# 5

# Interfirm and international differences in technology: A theoretical interpretation and some tests

## 5.1 Introduction: innovation, imitation and diversity

We now have most of the necessary ingredients for the explanation of some of the 'stylised facts' identified in Chapter 3, related to the international distribution of innovative activities and their evolution through time. A first implication is the general existence of *asymmetries*[1] between firms and between countries in technological capabilities, technical coefficients and product performance. In other words, there exist unequivocal differences in product and process technologies, which can be ranked as 'better' or 'worse' independent of any knowledge of relative prices. This property stems from the very nature of technology, organised around technological paradigms and trajectories, and characterised by varying degrees of opportunity, cumulativeness, appropriability, local learning, and (in general) high levels of irreversibility in the pattern of technological advance.

This point can hardly be overstressed. It implies a *theory of production* that is an alternative to the familiar theory based on production possibility sets.[2] In the latter, 'free-good' technologies and uniformity between firms are core hypotheses. Conversely, here, the fundamental hypotheses are firm- *and* technology-specific forms of knowledge and widespread differences between firms. As already mentioned at the end of Section 4.1 in the previous chapter, the theory of technology and production implied by traditional, general equilibrium analysis, now becomes a particular case of our approach, when technical change is non-existent and the industrial world collapses into 'entropy' and uniformity.

A more realistic representation of the world includes the coexistence





of 'better' and 'worse' firms, characterised by different technological and economic performances, compared to the technological frontier. Thus, in representing the technological structure of production of an industry at any one time in an $n$-dimensional space defined by $n$ inputs, one would find a discrete set of points more or less ordered along a ray departing from the origin. The nature of the technological paradigms defines the $n$ inputs and the direction of the ray (the 'trajectory'). The distance between the outer points and the one nearest to the origin defines the technological gaps between firms (that is, the *degree of technological asymmetry* of the industry). From a dynamic point of view, *innovation* and *diffusion* processes are the core mechanisms of change. To be more specific, all innovations, whether related to products or processes, represent an *asymmetry-creating* mechanism which, *ceteris paribus*, increases the technological and performance gaps between firms, and – as we will discuss in the next chapter – between countries. Conversely, diffusion processes can be regarded as *mechanisms of convergence*.

In this evolutionary world, one may of course still draw *ex-post* gradients departing from the points representing best-practice techniques, and call these 'production possibility sets'. However, such a procedure is more likely to obscure the difference between two fundamentally different theories of production: namely the neo-classical based on the idea of substitutability between inputs and the concept of technology as a set of 'blueprints', and the one put forward here, based on irreversibility, a limited number of techniques corresponding to the technological frontier, cumulativeness of technological advances, and changes in techniques as the result of processes of innovation, imitation and diffusion.

Along a relatively well-established technological trajectory, the evolution of an industry can then be described by two dynamic features. First, the changing balance between innovative and imitative efforts in relation to the 'set of basic design parameters, which guides and constrains engineers and innovators in the design of a range of products and their related processes of production', shared 'by all firms in a given technological area'.[3] Second, the competition between specific design configurations, which in Metcalfe's words 'relate to specific products and processes and is to be identified and mapped in terms of the performance characteristics, input coefficients and product attributes which embody a particular constellation of the basic design parameters'.[4] The development of what we called here technological trajectories is then again in Metcalfe's words 'determined over time by three interdependent processes: the selection process, the diffusion process and the inducement process'.[5] In other words, the evolutionary pattern of any one industry will be characterised by both mechanisms of 'Darwinian' selection and 'Lamarkian' learning/adaptation/imitation,[6] intertwined with major discontinuities in the technologies generally associated with the emergence of new technological paradigms.

## 5.2 Product innovations: innovation, competition, diffusion

Let us first consider an industry where technical change only takes the form of product improvements. For simplicity, suppose that this industry produces a set of products which can be unequivocally ranked by their performance characteristics. In Figure 5.1, it is assumed that the performance features of the product, weighted by the cost of production, can be represented synthetically by the index $\theta$. Thus, technical progress is assumed to be entirely represented by the increase in the $\theta$ index. Conversely, the $x$-axis represents an indexing of the firms in the industry, weighted by their share in production, $\mu$. Suppose that at time $t = 0$ the broken line $AA'$ represents the distribution of firms according to their technological performance (measured by $\theta$). The *degree of asymmetry*, which is an inverse measure of the diffusion in production of best-practice products, will then be related to the slope of the $AA'$ line. For simplicity, we will also assume that the $\theta$ index is not only cost-weighted, but that the products of different 'technological vintages' are in a loose sense homogeneous, in such a way that the structure of demand becomes irrelevant: 'backward' producers, if they want to sell, will have to charge prices corresponding to lower profits.

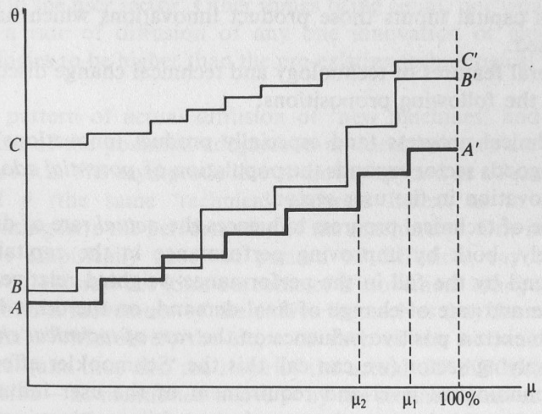
In this stylised representation, firms will continue to innovate and/or imitate in 'best-practice' products. The lines $BB'$ and $CC'$ represent two possible developments over time. $BB'$ shows a trend towards *increasing asymmetry* while the $CC'$ line points towards a *tendency to convergence*. What determines these possible alternative trends? Part of the answer stems from some of the features of technology discussed above:

1. The higher the cumulativeness of technical progress, the higher the probability that the best-practice firms will maintain/increase their lead. Similar considerations apply to the degrees of appropriability of innovations.
2. Conversely, the easier it is to 'watch and learn', do reverse engineering, etc., the greater, other things being equal, the degree of diffusion (cf., for example, the $CC'$ line).
3. The issue of cumulativeness relates clearly to that of *capabilities*: each agent's *present* technological performance is one of the determining factors of its *future* performance.



