomic link between technological advantage, international competitiveness and incomes, and discussed whether the product-cycle effects induced by the lower wages of the "poor country" would eventually reverse the competitive position of the "rich" vis-à-vis the "poor". His answer is reassuring for England; continuous technical progress, increased capabilities of accumulation and institutional factors would keep an absolute advantage there, despite the lower wages of the more backward countries. Ferrier (1805) dealt with the relationship between trade and the Continental Blockade, arguing that there was a direct negative link between import penetration and employment levels in the relatively backward country due to a generalized technological disadvantage and to the long-term effects that despecialization in the most advanced products (in that case, manufactures) exerted upon the capability of progress and accumulation: "... I compare a nation which with its money buys abroad commodities it can make itself, although of a poorer quality, with a gardener who, dissatisfied with the fruits he gathers, would buy juicier fruits from his neighbours, giving them his gardening tools in exchange".
Interestingly, Adam Smith was equally aware of the dynamic implications of trade and his position appears almost symmetrical to that of Ferrier, from the "advanced country" point of view. First, he argued, trade has a beneficial effect upon the rates of macroeconomic activities and employment because, in contemporary words, exports increase aggregate demand. This is close to what Myint (1958) later defined as a "vent-for-surplus" model of trade. Second, he maintained that the enlargement of the market due to international trade fed back upon the domestic division of labour and thus on trends in productive efficiency.

The argument of List (1904) is directly against Ricardo and Say. The practical matter at stake was the political advocacy of protectionism and industrialization. In List's view, there was nothing in the adjustment mechanisms on the international market (in his terminology, the adjustments "based on the theory of exchange values") which guaranteed dynamic convergence between nations in terms of productive capabilities and incomes (the "growth of productive forces of a nation"). In several respects, this view involved much more than an "infant industry argument", the idea being that the long-term position of each country depended jointly on its degrees of capital accumulation, its global technical and learning capabilities, and a set of institutional factors (social consensus, factory discipline, political conditions). According to List, the adjustment processes set in motion by international trade might well be detrimental to the development of these aspects of the "national productive forces". In terms of contemporary economics, static and dynamic economics of scale and differing income elasticities of the various commodities would lead under freetrade conditions to divergence rather than factor price equalization, and to growth polarization, with the concentration of production in one country, rather than to welfare gains for both partners. In a similar perspective, these points have been emphasized in much of the early development/trade/dependency literature, and in the historical analysis of the early industrialization/opening of trade process in the United Kingdom.

More recently Thirlwall and Vines (1983), along the lines suggested by Kaldor (1970, 1975 and 1980), have formalized such views in a multisector North-South model and have studied the "consistency
conditions between the two countries and the various sectors. The Kaldor-Thirlwall-Vines approach, while incorporating some ideas similar to earlier "two-gap" models of development - whereby the growth of the industrializing countries is shown to be constrained by either saving/investment capacity or by the foreign exchange requirements - embodies a general hypothesis that world growth is determined by "asymmetrical" patterns of change in technical coefficients and demand composition. In this view, processes of inter-factorial and inter-commodity substitution in response to relative prices and excess factor supplies are of minor importance. What adjusts is the level of sectoral and macroeconomic activity.

In all these models the difference in the income elasticity of demand for the various commodities plays a fundamental role and is assumed to be more important than the price/quantity adjustments in consumption baskets. Thus, as Thirlwall (1980) shows, income elasticities enter into the determination of the foreign trade multiplier of each economy (via import propensities and export elasticities to world income). The other factor is obviously technology. "Polarization" in innovativeness is shown to imply "polarization" in growth.

Interestingly, while both the Ricardian and the neoclassical perspectives focus upon the determinants of the patterns of specialization, the set of contributions reviewed above focuses on the relationship between trade, levels of activity and growth. In terms of adjustment mechanisms, both Ricardo and the neoclassical school held the rates of activity constant and studied trade-induced changes in relative prices and relative quantities; conversely, the alternative dynamic contributions assume away price/quantity adjustments and study the link between trade and rates of activity in both the short and the long term.

