Catching up in technology: entry barriers and windows of opportunity

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Introduction

The importance of 'foreign' technology and its international diffusion is undoubtedly a historically well-recognised factor in the industrialisation of both Europe and the United States in the nineteenth century, and even more strikingly of Japan in the twentieth century. That importance emerges again and significantly stronger from the evidence of the rapid industrialisation of some so-called newly industrialising countries, such as South Korea, over the last two decades.

In fact, the great majority of developing countries continue to face enormous difficulties in their efforts to industrialise. This has lent credence to the theories of 'dependency' which hold that there is a structural gap between developing and developed countries that remains and widens. Thus the few recent examples of relative success which seem to counter that theory have, not surprisingly, aroused intense interest and demand a satisfactory explanation. In our view, what is required is a deeper understanding of the technological issues which underlie the process of development. More adequate attention must be given to the questions of how technologies evolve and diffuse and under what conditions a process of *effective* technological catching up can take place.

There is, of course, a voluminous literature on this subject which has been a focal point of research for economic historians (see, e.g. Landes, 1969; Rosenberg, 1976). We do not intend to review this literature here. Suffice to point out a fruitful convergence appearing between two streams of work: on the one hand, that based on in-depth case studies of countries catching up in the production and use of particular technologies (see especially Ames and Rosenberg, 1963; Habakkuk, 1962, von Tunzelmann, 1978; and many others); and, on the other, some of the recent international trade and growth models – reviewed in the chapter by Dosi and Soete—based on imitation and 'catching up' (see in particular Posner, 1961; Freeman, 1963, 1965, Gomulka, 1971, Cornwall, 1977, etc.). That convergence puts the emphasis clearly back on the historical context and the institutional framework (see also Section V) within which the process of imitation/technological catching up takes place. It includes 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 (see Scoville, 1951) and other 'germ carriers', the crucial role of governments (for a broad overview, see Yakushiji, 1986), and, of course, the role of historical accidents.

From such a perspective, the international diversity in growth performance of countries—as illustrated in the previous chapter by Fagerberg—could well provide a case *par excellence* of the importance of path-dependent development, with possibilities of 'locked-in' development (see B. Arthur's chapter). It could mean that some industrialisation locations got 'selected' early on and, by appropriating the available agglomeration economies, exercised some 'competitive exclusion'—to use Arthur's (1986) term—on other locations. Indeed, and as also illustrated in Arthur's chapter, it is the increasing returns associated with industrialisation and development which 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 infrastructure and the agglomeration economies that make development possible. In summary, it is within the logic of the dynamics of the system that the rich get richer and the gap remains and widens for those left behind.

All development policies have in one way or another been geared to breaking away from 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 constraints.

The question we wish to tackle here is whether these constraints are always equally formidable or whether their intensity varies in time with some increasing and some decreasing, thereby opening windows of opportunity to escape the vicious circle. According to some of the neo-technology accounts of international trade, comparative advantage would shift to 'less developed' countries with the further international diffusion of technologies as they reach maturity. Thus through the 'use' of imported technologies these countries would acquire some comparative industrialisation advantage but only in mature products and industries.

Indeed at first sight, the choice of *mature* products as a point of entry is probably the only one available to initiate a development process. 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, this choice implies a clear risk of getting 'fixed' in a low wage, low growth, development pattern. A real catching-up process can only be achieved through acquiring the capacity for participating in the generation and improvement of technologies as opposed to the simple 'use' of them. This means being able to *enter* either as early imitators or as innovators of new products or processes. Under what conditions would this be possible?

To answer this question, the long term nature of technological change as a disruptive process with changes in direction and deep structural transformations needs to be far better understood. The notion of technological change as a global, more or less continuous process underlies the traditional way development is viewed. As long as technology is understood as a cumulative undirectional 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.

In this chapter we begin to look at some of the specific conditions under which technological catching up and imitation could take place. In a short introductory section, we set out, in line with the chapter by Metcalfe on diffusion, some of the most salient points with regard to diffusion theory which appear of relevance to theories of industrial development and economic growth. In the second section, we go in more detail into the conditions for imitators to enter and effectively catch up.

We begin with a static view of technologies in order to look at how the actual costs of developing, imitating or buying a production technology are influenced by the characteristics of the acquiring firm and by those of its location. We then introduce technological dynamism and examine how the various elements of those costs (and the barriers they erect for new entrants) increase or decrease as technologies evolve from introduction to maturity. This leads us to identify the importance of the timing of entry in terms of individual technologies. Finally, we introduce the interrelatedness of technologies in complex technology systems and the notion of changes in techno-economic paradigms, i.e. the emergence of radical discontinuities in overall technological evolution. This brings us to the concluding argument that catching up involves being in a position to take advantage of the window of opportunity temporarily created by such technological transitions.

Technology diffusion models and industrial growth and development

Some introductory comments

Diffusion models, at least in their simplest 'epidemic' representation, have, as already noted in Metcalfe's chapter, a striking level of methodological similarity with some of the models of industrial growth and economic development developed in the 1930s by Kuznets (1930) and Schumpeter (1912/34) 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 in 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 is made in Freeman *et al.* (1982). Here it is precisely the notion of 'clusters' of innovations including the follow-up innovations made during the diffusion period which are linked to the rapid growth of new industries, and will in the extreme case even provide the ingredients of an upswing in overall economic growth. In the more restrictive diffusion terminology, this could be viewed as an 'envelope' encompassing the diffusion curves of a set of closely interrelated clusters of innovations which, occurring within a limited time span, might 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 standardisation. 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'. Similar notions underlie the argument 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 after him Vernon (1966) and many other proponents of the product life-cycle trade theory illustrated how such changes could 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 criticised; the mechanistic, quasi-autonomous nature of the process of economic growth assumed by Rostow was seen as 'ahistorical'. Interestingly, though, the critique of Rostow's growth model finds its reflection in much of the recent diffusion literature, criticising 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 between 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) at a particular time 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 be 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 both to imitation, more and better information, band-wagon effects. etc.