Moreover:

4. The diffusion of any one vintage of innovations may well never reach 100 per cent, at any one point in time, being superseded by 'better vintages'.
5. More generally, one of the determinants of the degree of asymmetry (which, to repeat, is an inverse measure of the degree of diffusion) is the rate of technical progress. The higher the technological opportunity, other things being equal, the higher the degree of asymmetry.
6. In addition to technological cumulativeness, other factors which are asymmetry-inducing are economies of scale in production/research/marketing; various forms of 'externalities' (for example, a special user–producer relationship enjoyed by virtue of location); and the availability/absence of particular skills, services, etc.
7. The degree of asymmetry is directly linked with *entry* and *mobility barriers* within each industry. Interfirm differences in technological capabilities (among existing producers and between producers and potential entrants) act as structural barriers to intra- and interindustrial mobility. An implication[7] is that, other things being equal, the *level* of profit margins (for the leaders as well as for the industry)




Notes:
$\theta$ = index of cost-weighted performance of output.
$\mu$ = firm's index in relation to output shares.

**Figure 5.1** Technological asymmetries, innovation and diffusion and the variance in the margins will be a positive function of the degree of technological asymmetry of the industry.

8. From a behavioural point of view, the existence of technological asymmetries will at the same time act as an entry barrier and as an incentive to innovate – by virtue of the differential profits and market-shares that technological upgrading generally yields. Which one of the two effects will prevail, depends again on the nature of the technology (cumulativeness, appropriability, opportunity, etc.) compared with the technological capabilities of 'backward' producers and potential entrants.

To summarise, both the pattern of diffusion in production and the long-term rate of technological change are a function of the interaction between some of the intrinsic features of each technological paradigm and the endogenously generated set of stimuli/constraints which the moving sequence of leads/lags poses to each firm.

## 5.3 Innovation and diffusion of capital-embodied innovations

Let us now consider the opposite case of a 'user industry' (in the terminology of Section 4.2, a 'supplier-dominated' industry) that utilises, for example, as capital inputs those product innovations which have just been analysed.

The general features of technology and technical change discussed so far suggest the following propositions:

1. All technical progress (and especially product innovations) in the capital goods sector expands the population of *potential adopters* of the innovation in the user sector.
2. The rate of technical progress influences the *actual* rate of diffusion positively, both by improving performance in the capital goods sector and by the fall in the performance-weighted relative price.
3. The size and rate of change of final demand, on the other hand, is likely to exert a positive influence on the *rate of technical change* in the supplying sector (we can call this the 'Schmookler effect').[8]
4. The technological level and requirement of the user industry (its degree of sophistication, the complexity of its products, etc.) will generally exert an 'inducement effect' on the technological level of the supplying industries (see the discussion in Section 4.3).
5. The existence of technological bottlenecks, unsolved technical and organisational 'puzzles' in the user industry, represents, as



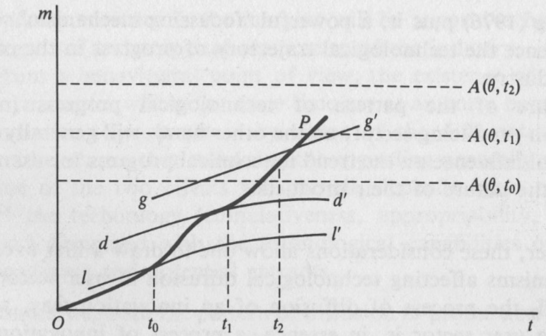
Rosenberg (1976) puts it, a powerful 'focussing mechanism' which will influence the technological trajectory of progress in the capital goods industry.

6. The nature of the pattern of technological progress in the innovation-producing sector, on the other hand, will generally exert a powerful influence on the trend in technical progress for users and even on the nature of their products.

Taken together, these considerations allow one to draw a first overview of the mechanisms affecting technological diffusion in user sectors.

First of all, the process of diffusion of an innovation (say, a new machine) in a user sector is, in essence, a process of innovation and technological change for the user itself. In other words, far from being simply a decision of buy-and-use, diffusion will involve a process of *learning, modification of the existing organisation of production* and, often, even a *modification of products.* An important consequence is that the process of adoption of innovations is also affected by the technological capabilities, production strategies, expectations, and forms of productive organisation of the users. One can find here the first reason why the empirical evidence shows relatively slow diffusion patterns over time: quite apart from any kind of 'non-optimising behaviour' or 'information failure' – as sometimes suggested by the literature – the 'pecking order' in the adoption process is influenced by the technological asymmetries in the user sector. Other things being equal, one would therefore expect a rate of diffusion of any one innovation or cluster of new technologies to be higher than the pre-existing technological levels of the users.[9]

The pattern of actual diffusion of 'new machines' and the change over time of the potential adopters in an ideal industry are represented in Figure 5.2. The asymptotic line *A* moves upward as a function of time and of $\theta$ (the same 'technical progress index' as in Figure 5.1, representing here the performance of the machinery). One implication is that the empirically observed pattern of diffusion, say the line *OP* (Figure 5.2) is now the joint outcome of a movement *along* the diffusion curves and a movement *of* the curves themselves (say from *ll'* to *dd'*, *gg'*, etc.).[10] Moreover, the *slope* of each of the notional curves *ll'*, *dd'*, etc. (and thus also the slope of the actual *OP* diffusion curve) will be affected – as mentioned above – by the technological capabilities of the adopters. Even if we assume that the new technology would be *ideally* profitable for all of them, the pattern of asymmetry in their technological capabilities, the degree of uncertainty associated with the new technologies and the particular search strategies of each firm will influence their pace of adoption (Silverberg, Dosi and Orsenigo (1988)).



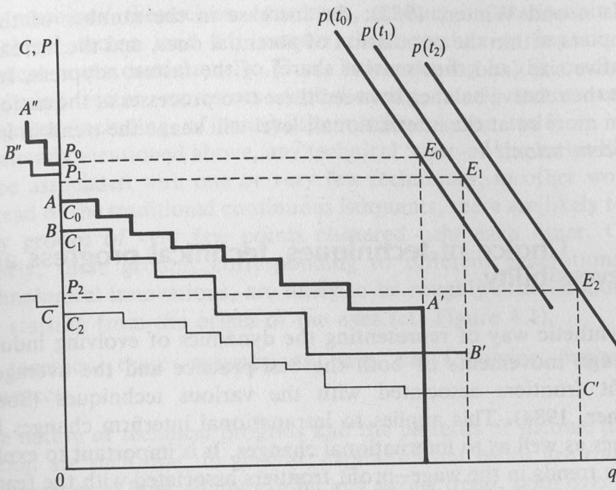

Notes:
$t$ = time.
$m$ = number of adopters.
$A$ = number of potential adopters.
$\theta$ = index of technological performance of the innovations (see Figure 5.1).

**Figure 5.2** Patterns of diffusion of new technologies in a 'supplier dominated' sector: an illustration

In other words, it may well be that the adoption of any one innovation is economical for a certain population of potential adopters and that all of them *know* about its existence and its main features. However, most of these potential adopters may well not utilise the innovation for the simple reason that they do not have the technological/organisational capabilities for doing so. To put it simply, they do not adopt because they do not know *how* to.