A major factor counteracting this link between polarization in technology and income levels is, of course, the international diffusion of technology. Indeed, most modern technology gap models focus on the crucial time element between innovation and imitation abroad as the trade and income-polarizing 'reversal' factor. The theoretical and methodological tradition here is one based on diffusion models. Before turning to the relationship between international technology diffusion and effective 'catching up', the present paper reviews briefly, in the next
section, diffusion theory and its relationship to economic growth and structural change.

II. TECHNOLOGY DIFFUSION AND INDUSTRIAL GROWTH

There is, as many authors in the diffusion literature have recognized (e.g. Metcalfe, 1988), a striking methodological similarity between the traditional epidemic innovation diffusion model and some of the models of industrial growth and economic development formulated in the 1930s, by Kuznets and Schumpeter among others. This is in many ways not surprising. The concepts of 'imitation' and 'bandwagons', so crucial to the diffusion literature, have been and still are central to many of the more structural accounts of economic growth, where the S-shaped diffusion pattern is similar to the emergence and long-term rise and fall of industries. An attempt at linking the two theories was made by Freeman, Clark and Soete (1982). Here it was precisely the notion of 'clusters' of innovations, including the follow-up innovations made during the diffusion period, which was linked to the rapid growth of new industries, and in the extreme case could even provide the ingredients of an upswing in overall economic growth.

In the more restrictive diffusion terminology, this could be viewed as an 'envelope' of diffusion curves of a set of closely interrelated clusters of innovations which, occurring within a limited time span, would tilt the economy in the early diffusion phase to a higher rate of economic performance.

Another similarity with diffusion models can be found in Rostow's theory of the stages of economic growth (1960), with again a distinct S-shaped pattern of take-off, rapid growth with the 'drive to maturity', and slower growth with the 'age of high mass-consumption' and standardization. Rostow phases contain many of the S-shaped development patterns assumed to exist for new products, as typified in the marketing and subsequent international trade literature on the 'product life cycle'. Such an argument was also put forward in the mid-1960s by Hirsch (1965), who showed how the relative importance of certain production factors would change over the different phases of the product cycle. Hirsch, and subsequently Vernon (1966) and many other proponents of the product life cycle trade theory, illustrated how
such changes would shift comparative advantage in favour of less developed countries as products reached the maturity phase.

Within the development literature, particularly the *dependencia* school, such views, and particularly Rostow’s theory, were heavily criticized; the mechanistic, quasi-autonomous nature of the process of economic growth assumed by Rostow has even been brand-named as ‘ahistorical’. Interestingly though, the critique of the mechanistic nature of Rostow’s growth model finds its reflection in much of the recent diffusion literature, criticizing the ‘mechanistic, atheoretical’ nature of the S-shaped ‘epidemic’ technology diffusion models.

These recent diffusion contributions provide also a number of interesting insights into some of the broader industrial growth theories mentioned earlier. The first area of critique of the ‘standard’ diffusion model has led to the application of ‘probit analysis’ to develop a new model of inter-firm diffusion. Probit analysis was already a well established technique in the study of the diffusion of new products among individuals. The central assumption underlying the probit model is that an individual consumer (or firm) will be found to own the new product (or adopt the new innovation) when his income (size) exceeds some critical level. This critical, or tolerance, income (or size) level represents the actual tastes of the consumer (the receptiveness of the firm), which itself can related to any number of personal or economic characteristics. Over time, though, with the increase in income and assuming an unchanged income distribution, the critical income will fall with an across-the-board change in taste in favour of the new product, due to imitation, greater and better information, bandwagon effects, etc.