The probit model can be a useful tool for industrial growth theory. A 'critical' income *per capita* level is a concept which can be introduced in Rostow's theory of the stages of economic growth. Replacing the concept of individuals or firms by 'countries', different growth performances can be explained and expected. The problem is, of course, more complex. The example of the OPEC countries shows that even with a tremendous increase in income the absorptive capacity of a country might still be below the critical level needed for take-off. Thus, considering both the extreme variation in each country's ability to use and manage resources, to take risks and 'assess new innovations' (the variation in consumer tastes in the probit model), as well as the extreme income inequalities at the world level, it should come as no surprise that world-wide industrialisation (diffusion) has been so slow and uneven.

The second major set of criticisms against the standard diffusion model relates primarily to its *static* nature and the way the diffusion process is reduced to a pure demand-induced phenomenon. Metcalfe (1981, 1982) in particular has emphasised the limits of the standard model in this area. As many detailed studies of the 'innovation process' have indicated, there are plenty of reasons for expecting both the 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 evolves. At the economic end the price of the innovation will change throughout the process of diffusion. In addition, the supply of the innovation will depend on the profitability of producing it.

Once the importance of the strong feedback between supply and demand factors in innovation diffusion is fully recognised, it is easier to see how past investment in the 'old' established technology can slow down the diffusion of the new innovation. This applies to past investment not just in physical capital but also in human capital, even 'intellectual' capital. As Rosenberg (1976) and von Tunzelmann (1978) have 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 decline and disappearance of an old technology is indeed slow, with the old technology firms often living off past, fully recovered investment and being sometimes able to underprice the innovation-adopting firms.

The implications for the international diffusion of technology and the potential for technological catching up are far-reaching. There is every reason to expect that the vast majority of new technologies will originate primarily within the technologically most advanced countries. There are also, however, good reasons to expect that the diffusion of such major new technologies will be hampered in some of those countries by the heavy investment outlays in the more established technologies, the commitment of management and the skilled labour force to them and even by the research geared towards improving them. This could mean that the new technology might diffuse more quickly elsewhere, in a country less committed to the old technology in terms of actual production, investment and skills. At the same time, as diffusion proceeds, some of the crucial, incremental innovations, resulting from user–feedback information and other dynamic factors, could tend to shift further the technological advantage to the country in which the new technology is diffusing more rapidly.

The industrialisation in the nineteenth century of Germany, France and the United States and a number of smaller European countries provides ample support for this view. The dramatic change in fortune in the United Kingdom's position from an absolute technological leadership, producing in the mid-nineteenth century more steam engines than the whole of the rest of the world put together, is a powerful illustration of this phenomenon. In recent times, this has been most obvious in the case of Japan in the 1960s and 1970s where world 'best-practice' productivity levels were achieved over a very short time in steel, cars, electronics, numerically controlled machine tools, and, in the most recent years, computers, largely on the basis of initially imported technology. More recently, and more strikingly, South Korea has achieved similar successes in some of these sectors.

These successful examples illustrate the existence of windows of opportunity for 'late industrialisers'. However, their scarcity highlights how 'non-automatic' and exceptional such processes of effective technological catching up are. The use of foreign, imported technology as an 'industrialisation' short cut depends on having the required conditions to undertake the difficult and complex process involved in its effective assimilation.

A first approach to the real cost of production technologies

There is a fundamental difference between the diffusion of a final consumer product in a population and the diffusion of capital goods or production technologies in general. In the first case, the product is developed with the clear intention of selling it. Thus the innovator will be pushing diffusion and trying to overcome obstacles to adoption. The price of the product is one of the tools to push diffusion. In the case of production technologies there is a whole range of situations. At one end of the spectrum, we find the innovator who develops the technology for his own use and wants to monopolise it, going to all lengths to avoid diffusion. At the other end, we find the supplier who develops a new machine or process with the intention of selling it to users, pushing, as in the case of consumer products, for widespread adoption. Metcalfe's diffusion models refer mainly to the latter part of the spectrum.

Yet, there is another, perhaps even more fundamental difference between the conditions for diffusion of innovations among consumers and among productive users. For someone to buy a personal computer and never learn to use it is certainly of little consequence. But for a firm buying a steel plant it is absolutely crucial that it be able to use the plant effectively to make steel, achieve a viable share of the market and make a profit. This means that besides having enough income to invest in the equipment, there are other more intangible assets that the would-be producer *must* possess or acquire. So the characteristics of the buyer (or imitator) will have enormous influence on the actual cost of the technology to that particular firm.

What this means is that production technologies have no single price tag. This is quite different from the assumption of most diffusion models that all adopters at a particular moment in time face the same cost. It will be argued here that the notion of a threshold for entry is not limited to the 'price' of the equipment but involves a set of interrelated conditions and leads in fact to vastly different costs of entry depending on the characteristics of the acquiring firm and of the environment in which it operates.