In turn, the pattern of diffusion shapes the performance of each firm in the sector. Figure 5.3 illustrates such a case. The pattern of adoption of the new technologies determines the pattern of asymmetry in the industry concerned, as expressed here by production cost differentials. Through time, the rate of *best-practice* technical change (as expressed by the movement down from $A'$ to $B'$, $C'$, etc., in Figure 5.3) jointly with the *pattern of diffusion* of new technologies (reflected in the slope of the lines $AA'$, $BB'$, $CC'$, etc.) determines the moving sequence of asymmetries in the performance of firms. Some of the formal aspects of this process are discussed elsewhere (Soete and Turner, 1984). Suffice it to suggest here a few implications of this approach. First, it is interesting to observe how interfirm (and, by extension, international) asymmetries play a double role. *Asymmetries* in *capabilities* provide an explanation for the differentiated pattern of diffusion. Correspondingly, *asymmetries* in the *degrees* of *diffusion* determine differentiated perform-






Notes:
$C$ = cost of production
$p$ = price
$q$ = quantity
$\mu$ = production share of each firm (= 1, ..., $n$)

**Figure 5.3** Diffusion of process innovations and technological asymmetries

ances (as shown by the slope of the $AA'$, $BB'$, $CC'$ lines, in Figure 5.3). Second, by extending the analysis to would-be entrants, it is easy to see how the pattern of asymmetry in the adoption of new technologies provides the structural foundation for both *entry* and *mobility barriers*, and thus the structural ground for an explanation of the variance in profitability between firms (compare, for example, in Figure 5.3 the gross profit margin of the 'leader', at $t = 0$, equal to the segment $E_0A'$, with that of the inframarginal firm, equal to the segment $P_0C_0$). A corollary to this is that, once given any pricing rule, the higher the asymmetry in diffusion (i.e. the higher the slope of the lines $A''AA'$, $B''BB'$, etc.), the steeper the 'profitability gap' between leaders and followers. Conversely, the neo-classical conditions of 'pure competition' and identity between firms can be considered only when technical progress tends to stop and diffusion reaches its asymptotic limit.

Finally, these evolutionary patterns of change bring to the forefront two endogenously determined mechanisms of diffusion (cf. Iwai, 1981;

Nelson and Winter, 1982): the increase in the number of the actual adopters within the population of potential ones, and the increase in the relative size (and thus market share) of the fastest adopters. It is clear that the relative balance between these two processes at the national, and even more so at the international, level will shape the trend in industrial *concentration*.[11]

## 5.4 Choice of techniques, technical progress and irreversibility

A synthetic way of representing the dynamics of evolving industries is through movements of both the best-practice and the average wage-profit frontiers associated with the various techniques (Soete and Turner, 1984). This applies to intranational interfirm changes in techniques as well as to international changes. It is important to explore the likely trends in the wage–profit frontiers associated with the features of innovation/diffusion discussed so far. Let us recall the following properties of a model characterised by reproducible capital goods and non-decreasing returns in production:[12]

1. The choice of techniques is not influenced by variations in the wage rate as long as the rate of profit does not change.
2. Conversely, *international* differences in wage rates do not influence the choice of techniques, if every country is characterised by an identical rate of profit and has access to the same techniques.[13]
3. Even when the relationship between wages and profits matters, the latter influence the choice of techniques only in so far as they influence the relative price of machines. In other words, it is the ratio between the price of labour and the price of machines which is the relevant one.[14] As regards the price of machines, one may reasonably assume an approximately unique international price.

In addition to these theoretical properties, let us also make explicit the following hypotheses, consistent with some of the 'stylised facts' about technical change summarised in Chapter 3:

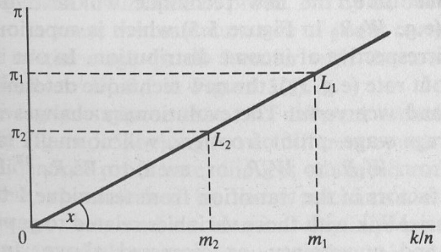
4. From an empirical point of view, international differences in the profit rates appear in any case to be more limited than international differences in wage rates.
5. One of the fundamental characteristics of the technological trajectories of progress is the trend towards mechanisation/automation of production and the substitution of 'machines' for labour.
6. The same process occurs both in the use and the manufacture of the 'machines' themselves. Moreover, product innovations in the 'machine' sector tend to increase their productive capacity in physical terms continuously. Thus, labour-saving in the machine-producing sector represents capital-saving in all sectors using machines (including, of course, the machine sector itself).
7. As already mentioned above, any technical 'state-of-the-art' is likely to be associated with one or very few techniques; in other words, instead of the traditional continuous isoquants, there are likely to be only groups of very few points clustered near each other. Conversely, these groups, corresponding to different generations of technological innovations, are likely to be roughly ordered along a ray starting from the origin of the axes (cf. Figure 4.1).



Taken together, these assumptions have the following important consequences:

1. The nature of technical progress and the patterns of income distribution are such that, in general, capital/output ratios are *roughly* constant, or at least do not exhibit any strong trend, both over time and across countries.[15]
2. Technical progress generally brings about techniques showing *superior* wage–profit frontiers, irrespective of relative prices.

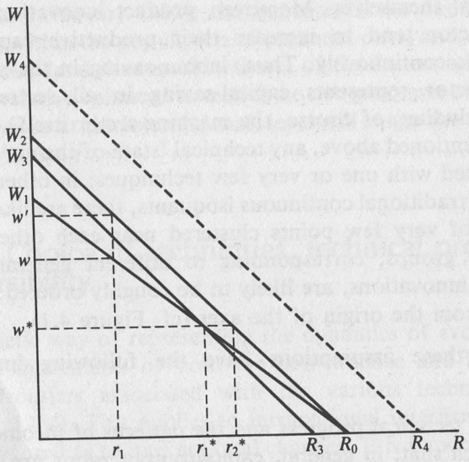
These properties are illustrated in Figures 5.4 and 5.5. Harrod neutrality of technical progress implies that increasing mechanisation of production (as expressed by increasing capital/labour ratios, in Figure 5.4) corresponds to proportional increases in labour productivity, with constant




Notes:

$\pi$ = labour productivity
$k$ = capital
$n$ = employment

**Figure 5.4** Labour productivity and mechanisation/automation of production




Notes:
$W$ = wage
$R$ = rate of profit

**Figure 5.5** Technical progress and wage–profit frontiers

capital/output ratios. Moreover, 'new' techniques are unequivocally superior to 'old' ones.[16] Suppose technical progress leads to a new (more mechanised) technique ($m_1 > m_2$) yielding a higher labour productivity ($\pi_1 > \pi_2$); at the same time, the new technique will also define a wage–profit frontier (e.g. $W_2R_0$ in Figure 5.5) which is superior to the old one (e.g. $W_1R_0$), irrespective of income distribution. In our illustration, for any given profit rate (e.g. $r_1$), the new technique determines the wage rate ($w' > w$), and *vice versa*. The evolutionary changes in both best-practice and average wage–profit frontiers, will normally take the form of a transition from $W_1R_0$ to $W_2R_0$ or, even, to $W_4R_4$.[17] In such cases, the retardation factors in the transition from technique 1 to technique 2 will have a crucial link with those variables related to capability, learning, knowledge and uncertainty, as discussed above. In other words, even if the new technique is *economically* superior it may well be that firms do not know how to master it, exploit it efficiently or do not have the necessary skills to run it and/or provide maintenance. In our view, this also lies behind the widespread existence of technology gaps in production processes among OECD countries and, even more so, among all industrialising countries.