The relevance of the probit model for industrial growth theory is self-evident. A ‘critical’ income per capita level is a concept which can be introduced in a straightforward manner in Rostow’s theory of the stages of economic growth. Replacing the concept of individuals by ‘countries’, different behaviour between countries in their growth performance can be explained and expected. Considering both the extreme variation in a country’s ability to take risks and ‘assess new innovations’ (the variation in consumer tastes in the probit model) and the extreme levels of income inequality at the world level, it should come as no surprise that industrialization worldwide (diffusion) has been slow, and that many poor countries, even with the fall over time
technology - not just in physical capital but also in human, and even "intellectual" capital - can slow down the diffusion of the new innovation. The importance of past investment in, and existing commitment to, the technology which is being displaced, in slowing down the diffusion of the new technology, points to the phenomenon of inter-technology competition and brings us back to the questions of non-ergodicity and 'locked-in' technological development as discussed by Arthur (1988). However, it should be clear that, as against existing technology, new technology will compete on disadvantageous terms. As Rosenberg (1976) has observed, the diffusion of steam power in the last century was significantly retarded by a series of improvements to the existing water power technology which further prolonged the economic life of the old technology. The process of a 'dying' technology is indeed a slow one, with the old technology firms often living off past, fully recovered, investment and sometimes able to underprice the innovation-adopting firms.

III. INTERNATIONAL TECHNOLOGY DIFFUSION AND TECHNOLOGICAL LEAPFROGGING

The implications for the international diffusion of technology and the potential for technological catching up are at least from this second methodological bifurcation far-reaching. There is, as illustrated in the first section, every reason to expect that the vast majority of new technologies will originate primarily from within the technologically most advanced countries. The virtuous circle of technological accumulation, growth and international competitiveness is unlikely to be broken at the 'innovation' end. However, as we have just seen, there are good reasons to expect that the international diffusion of major new, disruptive technologies will be hampered by the various factors mentioned above, with the new technology competing (in its diffusion) on disadvantageous terms.

Thus, the possible previous investment outlays in the existing technology, the commitment to the latter from both management and the skilled labour force and even the 'development' research geared towards improving upon the existing technology might all hamper the diffusion of the new technology to such an extent that it will diffuse more quickly elsewhere, in a country uncommitted, in terms both of
actual production and of investment, to the old technology. At the same time, as diffusion proceeds, some of the crucial, incremental innovations, resulting for example from user-feedback information, will further shift the technological advantage to the country in which the new technology is diffusing more rapidly.

It is here, of course, that historical analogy with the industrialization in the nineteenth century of Germany, France, the United States and a number of smaller European countries is a tempting argument to make. The dramatic change in fortune in the British position from an absolute technological leadership, producing in the mid-nineteenth century more steam engines than the whole of the rest of the world, is a powerful illustration of this phenomenon. This pinpoints the significant advantages of ‘late industrializers’, in terms both of catching up with present technological leaders as well as of acquiring foreign technology at a more ‘competitive’ price. In the postwar period, this has been most obvious in the case of Japan in the 1960s and 1970s, and more recently in the Republic of Korea. In these, by any historical standard, exceptional cases world ‘best-practice’ productivity levels were achieved over a very short time in steel, cars, electronics, numerically controlled machine tools and, more recently, computers, largely on the basis of initially imported technology.

The scarcity of such successful examples illustrates, though, how ‘non-automatic’ and exceptional such processes of effective technological catching up and leapfrogging are. While the role of the use of imported technology as an ‘industrialization’ shortcut might appear straightforward the effective assimilation of foreign technology is difficult and complex. As already hinted at above, a crucial element will be the “absorptive capacity” of a country’s institutions and domestic firms.

As discussed in greater detail in Perez and Soete (1988), a central problem in earlier debates on the international diffusion of technology is the sheer complete, and almost interchangeable, use of the words “use” in the narrow diffusion sense and “entry” in the broader technology sense. When discussing technological catching up or even technological leapfrogging, one is interested in the effective “use” of foreign technology with the aim of producing it one day - i.e. in the acquisition and assimilation of technology. From the viewpoint of an
industrializing country or from any other position of lag, this objective can in the first instance only be achieved through the "use" of foreign technology.