Beyond the fixed investment cost, there are at least three groups of elements which contribute to determine the actual cost of *entry* for each individual firm. One is the cost of the scientific and technical knowledge required to assimilate the innovation; another is the cost of acquiring the experience required to handle it and successfully bring it to the market; and third, but not least, is the cost of overcoming any 'locational' disadvantages related to the general infrastructure and other economic and institutional conditions surrounding the firm.

Consequently, also, the notion of an entry threshold for production technologies becomes much more complex than the straightforward income level of the probit model. Barriers to entry are then a fourfold combination where each of the elements mentioned above would impose a threshold below which costs for the would-be entrant become formidable. To take the most absurd limiting conditions, no one would consider setting up an automobile plant in the middle of the Sahara, and an illiterate peasant who hit the jackpot would be hard put to set up a firm to produce monoclonal antibodies.

All these cost elements are fully recognised in practice in many technology-transfer contracts to developing country firms. These generally include not only the cost of the 'turn-key' plant but also payment for the technology licence and for technical assistance or transfer of experience and 'know-how'. Additionally, government aid is usually expected to counteract locational disadvantages or provide tariffs to shield the higher local costs.

Threshold levels and entry costs: a simple world

To examine the way in which these various factors might influence the cost of entry, we start out with a simple world where technologies do not evolve and are of a 'free nature'. In other words, technologies are introduced in their final and only form and the innovator does not try to appropriate any part of the technology but is willing to sell the required information and equipment to imitators at their *net* cost.

By entry costs we now understand the total costs of everything the innovator or imitator requires for setting up production facilities, successfully launching the product, and reaching a viable market volume. For any innovation, the costs of entry for the innovator (C_a) could be represented as the sum of the following components: the fixed investment costs (I) in plant and equipment; the cost (S_a) incurred by the innovator in acquiring the scientific and technical knowledge relevant to the innovation which was not possessed by the firm at the beginning of the innovation process; the cost (E_a) incurred by the innovator in acquiring the relevant experience (know-how in organisation, management, marketing or other areas) required to carry the innovation through; the cost (X_a) borne by the innovator to compensate for whatever relevant externalities are not provided by the environment in which the firm operates. Finally, as regards the innovator, there would generally be certain costs (W), due to following 'wrong' leads in the trial and error process involved in innovating. Those extra costs could express themselves in terms of extra costs in each of the previous four components.

In the first instance, the difference with the imitating firm's costs (C_i) relates to W: i.e. the 'wrong' costs that will not be incurred. The imitating firm will know exactly where it stands and exactly where it is going. Given our assumptions, the imitator can purchase in the open market or from the innovator all the required equipment, plant, knowledge and know-how. Nevertheless, the savings in W are not enough to predict that the imitator will have lower costs of entry than the innovator. It all depends on the relative starting positions of the innovator and imitator in terms of relevant knowledge, experience and location. Let us briefly examine each of the components of the cost of entry.

(a) Fixed investment: the basic cost

With regard to the *fixed investment costs* (I), these are defined by the character of the innovation itself and can be very large or very small depending on the product. In our simple model they are fixed once and for all at the level determined by the net costs of the innovator. Since the innovation cannot be made without this investment, I represents the absolute minimum threshold of entry for any producer. If the innovator purchased or developed any unnecesary equipment, its costs would be included in W as W_k. An imitator then would enjoy a fixed cost advantage of W_k.

(b) The cost of closing the knowledge gap

The *scientific and technical knowledge* (S) required for an innovation generally includes a fair amount of what is called 'freely' available knowledge and information which serves as a platform for generating the new or innovation-bound knowledge (which in the real world would usually be patentable or kept secret). However, the fact that knowledge is freely available cannot be understood as having no cost of acquisition. Even if the information is in a library, a firm requiring it will incur various costs, in time, transportation and personnel to 'purchase' it. More likely the firm will have to hire consultants or qualified personnel as well as buy the relevant reference materials. The generation of new knowledge obviously has costs in time and personnel for design and experimentation as well as equipment and prototype expenses. The actual costs for the innovator will consequently include not only that of generating the new innovation-bound knowledge but also the cost of acquiring that part of 'freely' available relevant knowledge which the innovating firm did not possess to begin with.

To bring back the discussion to the concept of threshold levels, it should be clear that it would be absurd to assume that a firm can start with zero previous knowledge. There is a threshold level below which costs to the firm would be infinitely high. This threshold cannot be defined *a priori*, but would vary depending on how science-based or how truly 'new' the innovation is.

On the other hand, it is well established that the capacity to absorb new knowledge is greater the larger the amount of relevant knowledge already possessed. This in terms of cost would imply that the closer the firm is to the required frontier in terms of knowledge, the less costly it will be to acquire an additional 'unit' of information. Graphically, the relationship between the knowledge-related technology acquisition costs (on the vertical axis) and the various possible starting levels at which acquiring firms may find themselves in terms of the relevant scientific and technical knowledge required (on the horizontal axis) is represented in Figure 21.1

The minimum knowledge threshold s indicates the level at or below which the firm, whether innovator or imitator, would face infinite knowledge-related entry costs for lack of absorptive capacity. The level s_n is the total amount of relevant knowledge required for using the innovation, whereas the level s_p is the publicly available knowledge upon which the innovation-bound knowledge $(s_n - s_p)$ was built. Since there is no reason to assume that the innovator possessed all the relevant 'free' knowledge before generating the new, the firm's starting point s_a would be somewhere between s and s_p.