Obviously, one cannot, *a priori*, rule out cases such as those depicted by technique $W_3R_3$ (Figure 5.5), whereby the new technique is 'superior' only for high wages. We would maintain, though, that, even when this occurs, processes of innovation in capital-goods production, learning-by-doing and changes in relative prices will tend to push the *WR*-line outwards, thus making 'irreversible' the transition to the new technology.

Consider now this same process of technical change from the point of view of intersectoral technology flows. Suppose there are two sectors, one producing a final good and the second producing machines – for itself and for the consumption sector. Suppose also that a change in relative prices induces a demand for 'new' machines so as to save labour. Recalling Figure 4.1, imagine that product innovations in the machine sector yield new techniques for the consumption sector represented by a point somewhere between $E$ and $F$. In other words, technical progress is labour-saving and capital-using in the Harrod sense. However, if the new machines are also adopted in the machine-producing sector, this will reduce the unit price of machines, thus reducing correspondingly the capital/output ratio in the machine-using sector.

Whenever the rates of technical progress in the two sectors do differ, because the rate of product and process innovation in the input-producing sectors is higher, as for instance in the case of microelectronics, our hypothesis on the univocal superiority of new techniques will apply even more strongly. In this case, technical progress is such that labour productivity will increase, while the capital/output ratios may even fall.[18] The wage–profit frontier of the new techniques is no longer determined by a clockwise rotation of the old one around an unchanged maximum rate of profit, but by an outward movement which may also increase the maximum rate of profit corresponding to the intersection of the wage–profit frontier with the *x*-axis (e.g. a movement from $W_1R_0$ to $W_4R_4$, in Figure 5.5).

Conversely, suppose that two different techniques (say, $W_1R_0$ and $W_2R_0$ in Figure 5.5) belong to two different countries. At any given time, for an identical profit rate, the less advanced country has an 'inferior' technique, characterised by lower mechanisation, lower productivity, lower wage rates and an identical capital/output ratio. The 'stylised facts' discussed above tend to suggest that this might well be the *general case*.

The process of development and catching-up acquires, in this framework, an unequivocal meaning: it is the process of diffusion of strictly superior techniques. At the same time, though, the less advanced country may well find a competitive advantage in the commodity to which the two techniques refer, whenever wage rate differentials more than compensate for the absolute technological advantage of the more advanced country.[19]

This argument on the irreversibility of technical change and the unequivocal inferiority/superiority of techniques, it should be stressed again, does not imply any irrelevance of relative prices.

First, changes in relative prices might be important focussing and triggering mechanisms which stimulate innovation (see Section 4.1). Second, even when a new technique is unequivocally superior to another one, the *differential* profitability of adopting it (and thus the incentive to do so) will still bear a relationship with income distribution and relative prices under conditions of 'bounded rationality'. Take, for example, techniques $W_2R_0$ and $W_1R_0$ in Figure 5.5. Other things being equal, the profitability gain of adopting the better one is proportionally much greater for a country which happens to have a wage rate, say at $w$, than for a country with a wage rate at $w^*$. We shall return to this point when we try to explain the different patterns of technological accumulation in the different OECD countries.

## 5.5 Evolutionary patterns of industrial change

The two stylised models of innovation and diffusion of 'products' and 'processes' discussed so far are obviously extreme 'ideal types': as shown earlier, one observes in reality different combinations of product and process innovations, different balances between embodied and disembodied technical progress, different weights of internally generated innovations as opposed to innovations acquired from other industries and/or firms, etc.

However, all processes of innovation *and* diffusion are *search processes*: linked to the opportunities of technological advance – whether generated endogenously within the firm, opened up by advances in pure science achieved in non-profit institutions, or generated in other industrial sectors – driven by the perspective of (partial) appropriation of the economic benefits, and based on the specific (and differentiated) technical and organisational capabilities of each firm.

However, there are important specificities of the innovation/diffusion processes, which stem from the following:

(a) the knowledge base on which technical advances can draw;
(b) the nature of the technology and the techno-economic dimensions of progress;
(c) the intersectoral distribution of both technological opportunities and search capabilities;



(d) the sources, means, and degrees of appropriability;
(e) the nature of the interactions between users and producers of innovations (whenever they are different economic agents) and the characteristics of the product markets.

Clearly, the evolutionary world described here is characterised by continuous disequilibrium, in a static allocative sense. A wide range of more and less efficient methods of production continuously coexist within each industry (within each national industry and even more so within world industry). Even in a hypothetically closed but evolving economy:

> ... not only the fittest but also the second, third, fourth ... indeed a whole range of less fit will survive in the long run. The forces of economic selection working through the differential growth rates among firms with different unit costs is constantly outwitted by the firms' imitation activities and intermittently disrupted by the firms' innovation activities.[20]

Only under particular circumstances, will

> the processes of growth, imitation and innovation interact with each other and work ... to maintain the relative structure of industry's state of technology in a statistically balanced form in the long run.[21]

We must wonder whether there are particular *paths* which any one particular industry will follow. That is, whether there are 'evolutionary equilibria', whereby the balance between innovative mechanisms and diffusion mechanisms will keep a relatively ordered pattern of transformation of the industry.[22]

A simple example of such evolutionary equilibria is discussed in Nelson (1985). Suppose there are two firms (or groups of firms): an innovative one and an imitative one. Suppose also that all 'Schumpeterian behaviours' (related to innovation and imitation) are expressed by the R&D efforts of the firms. Following Nelson, $(R/S)_{IN}$ is the ratio of R&D to Sales; $P$ is the price of output; $C_{IN}$ are the total costs for the innovator(s); $\Delta A/A$ is the total cost-saving stemming from innovative activities; $L$ is the time lag after which the imitator can learn from the innovator's advances, with an R&D cost which is a fraction ($\lambda$) of the original innovator's cost. In addition to Nelson, let us add the possibility of differential profits of the innovator ($\psi$), which we assume to be linear to the degree of asymmetry (i.e. the gap in technological capabilities) between the two groups of firms. Then an 'evolutionary equilibrium' will be defined by the condition:

$$\psi\left[\left(\frac{R}{S}\right)_{IN} \cdot P + C_{IN}\right] = \lambda\left(\frac{R}{S}\right)_{IN} \cdot P + \left(1 + \frac{\Delta A}{A} \cdot L\right) C_{IN} \qquad (5.1)$$