Diffusion theory gives us hints as to why such international diffusion is not automatic and the reasons for delays in 'adopting'. As was seen in the previous section, the profit model emphasizes the threshold level below which no 'adoption' will take place. Below this level, there will, as was illustrated in section I above, be no emergence of any virtuous link between technology use, growth and technology accumulation. There will, practically by definition, be no acquisition of technology or learning. The process of 'convergence' in growth, of technological catching up, will be more or less blocked.

When diffusion models, such as the probit model, are applied to the diffusion of a new product, the notion of threshold determined by income level and taste is fairly straightforward. When referring to the diffusion of technology, the concept of a threshold for entry as opposed to a minimum use level is considerably more complex. However, from the detailed analysis in Perez and Soete, 1988, it appears that, given the appropriate conditions, some general arguments can be put forward. The earliest as well as the most mature phases of the life of a product or process provide the two extremes, but they are also the easiest phases to attain threshold conditions for new entrants, though not surprisingly under radically different costs and requirements.

As Perez and Soete pointed out, "With little capital and experience, but with scientific and technical knowledge plus an adequate provision of locational advantage or compensatory 'help', an innovator or imitator can enter the market at the early stages. Entry at maturity of a product depends on more traditional comparative and locational advantages. But it requires considerable amounts of investment and technology purchase funds. An important difference between the two entry points is that early entry does not guarantee survival in the race. Much further investment and technology generation efforts are required as competitors advance along the improvement path. A maturity entrance appears relatively safer as long as the product in question is not substituted by a newer one in the market. Profits will depend on how many other new producers struggle for a share at this stage" (Ibid.).
Why, in this case, is there an argument to be made for early entry? The particular advantage appears to be based on some of the structural 'disruption' features of major new technologies, as discussed in the previous section. Indeed, it could be argued that much of the knowledge required to enter a new technology 'system' is in its early phase public knowledge, available in universities. Many of the skills required must still be invented in practice. It is only as the system evolves that it will generate new knowledge and skills which might increasingly fall within the private domain and not willingly be sold to competitors anywhere.

Given the availability of well qualified university personnel, opportunities might therefore emerge for relatively autonomous entry into new products in a new technology system in its early phases. This partly explains the cases of innovation in one or two unexpected information technology areas outside the main industrialized countries. It also explains why the one or two technological catching-up or leapfrogging cases took place in countries with a relatively well established higher education and university system.

Higher and university education does not have to be widespread but might well be limited to the 'core' scientific areas of the new technology system. In the case of the major new technology system of the recent past - new information technologies - it is indeed interesting to observe (tables 1A and B) how an increasing number of primarily Asian industrializing countries have developed a 'scientific' specialization pattern very much based on the core 'scientific' areas of information technology. As table 1A illustrates, those countries appear, in contrast to other Asian developing countries (table 1B), to be more specialized in scope (i.e. the extent to which they participate in world research) in those fields with applications potential in solid state and materials science, engineering and maths and computer sciences, among others. The other Asian developing countries are more likely to be involved to a larger (although relatively small) extent in research in the biologically-based fields.