The knowledge-related entry costs for the innovator are then composed of the cost S_g of closing the gap between s_a and s_p, the cost S_n of generating the new knowledge $(s_n - s_p)$ and the costs incurred in following 'wrong' leads S_w. Obviously, the higher the level of relevant scientific and technical knowledge possessed by the innovating firm, the smaller the gap it has to close and the lower its entry costs. But this, of course, also holds for the imitator. Following our assumptions, an imitator with a starting knowledge level equivalent to that of the innovator would face equivalent costs S_g of closing the 'free' knowledge gap plus the net R & D costs S_n charged by the innovator who is assumed generously to spare him the 'wrong' development costs. So the imitator's cost curve would be lower (dotted line in Figure 21.1) for any starting level of knowledge than for the innovator. It is

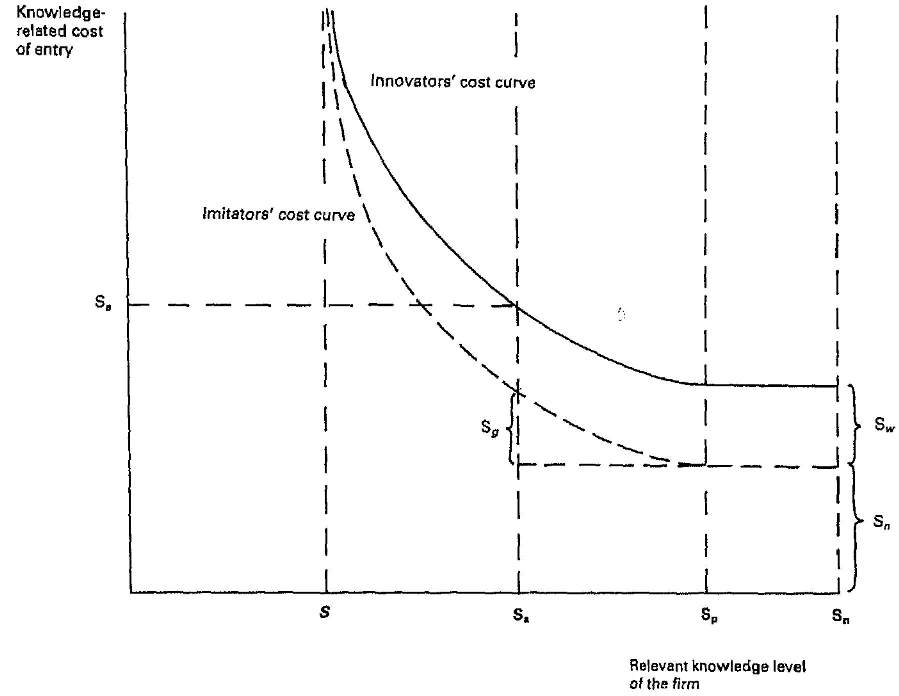

Figure 21.1 Varying knowledge-related cost of entry for different innovating and imitating firms.

clear, however, that even in our simple model the imitator's knowledge-related entry costs will depend crucially on his own initial scientific and technical knowledge base in the relevant areas. Consequently his entry costs may be much higher or much lower than the innovator's, depending on their relative starting positions on the horizontal axis.

(c) The cost of closing the experience and skills gap

With regard to the third set of entry costs, the *experience-related* costs, a similar argument could be put forward. For a product or process design to go beyond the prototype stage into a fully fledged innovation in the market, many skills must come together. From management, through production to distribution and marketing, experience is required and acquired. And the same holds for the success of an imitator.

Although the actual levels as well as the slope of the curves would be different within each particular technology, the entry costs curve for closing the varying gaps in experience levels could be of the same general shape as that discussed above where again a minimum threshold level of experience would exist below which the firm would face infinite costs. Again, a higher initial experience level would mean lower costs of closing the gap. We are, as in the case of knowledge, referring here to *relevant* experience. This creates an important difference between the two types of information discussed. Having a certain amount of 'irrelevant' knowledge does not harm the innovating firm. A wider knowledge base, even if in apparently unrelated fields, can be a source of originality and strengthen the absorptive capacity of the firm. By contrast, irrelevant experience, or rather experience in 'the old way of doing things', can be a dead weight when it comes to innovating and imitating. As already hinted at in the previous section, there could be a cost attached to getting rid of such 'wrong' experience.

So even in this simple view of the world there would be significant differences in the experience-related costs of entry, not only between innovators and imitators but also between new and old firms, i.e. between firms that have inertial 'wrong' experience and firms that do not.

(d) The cost of compensating for lack of externalities

Whatever the endowment of a firm, in financial resources, knowledge and experience, its capacity to innovate will be much influenced by the characteristics of the environment in which it operates or plans to operate. Moreover, every single entry-cost component will be affected by the surrounding advantages or disadvantages.

Even in the simple model discussed here where the cost I of the necessary plant and equipment is the same for all entrants, the locational (dis)advantages will produce big variations. Making realistic assumptions about economic geography, the distance from equipment suppliers, the adequacy of the transport infrastructure, and the local availability of competent design, construction and engineering contractors would result in vast actual cost differences for firms in different locations. So extra investment costs X_k accruing to each firm from disadvantages in location would increase I to $(I + X_k)$. Furthermore, the disadvantages can be so large, as in the extreme case mentioned of the automobile plant in the middle of the desert, that X_k erects a formidable entry barrier.