This condition states, for example, that an industry will not be in 'evolutionary equilibrium' if the reward of imitation is in excess of that of innovation, when compounded by the maximum differential profitability that the innovator can enjoy due to the differential capabilities it embodies, etc. One can find a straightforward link with the features of technology discussed earlier on: the values of the parameters $\lambda$ and $L$ (the relative cost of imitation and the lag of the imitator, respectively) are functions of the degrees of appropriability and cumulativeness of technological advances; $(R/S)$ and $(\Delta A/A)$ can be taken to measure the technological opportunities and the degrees to which they are exploited via formalised R&D.[23] In the long term, innovative and imitative processes also change the values of the parameters, and with that also the technology gaps between leaders and followers (that is, the degree of asymmetry implied by each 'evolutionary equilibrium'), the opportunities of advance and the degrees to which they are exploited by the economic agents. Admittedly, in the interpretation of trade patterns presented here and despite our emphasis on oligopolistic forms of market organisation and widespread product differentiation, we almost entirely neglect any explicit account of purposeful '*strategic*' interactions among different firms on the world market. Our analysis is, however, quite complementary to investigations such as Cantwell's (1989) focussing on the dynamic links between firm-specific characteristics of multinational enterprises, national/regional context conditions and technological learning. In any case, the perspective of this book rests on the conjecture that, *in a first approximation*, diverse national constraints and opportunities shape technological and economic performances of firms irrespective of any detailed reconstruction of their particular strategic behaviours.

## 5.6 International patterns of evolution

The analysis developed so far finds a direct application not only to the structure and evolution of industries within each country, but also to the differences between countries in technology and economic performance, which were identified among the main 'stylised facts' of Chapter 3.

If technical progress is cumulative not only at the company level, but also at the country level, the relative advantage of one country vis-à-vis others does not stem from any 'original endowment' but from differential technological knowledge, experience, etc., which are reproduced through time. In many ways, these differential advantages will be jointly produced with the production of the commodities themselves. From such a perspective, one can easily point to the possibility of the existence of 'virtuous circles' and 'vicious circles' in the patterns of international technological advantages/disadvantages.



Cumulative processes have a technological dimension (the nature of the technological trajectories), an economic one (the profitability signals which stem from technological asymmetries between firms, sectors and countries, and – as we will see in Chapter 6 – may be re-enforced by the trends in international specialisation), and, finally, a behavioural one (the different search and learning capability, different efficiency and different incentives of firms placed in different positions vis-à-vis the technological frontier and facing different relative profitability patterns).

While the positive feedbacks associated with virtuous circles imply that, other things being equal, 'success breeds success', there is a fundamental way in which 'past success constrains the future'. Past technological success is indeed also embodied in the stock of existing capital equipment, the particular structure of skills and the behavioural commitments of past successful firms to what may have become old technologies.

These factors are likely to become important during the process of substitution of a new technological paradigm to an old (and competing) one. In these circumstances, a leadership in the old paradigm may be (although it is not always) an obstacle to a swift diffusion of the new one, especially owing to the interplay between the constraint posed by the old capital stock to a readjustment of productive activities and the behavioural trends in 'old' companies which may embody differential expertise and enjoy high market shares in 'old' technologies. In some previous work, one of us (Soete 1981b, 1985) has stressed how the change in international technological leadership is generally associated with the transition from one fundamental paradigm to another. This is a convergence mechanism, which might also apply to interfirm diffusion and competition in the domestic context.

More generally, there are a number of factors which tend to induce *convergence* and the *international* diffusion of technology.[24] Among these are the following:

(a) the 'free' international diffusion of codified scientific and technological knowledge (e.g. publications, qualified scientists, engineers and technicians, etc.);
(b) traded transfers of technology (licensing, transfer of know-how, etc.);
(c) processes of technological imitation (e.g. reverse engineering) by late-coming companies and countries (both 'spontaneous' and government-induced processes of imitation);[25]
(d) direct foreign investment in 'late-coming' countries, by companies

which own – among their company-specific advantages – differential technological capabilities;

(e) international trade in capital goods and intermediate components.

In general, there appear to be three factors that encourage international diffusion of both technology and production, namely international differences in variable costs (primarily international differences in wage rates); 'specificity' of local markets (including everything which goes under the heading of 'market imperfections', such as the advantage enjoyed by local manufacturing due to: proximity-to-the-market; forms of government intervention; tariff and non-tariff barriers; transport costs; etc.); and the autonomous efforts in the catching-up countries at technological accumulation (reflected in investments, indigenous R&D efforts, the development of skills, improvements in organisational sophistication and complexity).

It must be stressed that these diffusion mechanisms are highly complementary. As Sahal puts it,

> ... a characteristic feature of technical know-how is its lack of permeability: it is often acquired in bits and pieces, and is fractioned to a far greater extent than is commonly believed.
>
> Moreover, advances in technical know-how generally depend on accumulation of *hands-on experience* in the design and production activities. Thus, the relevance of technological learning is often bounded by a particular system of doing. It is context-dependent. Unlike pure scientific knowledge, which is freely available to all, technical know-how is largely product and plant specific ... . Technology transfer can never be a total substitute for independent R&D activity ... the development and transfer of technology ought to be regarded as a part and parcel of the innovative activity from the very beginning.[26]

A synthetic way of summarising the forces of innovation and diffusion in the international context consists of rewriting equation (5.1) so as to take into account explicitly the international differences in wage rates (call these proportional differences $\omega$). Moreover, for simplicity, call the R&D intensity of the industry,

$$N = \left(\frac{R}{S}\right)_{IN} \cdot P$$

Thus:

$$\omega \cdot g = \frac{(\psi - \lambda)N + \psi C_{IN}}{C_{IN}} \tag{5.2}$$

The technology gap of the imitative companies (country) is $g = (1 + \Delta A/A \cdot L)$, while their cost (i.e. wage) advantage, at current exchange rates, is expressed by $\omega$.



Equation (5.2) implies a relationship between technology and wage gaps as illustrated in Figure 5.6. The interpretation is straightforward: at the international level, an 'evolutionary equilibrium' will exist whenever the differential cost of innovating first (as opposed to imitating) and the differential profits allowed by the differential technological capabilities (summarised by $\psi - \lambda$) just corresponds to the technology gap vis-à-vis the imitators, discounted by the cost (= wage) advantage of the latter.