Over time, the problem of these industrializing countries will face in their efforts to catch up on or even leapfrog in new information technologies will consist of whether the endogenous generation of knowledge and skills, in combination with widespread access to foreign
<table>
<thead>
<tr>
<th>Area</th>
<th>Japan</th>
<th>China</th>
<th>Taiwan Province of China</th>
<th>Republic of Korea</th>
<th>Hong Kong</th>
<th>Singapore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical medicine</td>
<td>33.0</td>
<td>2.0</td>
<td>2.1</td>
<td>0.6</td>
<td>2.2</td>
<td>0.9</td>
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<td>Basic biosciences</td>
<td>59.0</td>
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<td>2.3</td>
<td>0.7</td>
<td>2.2</td>
<td>1.0</td>
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<td>General biology</td>
<td>31.5</td>
<td>3.8</td>
<td>2.9</td>
<td>1.0</td>
<td>0.4</td>
<td>1.4</td>
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<tr>
<td>Agricultural sciences</td>
<td>23.7</td>
<td>2.1</td>
<td>1.0</td>
<td>0.8</td>
<td>1.3</td>
<td>0.2</td>
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<tr>
<td>Chemistry</td>
<td>67.2</td>
<td>9.61</td>
<td>4.3</td>
<td>6.9</td>
<td>2.4</td>
<td>1.1</td>
</tr>
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<td>Physics</td>
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<td>18.3</td>
<td>5.4</td>
<td>7.3</td>
<td>1.5</td>
<td>1.4</td>
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<tr>
<td>Solid state/materials sciences</td>
<td>67.7</td>
<td>14.4</td>
<td>4.7</td>
<td>4.2</td>
<td>1.0</td>
<td>0.8</td>
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<tr>
<td>Geosciences</td>
<td>36.2</td>
<td>13.0</td>
<td>0.9</td>
<td>1.1</td>
<td>0.9</td>
<td>1.2</td>
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<td>Astronomy</td>
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<td>11.2</td>
<td>0.5</td>
<td>0.2</td>
<td>1.4</td>
<td>0.0</td>
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<tr>
<td>Math/computer sciences</td>
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<td>2.2</td>
<td>2.4</td>
<td>3.3</td>
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<td>Engineering</td>
<td>42.4</td>
<td>12.1</td>
<td>5.4</td>
<td>4.8</td>
<td>2.0</td>
<td>3.4</td>
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<td>Psychology</td>
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<td>1.1</td>
<td>0.9</td>
<td>0.7</td>
<td>3.6</td>
<td>1.0</td>
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<td>Economics/management</td>
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<td>2.6</td>
<td>2.8</td>
<td>1.6</td>
<td>3.0</td>
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<td>Social sciences</td>
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<td>0.9</td>
<td>1.1</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Science &amp; eng. education</td>
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<td>0.0</td>
<td>1.7</td>
<td>0.0</td>
<td>1.7</td>
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<tr>
<td>Multi/general</td>
<td>36.2</td>
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<td>1.0</td>
<td>1.4</td>
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<td>0.6</td>
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<td><strong>Total</strong></td>
<td><strong>47.6</strong></td>
<td><strong>6.2</strong></td>
<td><strong>2.9</strong></td>
<td><strong>2.0</strong></td>
<td><strong>2.0</strong></td>
<td><strong>1.1</strong></td>
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</table>
Table 1 (continued)

1985 RESEARCH ACTIVITY IN PACIFIC RIM DEVELOPING COUNTRIES BY AREA OF RESEARCH

(Percentage share of world research in each area)

B. Other Pacific Rim developing countries

<table>
<thead>
<tr>
<th>Area</th>
<th>Thailand</th>
<th>Malaysia</th>
<th>Philippines</th>
<th>Indonesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical medicine</td>
<td>0.9</td>
<td>0.2</td>
<td>0.3</td>
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Total: 0.8  0.5  0.3  0.3

*Source: SRI International: Science and Technology Policy Programme*
technology, will be sufficient to remain in business as the system evolves. This implies not only scientific expertise, but also a constant technological effort, both domestic and in terms of foreign access, with increasing flows of investment. It is in the last resort the capacity to establish interconnections, of interrelated technology systems in evolution, which should generate synergies for self-sustained growth processes. The data in table 1 illustrate how, at the 'domestic' scientific input level, such a process slowly emerges.

From what has been said it is clear that an appropriate institutional framework will be crucial in 'enabling', if not 'enhancing', such a process of technological catching up or technological leapfrogging. It is these broad policy questions that are reviewed in the next section of this paper.