The same can be said for both scientific and technical knowledge and experience. There were obvious advantages for an electronics firm located in Silicon Valley in terms of access to relevant university research and researchers which made its knowledge-related costs of entry lower than those of an equivalent firm planning to set up in, say, Arkansas or Ecuador. It is also well known that these firms profited from a certain amount of synergy in terms of both knowledge and experience through the frequent communication between personnel of different nearby firms. Equally, the buying-in of personnel from other firms became a common practice to take experience short-cuts in both highly qualified staff and skilled workers in the field.

Thus, in more general terms it can be said that the quality and the quantity of scientific and technological capacity offered by the surrounding environment will result in variations in the cost of acquisition of the required relevant knowledge for otherwise equally endowed firms. The distance (both geographic and cultural) from these possible sources of knowledge (including in our simple case the distance from the innovating firm) will increase the entry cost component S to $(S + X_s)$. And, again, X_s could become large enough to erect an effective barrier to entry.

Similar considerations apply to the availability of experience and skills in the surrounding environment. It is clear that if the required skilled personnel is abundantly available locally the cost of acquisition is the going market rate for this type of labour (which, being different in each locality, would already determine differences in costs for firms in different locations). Otherwise, the skills must be imported from distant markets in the form of people or training or they must be acquired with time and practice and mistakes. The same can be said for consumer education. If surrounding consumers possess both the income level and the habit of using similar products, the cost of penetrating the market will be much lower than if the firm has to carry the cost of educating the consumers. So the experience-related costs of entry for an innovating firm will increase and will therefore depend not only on its own level of experience endowment but also on the endowment of the surrounding environment.

Yet the locational (dis)advantages which affect the cost of entry for a firm are not limited to the three categories related to our previous entry-cost elements (X_k, X_s and X_e). There are required services both for the investment process and for regular operation, ranging from financial services to transport facilities and basic utilities (water, electricity, telecommunications, etc.), which determine the general conditions for business and can have crucial or lesser importance depending on the specific nature of the innovation. The relative costs, efficiency and ease of access to those that are relevant among these services will influence both the cost and the possibility of entry. Another set of locational (dis)advantages includes those elements upon which more traditional economic analysis has concentrated, i.e. the relative prices of the required inputs, the relative wage rates and the size and characteristics of the domestic market.

Last, but not least, the firm operates within a legal, social and institutional framework. Numerous aspects of this framework such as government regulations, standards, taxes, subsidies, tariffs, and other relevant policies or laws; trade-union organisation and practices; the structure and policies of the financial system; even the values of the local population in terms of willingness to accept or reject the innovation or its consequences will have a strong bearing on the actual costs of entry for an innovator in that particular country or locality. Even issues relating to language can be significant depending on the nature of the innovation.

In general, it could be said that what determines the level of relevant (dis)advantages for a firm in a particular location is the previous history of development in that location. Each additional producer in a country, region or locality would benefit from the agglomeration economies created by its predecessors and from concomitant factors such as the educational level of the population, government experience in dealing with and supporting industry and services, development of distribution networks, etc. So there would be a minimum environmental threshold x which, depending on the specific nature of the innovation, can be either very low or very high. Below this threshold the extra costs confronting the firm could become prohibitive and above it they would decrease until they disappear (or even turn into savings).

There is, however, as in the case of the wrong' experience which created additional costs for the firm, the possibility of confronting inertial or negative conditions in the environment. In this case, extra costs W_x would accrue to the firm, whether innovator or imitator, to surmount such 'obsolete' conditions. A high level of consumer saturation in TV sets is an infrastructural advantage for introducing video-recorders but would become an inertial disadvantage for introducing a digital system of transmission requiring a change in reception equipment. So, in some cases, an environment with high commitment to the old products or a high development of the old type of infrastructure can hold back the diffusion of radical innovations.

Similar arguments could be put forward with regard to certain types of conditions which are also related to the environment and can result in significant savings to the firm, reducing its costs of entry and operation. This cost of entry 'rebate' is composed primarily of direct government 'help'. It comprises government subsidies of all sorts, preferential interest rates, R & D grants, tax reductions, protective barriers, and any other form of direct or indirect absorption of what would otherwise have been a cost to the firm. These are advantages that can be politically created, increased, reduced or eliminated by governments. They are not rooted in the environment as ports, roads, services or skills are, but they can certainly reduce the costs of entry for any producer in that particular country or locality.

To conclude the analysis of threshold levels and entry costs in this first, highly simplified case of a 'static' and freely available technology, it is clear that there is no single price tag for production technologies nor is it solely determined by the supplier. Furthermore, the absolute threshold level is not limited to the price of the technology. It includes minimum levels of scientific and technical knowledge, practical experience and locational advantages. Thus, given the great variety of possible initial conditions of would-be entrants, there is actually no way of determining beforehand whether the innovator or any particular imitator in any particular location will have the lower entry cost.

Yet this model seems to reinforce the difficulty of catching up. It is clear that the starting points of developing country firms in all four components, but particularly the last, would tend to be lower than those typical of firms in the more advanced countries.

To examine the question of development we must come closer to the real conditions in the 'technology market'.