Suppose we start from the 'evolutionary equilibrium' defined by the pair ($\omega_1$, $g_1$). All improvements in the technological capabilities of the imitative company (country) will decrease the actual gap. Suppose also that the wage gap shrinks. The company will then follow, say, the trajectory $t_1$. On the other hand, the direction and speed of the shift in the locus of the evolutionary equilibrium (say to $g''g''$ or to $g'g'$) will depend on the evolution of the conditions of appropriability (expressed by $\lambda$) and of the technological opportunities (which link $N$ and $\Delta A/A$).

It can be easily seen that the evolution over time of the *relative competitiveness* between the two groups of companies (i.e., in an extreme simplification, the two countries) depends on the pace of change of the technological capabilities and the wage conditions relative to the pace of change of the structural parameters defining the conditions of opportunity and appropriability of the technology. For example, every loss in opportunity makes any given 'lead' more expensive to achieve, and thus

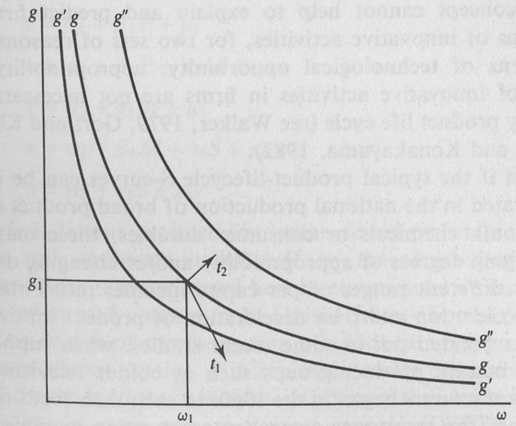



**Figure 5.6** Technology gaps and wage gaps in 'evolutionary equilibria'

shifts the locus of evolutionary equilibria to the top right (say to $g''g''$): being an imitator 'costs less' in terms of wage gaps. Conversely, any increase in appropriability makes imitation more difficult and thus shifts the $gg$ line to the bottom left, say to $g'g'$. Finally, the higher the differential profitability that the innovator tries to achieve (as expressed by $\psi$), the easier it is for the imitator to carve a niche in the international market.[27]

In general, in this interpretation the international patterns and dynamics of competitive advantages/disadvantages entail underlying microeconomic processes of innovation/imitation/diffusion which, in turn, are shaped by the characteristics (e.g. opportunity, appropriability, knowledge base, etc.) of each technology and by country-specific variables (wage rates, market features, public policies affecting technological capabilities and market signals, etc.).

## 5.7 What is left of product cycles?

From this perspective, one can also see that product-cycle accounts of the evolution of technological and productive advantages over time are only a *particular case* of a wide range of possible patterns.

The product cycle, as proposed by Vernon (1966), and later elaborated by Abernathy and Utterback (1975), implicitly assumes that processes of technological accumulation over time are the same for all product groups. In its appealing simplicity, it is not surprising that the product-cycle concept cannot help to explain and predict firm and country patterns of innovative activities, for two sets of reasons.

First, patterns of technological opportunity, appropriability, and accumulation of innovative activities in firms are not necessarily the same over every product life cycle (see Walker, 1979, Gort and Klepper, 1982 and Gort and Konakayama, 1982).

Second, even if the typical product-lifecycle S-curves can be empirically demonstrated in the national production of broad product classes such as steel, bulk chemicals or consumer durables, these may only reflect the changing degrees of appropriability and/or changing demand elasticities over different ranges of per capita income, rather than the autonomous acceleration and then deceleration of product innovation. Furthermore, as pointed out in some recent studies, when supposedly technologically mature product groups such as colour television and automobile manufacturers began in the 1960s to shift their locus of production to Japan, the result was a marked acceleration in the rate of product and process innovation (Peck and Wilson, 1982; Altshuler *et al.*, 1984).



Conversely, the model presented here can generate quite diverse patterns of international location of innovation and production, according to the nature of the various technologies and the features of technological accumulation. We will now turn to the interpretation of possible regularities in the levels and changes of national technological advantages/disadvantages, either in the form of different production efficiencies or in the form of different capabilities of generating new products.

## 5.8 Innovativeness, capital accumulation, labour productivities: intersectoral and international differences

Sectoral/technological specificities also affect the link between the leads and lags in innovativeness, the degree of capital accumulation, and labour productivity. As is well known, there is a great deal of literature and a highly controversial debate on the 'sources of productivity growth', which we cannot tackle here. Suffice it to present apparent empirical regularities, based on, admittedly crude, indicators and estimates which, however, appear broadly consistent with other more detailed investigations (cf. Fagerberg, 1987; Patel and Soete, 1987).

In Table 5.1 a summary is presented of the results of the econometric estimates obtained through linear and log-linear[28] regression analysis of the form:

$$\pi = \alpha_1 + \beta_1 P + \mu_1 \quad (5.3)$$

$$\pi = \alpha_2 + \beta_2 P + \sigma_2 M + \mu_2 \quad (5.4)$$

$$\pi = \alpha_3 + \sigma_3 M + \mu_3 \quad (5.5)$$

$$\pi = \alpha_4 + \beta_4 M + \tau_4 S + \mu_4 \quad (5.6)$$

$$\pi = \alpha_5 + \tau_5 S + \mu_5 \quad (5.7)$$

where $\pi$ is labour productivity (value added per employee at constant prices and exchange rates), $P$ is the degree of technological innovativeness (approximated here by the cumulative number of patents registered by each country in the United States over the period 1963–77), $M$ is the degree of mechanisation of production (approximated by the investment/labour ratio), $S$ is capital intensity of production (approximated by the investment/output ratio), and the $\mu$s are the error terms. The estimates were run on a cross-country (OECD) basis for some thirty-nine industrial sectors.