IV. TECHNOLOGICAL ACCUMULATION AND ECONOMIC DYNAMISM: THE ROLE OF POLICY

To the discussion above it is now necessary to add the specific contribution of institutional factors. Institutions constitute a set of crucial variables in any process of technological accumulation, whether a country is lagging or leading technologically. Ideally, it is desirable to develop a "policy taxonomy" bringing together the various institutional instruments/objectives according to the degree of technological and economic development of the various countries, as well as to the stage of development of the various technological systems.

There are two issues with respect to such a broad and general assessment of the role of institutions with regard to technological catching up and technological accumulation: a positive one and a normative one. On descriptive grounds there is little doubt that all market economies have, and have had for a long time, various combinations of policies affecting technological accumulation. The interesting question - too broad and general for this paper - is to make sense of the inter-temporal and cross-country institutional differences. On more normative grounds, on the other hand, one should be able to justify the requirement for policies in relation to some performance yardstick.

Let us start from the latter - normative - point of view. The brief discussion of the patterns of technical change in section I provides two
broad grounds for a normative approach. First, as was emphasized, technological accumulation necessarily embodies a complex and differentiated combination of private appropriation and public good aspects (see Nelson, 1981 and 1984) and involves an unavoidable "market failure". The normative counterpart of this intrinsic feature of the innovative process does not, however, consider if, but how and to what degree, policies should affect the innovative activities. Second, the existence of possible trade-offs between "static" comparative advantage or trade efficiency, on the one hand, and what may be termed (Dosi, Pavitt, and Soete, forthcoming) Schumpeterian efficiency, on the other hand, highlights a wide realm for institutional intervention. In a world in transformation the performance criteria and the link between such policies and performance are, however, fuzzy and uncertain. As discussed at greater length in this forthcoming publication, despite all features pointing to the dominance of 'Schumpeterian' efficiency over 'static' efficiency in the case of new information technologies, one is confronted with complex normative issues. For example: how far should one country depart from static efficiency, whenever the latter conflicts with the dynamic criteria of performance, in order to pursue these new technologies?; when is private appropriability so low that it hinders private innovative incentives?; to what extent and in what manner can public efforts efficiently substitute for decentralized innovative processes?; what are the most conducive institutional arrangements?

A discussion of possible answers to these questions goes beyond the purposes of this paper. However, some broad normative considerations on the links between policy measures related to the nature of technological environments and the phases of development can be put forward.

First, the normative counterpart of the discussion on the possible trade-offs between static and dynamic efficiency lies in the fact that the structural need for policies also affecting the pattern of economic signals emerging from the international market will be greater, the higher the distance of any one country from the technological frontier (for further detail see Cimoli and Soete, 1988). By contrast, endogenous market mechanisms will tend to behave in a "virtuous" manner for those
countries that happen to be on the frontier, especially in the newest/most promising technologies.

Second, as regards the time profile of technological developments, a clear separation can be drawn between policies related to the emergence of new technological systems and policies apt to sustain technological activities along relatively established paths. In the former case, policies should provide a satisfactory flow of scientific advances, establish "bridging institutions" between scientific developments and their economic exploitation, develop conducive financial structures to support the trial-and-error procedures generally involved in the search for new technological breakthroughs, and act as "focusing devices" in the selection processes of the direction of technological development.

As regards "normal" technical progress, important policy tasks are the maintenance of a relatively fluid supply of techno-scientific advances, coupled with "balanced" conditions of private appropriability of the benefits of innovating (e.g. through patent policies, etc.). Countries well below the technological frontier may also find it necessary to act directly upon both the capability levels of the domestic companies and against the appropriability features of the related technologies in so far as they constitute an entry barrier for laggard companies/countries.