The timing of entry

Technological evolution and the cost of entry as a moving target

Relaxing the freely available technology condition of the model will bring us closer to the real world. New entrants do affect both market share and profits of pre-existing producers. Consequently innovators will choose to sell or not to sell the relevant innovation-bound knowledge and experience as well as whatever equipment was directly designed for the innovation and is therefore not available in the market. Imitators will compare the cost of buying the technology with the cost of developing it themselves, if they can. Both these costs vary with the age of the technology, the level of diffusion and the three additional factors discussed above. We shall, however, not dwell on this here.

Let us turn instead to the most unrealistic of the assumptions in our simple model, i.e. the one relating to the once-and-for-all static nature of the technologies. When a product or process is first introduced it is almost inevitably in a relatively primitive form and is submitted to successive incremental improvements which either reduce its cost of production and/or increase its quality, performance, reliability, or whatever other aspect is important to the users or can contribute to enlarge the market. As discussed in the previous section, such improvements could follow what Nelson and Winter have termed a 'natural' trajectory and Dosi a 'technological' trajectory. As in the product life-cycle model, the path of such successive incremental innovations from introduction to maturity of any particular technology, could be represented in the familiar S-shape fashion. Improvements are achieved slowly at first, then accelerate and finally slow down again, according to Wolff's law of diminishing returns to investment in incremental innovations. (See Figure 21.2).

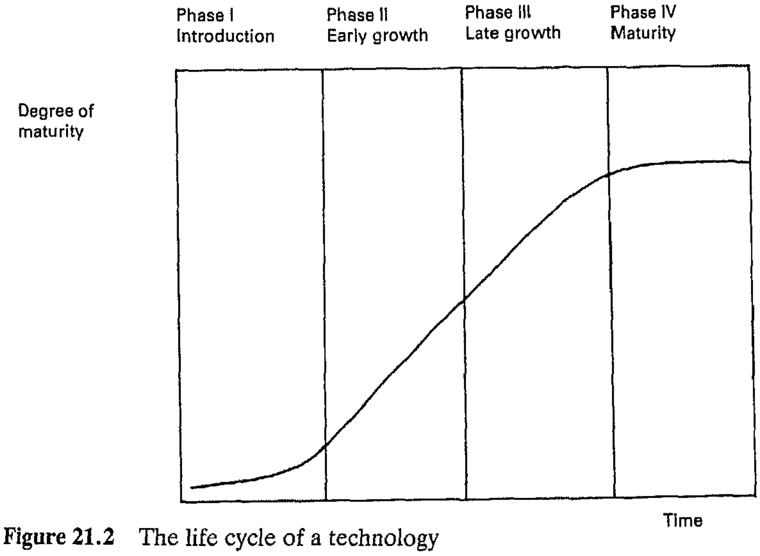

Figure 21.2 The life cycle of a technology

This means that the imitator does not always enter the 'same' technology as the innovator. Nor do later imitators enter at the same point in the technology's evolution or trajectory as earlier ones. All these improvements have a cost and they all imply the generation of additional, innovation-bound knowledge and experience. This implies that cost of entry curves vary in time. A reasonable assumption would be that they constantly shift upwards as they now cover the cost of the original investment plus all subsequent investment in incremental improvements. However, this is not necessarily so. As noted in the introduction, Hirsch (1965 and 1967) observed that requirements for entry vary in importance through the various phases of the product cycle. In our terminology, this would imply both that the various components of the cost of entry vary in relative importance, and that the minimum threshold levels move up or down as technologies evolve over the phases of the product life cycle.

Let us briefly examine what happens to each component in each of the four phases. Figure 21.3 illustrates graphically what we have in mind. Since different types of innovation can result in different evolutionary patterns, we shall take the simple case of a technology for producing a new final consumption product which eventually reaches massive diffusion.

Phase I is the period of first introduction where the focus is on the product itself. It has to perform its function adequately and break successfully into the market. It is a learning process for designers, plant engineers, management, workers, distributors and consumers. It is the world of the Schumpeterian entrepreneur. Since original design and engineering are involved, the s threshold is likely to be high, whereas e could be low. The level x of locational advantages required can be crucial and relatively high for successful introduction. Finally, investment costs I are likely to be low, if not always in absolute terms at least relative to what they will become as the technology evolves.

Phase II is the period of rapid market growth. Once the product is basically defined and its market tested and clearly capable of growing, the focus shifts to the process of production. Plant design becomes important and successive improvements are made to both the product and the process of production to achieve the optimal match between the two, in order to increase output and productivity. Materials and shape might be changed to lower costs and increase efficiency or respond to market demand. Plant organisation is gradually optimised and the most appropriate equipment chosen or specified. It is the world of the production engineer and the marketing manager. As the scientific and technical problems are gradually solved and their solution is embodied in both product and production equipment, the s threshold for imitators decreases. But the e threshold in terms of required skills increases rapidly as experience accumulates within the producing firm in relation to the product, the process of production and successful marketing. Locational and infrastructural economies of the sort generated by the innovation itself grow at the expense of the producers, so later entrants could find the relevant infrastructure more available than earlier ones. The cost of I is now higher than before as optimal plant size