The desire to undertake a relatively disaggregated analysis forced one

**Table 5.1** Labour productivities, innovativeness, capital intensities: the significant results

| | Degrees of innovativeness (patents per head) (a) | Degrees of mechanisation (investment/labour ratios) (b) | Capital intensity (investment/output ratios) (c) | Best fit Adj. $R^2 > 0.50$ $F > 5$ (d) |
|---|---|---|---|---|
| 1. Food products | + | + + | | * |
| 2. Textile products | + + | + + | | * |
| 3. Industrial organic chemicals | + | + | – | |
| 4. Inorganic chemicals | + | + | – | |
| 5. Plastic and synthetic resins | + + | + + | | * |
| 6. Agricultural chemicals | | + + | | |
| 7. Soap, detergents, cleaning toilet preparation | + | | | |
| 8. Paint, varnishes, lacquers and allied products | | + + | | |
| 9. Miscellaneous chemicals | + + | + + | – | |
| 10. Drugs | | + | | |
| 11. Rubber and miscellaneous plastic products | + | + + | | * |
| 12. Stone, clay and glass | + + | + + | | * |
| 13. Ferrous metals | | + + | | |
| 14. Non-ferrous metals | + + | + | – | * |
| 15. Fabricated metal products | + + | + + | | * |
| 16. Engines and turbines | + | + + | – – | * |
| 17. Farm and garden machinery and equipment | + + | | + | * |
| 18. Construction, mining, material | + | + | – – | * |
| 19. Metal working machinery | + + | + + | | * |
| 20. Office, computing and accounting machinery | + | + | | * |
| 21. Special industrial machinery | + + | + | | * |
| 22. General industrial machinery | + + | + | – | * |
| 23. Refrigeration and service machinery | + + | + + | | * |
| *24. Miscellaneous (non-electrical machinery)* | + | + | – | * |
| *25. Electrical transmission and distribution equipment* | + + | + + | | * |
| 26. Electrical industrial apparatus | + + | + + | | * |
| 27. Household appliances | + + | | – | |
| 28. Electrical lighting and wiring equipment | + + | | – | |
| 29. Miscellaneous electrical equipment | + + | + + | | |
| 30. Radio and television receiving equipment | + + | + + | | * |
| 31. Electronics components and communication equipment | + + | + + | | * |
| 32. Motor vehicles and parts | + | + + | | * |
| 33. Ships and boats | + + | – | | |
| 34. Railroad equipment | | + + | | |
| 35. Motorcycles, bicycles | | | – – | |
| 36. Miscellaneous transport equipment | | + + | | |
| 37. Missiles, space vehicles | | + + | | |
| 38. Aircraft and parts | | + + | | * |
| 39. Professional and scientific instruments | + + | + + | | * |

Notes:
1. The dependent variable is always labour productivity (i.e. value-added per employee).
2. Column (d) reports all cases (*) whereby the $R^2$, adjusted for the degrees of freedom, is greater than 0.50 and the $F$ statistics are greater than 5 in at least one of the sectoral estimates.
3. The dependent variables have been tested against (a), (b) and (c) in simple regression and against (a) and (b) and, (a) and (c). Relatively high multicollinearity prevented the joint use of (b) and (c).
4. The symbols stand as follows:
One sign (e.g. – or +): the variable is significant at 10% or more in at least one estimate with positive (+) negative (–) sign.
Two signs (e.g. – – or + +): the variable is always significant at 10% or more in all attempted estimates.
Note that nowhere did different estimates yield results with opposite and both significant signs within the same sector. With only 4 exceptions, the cases corresponding to one sign only (– or +) represent a variable which was significant in simple regression estimates and stopped being so with multiple regression analysis.
5. Sector 11 (petroleum and coal products) has been omitted due to the low reliability of productivity data.
6. For the sources of the variable used, cf. Appendix, Chapter 6.

to use 'heroic' proxies for both the capital/output and capital/labour ratios: constrained by the available data we had to use a two-year average in the investment/output and investment/labour ratios. (For more details on the data used, see Appendix to Chapter 6).

These 'heroic' approximations undoubtedly introduce much imprecision into the estimates. However, there is no reason to believe that a bias will have been introduced. The approximations by themselves will in any case not determine the nature of the results.

The analysis is econometrically very simple and does not amount to a comprehensive test of the various causal relationships of the model discussed in the preceding section. We would argue, however, that the results fulfil the weaker requirement of consistency with the theoretical framework proposed above.[29] The degrees of mechanisation and automation of production appear to be powerful factors in determining the levels of labour productivity. Moreover, productivity also appears to be influenced by our approximation of technological innovativeness which might not be directly embodied into physical equipment (if it is, it would also be capital-saving in addition to being labour-saving).

Three 'reasonable' interpretations can be drawn from the results.

First, the country-specific and sector-specific levels of technological innovativeness, which, at least in the short term, are statistically independent of the patterns of capital accumulation,[30] have a significant impact upon productivity levels within each sector. This result illustrates the broad complementarity between disembodied and embodied forms of technological progress and points to the importance of both in explaining international differences in levels of labour productivities. This applies to the majority of industrial sectors, irrespective of their average capital intensity.

Second, both patterns of accumulation and increasing mechanisation of the productive processes appear to be characterised by the absence of any capital-using bias (in the Harrod sense, i.e. in terms of capital/output ratios). In other words, technical progress appears to correspond broadly to an assumption of 'neutrality'. The relationship between labour productivity and the proxy for the capital/output ratio, when significant, always appears to have a negative sign, either when used alone or in conjunction with the innovativeness variable. This result might be interpreted as pointing to some of the higher capital-saving capabilities of the most high-technology countries. The pattern of technical progress is such that higher degrees of automation and higher capital/labour ratios are also likely to be associated with innovations in capital equipment and processes, thus increasing the physical productivity of the equipment and lowering its unit costs. In other words, countries showing the highest labour productivity, which one may expect



to also be the most advanced and the most capital 'endowed' countries, will also be those which show the lower capital intensity (in terms of output).

One could consider this to be the domestic counterpart of the so-called Leontief 'paradox': the most advanced countries are the most efficient not only in the use of labour but also in the use of capital. This result, as Pasinetti (1981) has observed no longer amounts to a 'paradox', as soon as one takes into account the dominant characteristics of *learning and progress* in modern economies. However, the evidence presented in Table 5.1 can also be interpreted as highlighting some of the fundamental features of the appropriation and irreversibility of technological advance, as discussed in the preceding section. With regard to irreversibility, it is obvious that any technique with both a higher labour productivity and a lower capital/output ratio is a 'superior' one. If such a technique is not adopted 'world-wide', this is because the technology is not a free good, but is often privately appropriated within individual economic units (possibly within individual countries) and requires complex processes of learning.

Third, the degree of mechanisation of production appears to be particularly important in some of the 'scale-intensive' and science-based sectors, such as most of the chemical sectors, food, construction materials, radio and TV equipment, and motor vehicles.

Innovativeness, as measured here, captures two phenomena: process innovations and product innovations, appearing in different relative proportions in the different sectors. One may reasonably expect the former to influence labour productivity *directly*. Conversely, new products are likely to show, if anything, a direct impact on market performance, while retaining an indirect or even ambiguous effect upon productivity.[31] Furthermore, on the grounds of the sectoral taxonomy set out above, one may expect a differentiated impact of technical change on productivity depending on the nature of innovations (product vs. process), but also on the sectors of origin and use. More specifically, and as illustrated in the results reported in Table 5.1, the technology variable is likely to perform well in those sectors where it can be expected to take the form mainly of process innovations, either generated within the sector or purchased from other sectors (such as in food products, textiles, stone, clay and glass, non-ferrous metals, etc.). The technology variable, on the other hand, is likely to perform poorly when it takes, essentially, the form of 'pure' product innovations, such as in the drug industry. Finally, within the group of sectors belonging to non-electrical and electrical engineering, innovativeness will have a statistically significant impact, as illustrated in the results, because product innovations and process innovations are overlapping in so far as 'new machines' and 'new components' will also be used within the sectors from which they originated.