Third, and of more direct relevance to technological catching up and leapfrogging, the most fundamental policy dimension relates to the so-called context conditions, i.e. the organization of externalities and infrastructures. As discussed in section II, these are likely to be particularly important in the transition between different technological systems, in which the new technologies involve not just new technology and skills but also new patterns of inter-sectoral commodity and information flows and new common infrastructures and synergies. In section III particular emphasis was placed, in relation to the new information technologies, on the role of higher education and universities. Clearly, these locational and infrastructural advantages do not fall from heaven, any more than does a country's endowment in scientific and technical personnel and skills. They are a result of the previous history of development and of social, cultural and political factors. However, they are one of the few areas where active policy can take advantage of new opportunities and favourable conditions.
Against this background it is interesting to observe the choice of instruments in relation to technological accumulation and catching up by some of the major developed countries in the recent past. At one extreme, there is the example of Japan, especially in relation to the cluster of electronics technologies. Japan appears to have acted comprehensively with respect to all levels of technological instruments/objectives. In particular, it appears to have succeeded in a difficult "fine tuning" between "signal policies" which, as such, risk shelving and protecting positions that promote inefficiency from an allocative point of view, and competition policies which stifle the adjustment processes. In this respect, the Japanese case is almost an archetype: heavy discretionary intervention in the structure of signals (by means of formal and informal protection against imports and foreign investments and an investment policy of financial institutions consistent with growth and dynamic efficiency) recreated the "vacuum environment" that is generally enjoyed only by the technological leader(s). However, this was matched by a pattern of fierce oligopolistic rivalry among Japanese companies and a strong export orientation which fostered technological dynamism and prevented any exploitation of protection simply in terms of collusive monopolistic pricing.

It is tempting to compare this Japanese experience to that of other, less successful countries such as many European countries, which relied heavily upon a single instrument, i.e. financial transfers (especially R and D subsidies and transfers on capital account), leaving to the endogenous working of the international market both the determination of the signals and the response capabilities of individual firms. Certainly, there are country-specific features of the Japanese example which are hardly transferable.

True as this may be, the experience of Japan, and more recently of the Republic of Korea, each with its own striking outcome, points to the general possibility of technological catching up and even leapfrogging. It also points to the possibility of reshaping the pattern of "comparative advantage" as it would notionally emerge from the endogenous evolution of international markets. As certainly the Japanese case illustrates, a successful catching-up effort in terms of per capita income and wages is contextual to technological catching-up and even leapfrogging in the new and most dynamic technologies, irrespec-
tive of the initial patterns of comparative advantage, specialization and market-generated signals.
References


Tucker, J. (1774), *Four Tracts, together with Two Sermons on Political and Commercial Subjects*, Gloucester.


in the 'critical income' industrialization level, have not reached the stage of takeoff.

The second major set of criticisms against the standard diffusion model related primarily to its static nature and the way the diffusion process is reduced to a pure demand-induced phenomenon. Metcalfe (1981 and 1982), in particular, has emphasized the limits of the standard model in this area. There are, as many detailed studies of the 'innovation process' have indicated, plenty of reasons for expecting both innovation and its surrounding economic environment to change as diffusion proceeds.

At the technological end, one may expect significant improvements to the innovation to occur as diffusion further proceeds. These incremental developments can be either more or less autonomous or induced by the diffusion process - e.g. through user feedback information as well as through the wider application of the innovation to new users, requiring better performance and/or more precisely defined quality characteristics. As diffusion proceeds, and the specific users' demands become more stringent, it can be expected that the effective use of 'scientific knowledge' in improving the performance, quality and reliability of the innovation will increase substantially.

From an economic perspective too, the static, demand-focused nature of the standard diffusion model is questionable. In the model developed by Metcalfe, the price of the new innovation is no longer a constant or evolving along a particular time path, but is determined itself by the process of diffusion. In addition, supply of the innovation is limited by productive capacity, the rate of increase of which depends on the profitability of producing the innovation. A typical Schumpeterian 'scenario' of an entrepreneur-innovation emerges, his temporary reward consisting of the initial monopoly profits which are gradually reduced by competition as imitation takes place and 'the innovative potential' is exhausted. At the same time, though, as the rate of return on the innovation supplier(s) falls, "the associated reductions in price increase the profitability of adopting the new innovation", which is further diffused.

Once the importance of these supply factors is fully recognized, it becomes also clearer how past investment in the 'old', established