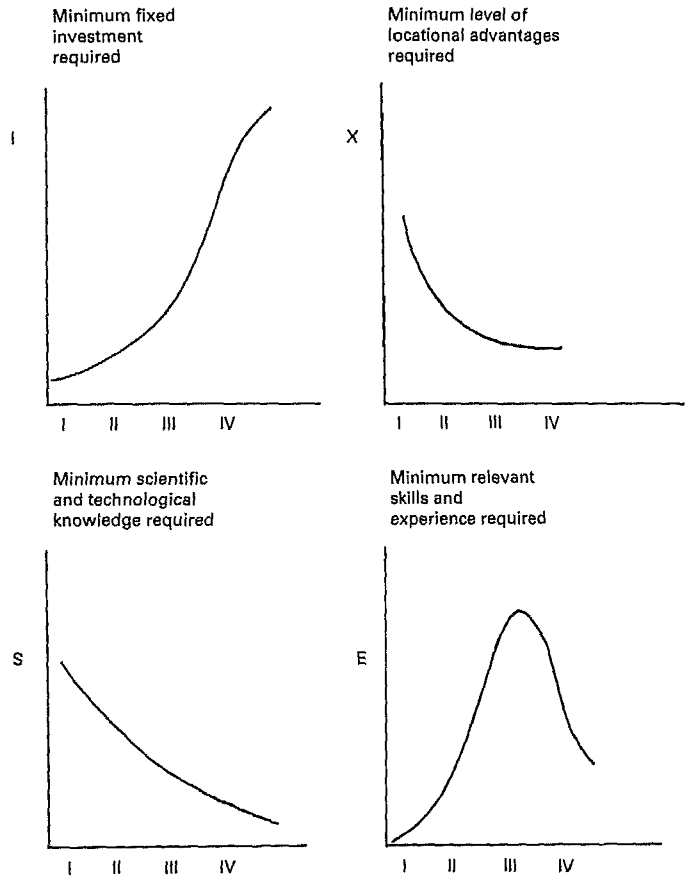

Figure 21.3 Variation in the components of the cost of entry over the four phases of the technology life cycle.

has grown and more sophisticated and better adapted equipment has been incorporated to handle the larger volumes.

By *Phase III* all the main conditions have been clearly established. Market size and rate of growth are well known, the relationship between product and process has been optimised, and the direction of further incremental innovations to increase productivity is clearly seen. The focus is now on managing firm growth and capturing market share. Scale-up of both plant and firm are the characteristics of this phase. As it proceeds many firms that were successful in the previous two phases might be eliminated. The actual capital costs and the management skills required to stay in the race in Phase III can be formidable. This is therefore no time for new entrants. The *S* component of entry costs is by now relatively low but the *E* and *I* components are at their highest and growing. Locational advantages become less important by comparison with the internalised economies that successful firms have accumulated in market and financial power by this time. Furthermore, regarding the price a firm would charge for selling the technology, one could say that in Phase I the price can tend to infinite due to an interest in monopolising the technical information of the *S* sort, but in Phase III it can again become relatively high in order to monopolize markets, through keeping the now much greater experience (*E*) within the firm.

Finally, in the maturity stage *Phase IV*, both the product and its process of production are standardised. Further investment in technological improvements results in diminishing returns. Since factor inputs are established and fixed, the advantage in costs of production goes to the firm or locality that can make the greatest comparative saving in any of them. This might lead the established firms to relocate some of their own plants even from the end of Phase III. But it can also lead them to concentrate on other innovations and to turn the technology acquired in the previous phases into a commodity, i.e. being willing to sell it at a discretionary price in the form of licences and 'know-how' contracts. This practice could eventually result in a buyer's market if there are competing suppliers. Thus, in the final or maturity phase of a technology the threshold of entry comes further down even though the actual costs of entry may still be high. The previous knowledge requirements are now very low because they are almost totally embodied in the product and the equipment. The required skills are well codified and can be purchased at a price, though their real acquisition for efficient production may not be guaranteed without enormous efforts on the part of the buyer (Bell, 1984). The relevant locational advantages continue to be important; those relating to the education of input suppliers and consumers are at their highest almost everywhere. Finally, the fixed investment costs are much higher than in Phase I but suppliers are available who have the experience and know the specifications for all the necessary equipment.

What this means is that, given the appropriate conditions, Phases I and IV provide the easiest-to-attain threshold conditions for new entrants, but with radically different costs and requirements. In Phase I with little capital and experience, but with the relevant 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 of the technology. By contrast, entry at Phase IV depends on 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 entry at Phase I 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.

This, then, appears to support both the view put forward by product life-cycle trade theory, illustrated in the success of export-led industrialisation strategies achieved on the basis of manufacturing mature traditional products, and the apparently contradictory early-entry 'events' of a number of industrialising countries in such technologies as digital telecommunications, electronic memory chips or PABX. The early-entry phenomenon is, as already mentioned in the introduction, further supported by much historical evidence with regard to the late but rapid industrialisation of many of the presently industrialised countries.

Windows of opportunity for catching up:

From product life cycles to techno-economic paradigms

One of the main shortcomings of the discussion above and indeed of the product life-cycle theory framework is that it assumes that products are independent of one another. Every new product is seen as a radical innovation, and the successive improvements to it and to its production process are the incremental changes which bring it to maturity, after which the next product is seen as a radical departure destined to follow a similar evolution.