These broad results are more or less complementary to other analyses on the relationship between R&D expenditures and productivity. These studies generally point to the positive impact of direct R&D and total R&D (direct plus indirect via input-output flows) upon productivity changes.[32]

With respect to the analysis of trade flows carried out in the following chapter, the results reported here illustrate the determinants of one source of *absolute advantage*, i.e. international productivity differentials, stemming from both 'disembodied' technological progress and capital accumulation. Of course, the dynamics of these lags and leads in production efficiency, together with the others more directly related to product innovations, depend on the rates at which the various domestic companies from any one country learn, innovate, imitate, and, in turn influence the evolution of international competitiveness, by sector and by country. We shall now turn to these issues.

## Notes

1. We discussed this concept at length in Dosi (1984).
2. For a similar argument, see Winter (1982).
3. Metcalfe (1985), p. 7.
4. *Ibid.*, p. 7.
5. *Ibid.*, p. 9.
6. For a thorough formalisation of these processes, cf. Nelson and Winter (1982), Winter (1984), Iwai (1981).
7. For more details see Dosi (1984).
8. Cf. Schmookler (1966).
9. For an illustration of this argument in relation to the diffusion of microelectronics in 'downstream' sectors, cf. Pavitt (1984c), and for a model of this process, Silverberg, Dosi and Orsenigo (1988).
10. On this point see also Metcalfe (1985).
11. The relative balance between these two mechanisms of innovation and diffusion clearly depends also on the nature of technological paradigms, on the degrees of appropriability and cumulativeness of technological advances, etc. For a discussion of the implications of different 'technological regimes', see Winter (1984).
12. Points (1) and (2) which follow are discussed in more detail by Pasinetti (1981).
13. Cf. *ibid.* pages 195–7. Note that by 'identical techniques', one also means the import content associated with each of them and the related terms of trade.
14. This is thoroughly argued by Sylos Labini (1982) and (1983–4).
15. Over the post-War period and with the exception of electronics, there seems to be some evidence of a capital-using bias of the rate of technical change, with the 'real', physical capital/output ratio increasing in most sectors (see Soete and Dosi, 1983, for more details). However, relative prices are likely to move in the opposite direction, since we may expect gross margins to increase in sectors whose 'physical' capital intensity increases. Thus, we would probably find relatively smaller changes in the capital/output ratio at *current* prices, which is the relevant indicator in our discussion here. For some comparative evidence on capital/output ratios, cf. OECD (1983) and (1984). These works show a relatively small variation over the last twenty years, with some increase after 1973 for the United States, United Kingdom, France, Canada and a fall in Germany and Japan. After adjusting for capacity utilisation and accelerated scrapping, however, that increase – it is suggested – is likely to disappear (OECD (1983a), pp. 65–6).



16. For a discussion of all the notional possibilities in the choice and change in techniques, see Schefold (1976) and (1979). For an analysis of the micro and 'macro' measures of technical progress, cf. Soete and Turner (1984) and, for a discussion of the measurements of the possible biases in technical change, cf. Steedman (1985).
17. In this case, technical progress is not only labour-saving, but also strictly capital-saving. The transition to either $W_2R_0$ or $W_4R_4$ is strictly consistent with the 'innovative search rules' discussed earlier on (cf. Section 4.1). Formally, these 'search rules' fulfil the conditions for the Okishio theorem to hold (cf. Okishio, 1961; Bowles, 1981): the new techniques will generally imply a straightforward saving of some inputs without a compensating increase in others, so that, the theorem shows, even after allowing for the appropriate changes in relative prices, the new techniques will be associated with a higher profit rate, once given the wage rate, or vice versa.
18. For more general formalised analyses of technical change, see Pasinetti (1981). See also Le Bas (1982), Spaventa (1970) and Opocher (1986).
19. Identical conclusions can be drawn from Pasinetti's model: see Pasinetti (1981), Chapter IX.
20. Iwai (1981), Part I, p. 26.
21. *Ibid.*, pp. 26–8.
22. This issue is discussed at greater length in Dosi and Orsenigo (1986).
23. For detailed empirical research on the innovative processes in Italy, showing, among other things, that the higher the technological opportunity, the higher is its exploitation through ***formal internalised*** R&D (as opposed to other mechanisms of production of innovation), see Momigliano (1985).
24. More detailed discussions of the convergency/divergence issue, by the authors, can be found in Pavitt (1979) and (1980), Soete (1982) and (1985), Metcalfe and Soete (1984).
25. By 'late-coming' companies/countries here we do not only refer to LDCs, but also to developed countries (and NICs) which happen to lag behind the technological frontier on any particular technological trajectory.
26. Sahal (1982), pp. 138–9.
27. A case of interest is that situation whereby $g$ and $\omega$ are both in the neighbourhood of 1. While in all other circumstances the attribution of competitive advantages to different groups of companies is dominated in the short term by technological conditions (the size of the technological gaps) and macroeconomic conditions (the wage gaps), in this case more

behavioural considerations tend to come in the forefront: that is, even in the short term, all (nearly equal) firms will be able to 'choose' their competitive position, according to their strategic rules in relation to uncertainty, profitability, 'being first' or 'early second', etc. In fact, this particular case tends to be privileged in the economic literature by e.g. game theoretical analyses.

28. The results summarised in Table 5.1 refer to the log-linear estimate which proved to yield a systematically better fit.
29. Thus, we cannot answer on *econometric grounds*, objections of possible simultaneity, etc., between the variables. However, we feel rather confident on the directions of the causal links for theoretical and empirical reasons related to the pattern of technical change. For example, it is clearly absurd to imagine that 1977–8 productivity levels feed back upon the 1963–7 number of patents. Even with regard to a possible relationship running from productivity to degrees of mechanisation or to capital/output ratios, one may think only of rather indirect links via changes in rates of return and relative prices.
30. Note that the multicollinearity between innovativeness and mechanisation is, on average, rather low (the simple average between the correlation coefficients across the thirty-nine sectors is 0.08 while they reach 0.50 in only three sectors).
31. The fact that a positive correlation appears only in a sector characterised by relatively low 'technological opportunity' is also meaningful. As suggested above (Section 4.1), the process of increasing mechanisation of production is likely to tend towards 'static' substitution only when the opportunity of genuine technological advances decreases.
32. See Terleckyj (1974), (1980) and (1982), Griliches and Mairesse (1984), Clark and Griliches (1984), Griliches and Lichtenberg (1984).