In fact, as discussed at greater length in the chapter by Freeman and Perez and in Perez (1988), products build upon one another and are interconnected in technology systems. Each product cycle develops within a broader family which in turn evolves within an even broader system. In this sense, successive products within a system are equivalent to successive improvements to a product. This means that each 'new' product benefits from the knowledge and experience developed for its predecessors and its producer profits from the already generated externalities. It is clear that the electric can-opener is one of the last minor innovations in a long series of consumer durables made of metal or plastic with an electric motor, which began fifty years back with refrigerators, vacuum cleaners and washing machines. The entrants at the can-opener stage of the system find consumers with 'all-electric' houses, a fully developed range of optional equipment and parts suppliers, managers and workers with all the required skills and ready-made distribution systems. This is certainly not the case for biotechnology today which, as a system, is in its very early stages of development. And the same holds for some of the technology systems presently growing around microelectronics and its applications.

There are, then, two reasons why the notion of life cycles of technology systems is more relevant for development strategies than that of single product cycles. One is that, as mentioned above the knowledge, the skills, the experience and the externalities required for the various products within a system are interrelated and support each other. The other is that the analysis of technologies in terms of systems allows the identification of those families of products and processes which will provide the time for learning and catching up as well as a wide scope for development and growth.

If we go back to the various entry phases of the previous section, we find that the requirements for entry in Phase I, i.e. into new products (but now we add 'within new systems'), are relatively low with regard to experience or managerial ability and capital, which would make them ideal for some developing countries if it were not for the other two factors: the need for high levels of externalities and of scientific and technical knowledge. Assuming that government action could eventually compensate for the lack of locational and infrastructural advantages, let us concentrate on the type of barrier created by scientific and technical knowledge in the context of new technology systems.

In the industrialised countries, truly new technology systems do not necessarily originate in the most powerful, large and experienced firms. They often involve small firms started up by entrepreneurs with advanced university training in specialised areas, such as has been seen in microelectronics and biotechnology, or revolutionary new ideas as those applied by Henry Ford. Much of the knowledge and skills which will later be required for the growth phase of the system and for subsequent products are developed within these firms as they evolve and either grow or are absorbed by large firms or simply disappear.

We are suggesting, then, that 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 discussed in the previous section, the system approaches maturity, and again both the knowledge and the skills tend to become public or are willingly sold at a price.

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. This partly explains the cases of electronic innovations occuring outside the main industrialised nations mentioned earlier on. The problem now becomes whether the endogenous generation of knowledge and skills will be sufficient to remain in business as the system evolves. And this implies not only constant technological effort but also a growing flow of investment. Development is not about individual product successes but about the capacity to establish interrelated technology systems in evolution, which generate synergies for self-sustained growth processes.

If we follow the taxonomy put forward in the chapter by Freeman and Perez, it will be clear that the technology systems discussed here are in turn the elements of a larger whole—a techno-economic paradigm which also evolves in time from an early phase through growth to maturity. The 'life-cycle' of such a techno-economic paradigm is composed of a series of interrelated technology systems. There is no need to discuss this issue here, but it is clear that each new techno-economic paradigm requires, generates and diffuses new types of knowledge, skills and experience and provides a favourable environment for easy entry into more and more products within these systems. In this view, the present transition period identified with a change in techno-economic paradigm will affect the whole range of technology systems which evolved and matured under the previous paradigm. Most of them will be profoundly transformed as the new information-intensive, flexible, systemic, microelectronics-based paradigm propagates across the productive system. Mature industries reconvert, mature products are redesigned, new products and industries appear and grow, giving rise to new technology systems based on other sorts of relevant knowledge and requiring and generating new skills and new locational and infrastructural advantages.

This implies, however, that firms and countries that had accumulated great advantages in the now superseded technology systems face increasing costs in getting rid of the experience and the externalities of the 'wrong' sort and in acquiring the new ones. Newcomers that, for whatever reason, possess the new relevant knowledge and skills are lighter and faster. That is why these periods of paradigm change have historically allowed some countries to catch up and even surpass the previous leaders.

What this means for lagging countries is that during periods of paradigm transitions there are two sorts of favourable conditions for catching up. First of all, there is time for learning while everybody else is doing so. Secondly, given a reasonable level of productive capacity and locational advantages and a sufficient endowment of qualified human resources in the new technologies, a temporary window of opportunity is open, with low thresholds of entry where it matters most.

Of course, any developing country that can truly take advantage of this sort of opportunity has probably reached that position through decades of efforts at entering mature technologies and probably with some successes. But breaking the vicious circle requires growing systems and synergies. Mature technologies are by definition the less dynamic ones. Fast growth is based on interrelated technological dynamism, on the capacity to make successive improvements across a wide range of technologies and to generate externalities for an even wider range of related activities. It is such processes that result in lowering the cost of entry (and of operation) for other firms. So early entry into *new* technology *systems* is the crucial ingredient for the process of catching up.

The potential for technological catching up remains, however, subject to many of the various threshold levels and the entry cost components mentioned earlier on. Locational and infrastructural advantages do not fall from heaven, nor does a particular country's endowment in scientific and technical personnel and skills. They result from the previous history of development, plus natural resources, and social, cultural and political factors. And, depending on the nature of the new paradigm, these can be excellent, very good, bad or hopelessly inadequate in any particular country. Furthermore, taking advantage of new opportunities and favourable conditions requires the capacity to recognise them, the competence and imagination to design an adequate strategy, and the social conditions and political will to carry it through.

The real chances of advance for any particular country may be very large or very small depending on all the factors mentioned, but they will also be affected by the ultimate shape taken by the socio-institutional framework at the international level. Our main point is that the present period has been and continues to be particularly favourable for attempting a leap in development of whatever size is possible. And this demands a complete reassessment of each country's conditions in the light of the new opportunities.

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