Part VI International diffusion of technology and international trade competition

Preface to Part VI

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In this section we bring in more explicitly some of the international implications of our analysis. The question as to the relationship between technical change and the international competitiveness of a country or industry is now a crucial item on any policy agenda: in the context of the international economic debate between industrialized countries as well as in the context of the industrialization (or lack thereof) of the newly industrialising and less developed countries. The five chapters in this section provide only a broad, impressionistic picture of the variety and diversity of questions which arise from the theoretical approach sketched out in the previous sections. The issues addressed here start all from the (by now) strong evidence, both of an empirical and historical nature, that the international patterns of competitiveness of the industrialized as well as less developed countries have been strongly influenced by their relative technological capabilities.

These international differences in technological levels and innovative capabilities are not only a fundamental factor in explaining differences in inter-country trade competitiveness; they are also an essential factor in explaining inter-country differences in macroeconomic growth as emphasized in the chapter by Dosi and Soete. Giving a broad overview of the voluminous literature in this area, Dosi and Soete's chapter illustrates how consideration of the dynamic implications of trade, and in particular of the allocative patterns induced by trade, will lead one to focus far more on the virtuous or vicious macroeconomic feedbacks which international specialisation will imply in the long run.

The point is made much more explicitly in the following chapter by Fagerberg, more empirical in focus, which looks at the 'classic' question of 'why growth rates differ' between countries. As Fagerberg illustrates, from a dynamic perspective the relative international competitiveness of a country has itself a strong influence on the relative rate of growth of its economy. The chapter provides further evidence that in the last three decades following the Second World War, this interactive growth process led within the group of OECD countries to a pattern of convergence: convergence in terms of technological levels, industrial structures, commodity composition of domestic production, per capita incomes, wages, and even forms of corporate organisation. With regard to technical change, the dominant pattern was one of a process of catching up with the American levels, or, put in other words, one where the rates of technological diffusion to other OECD (and non-OECD) countries was significantly higher than the American rates of innovation.

Whether this process of international technology diffusion can also lead to industrialization 'short cuts' within the development context is the general issue addressed in the next two chapters. The first one, by Perez and Soete, brings to the forefront the distinction between the technology 'transfer' or technology using costs and the actual technology assimilation 'entry' costs. The latter will be substantial and for most developing countries prohibitive and will exclude them from effectively 'catching up'. However, the Perez and Soete chapter, in line with the Freeman and Perez chapter in Part II, points to the existence of some temporary 'windows' of opportunity during periods of paradigm transition.

The next chapter by Unger is more pessimistic in tone. The developing world in Unger's view finds itself 'locked in' in a vicious circle of lack of entrepreneurship, increased protectionism in the developed world, a poorly developed capital goods sector, considered to be the main carrier—if not with regard to the origin, then certainly with regard to the effective assimilation—of technical change, and finally the dominant role of multinational enterprises in 'transferring' increasingly 'packaged' technology abroad.

This last issue is the focus of the chapter by Chesnais which discusses in more detail the patterns in foreign investment and international inter-firm technology agreements over the last decades. For Chesnais the reasons for the significant increase in inter-firm licensing agreements has to do with the increase in the scientific base, complexity and diversity of present technological advances. The international 'sourcing' of scientific and technological knowledge has also to be viewed from this perspective. No firm, not even the largest multinational corporation can rely on its own technological and scientific efforts. Chesnais's chapter calls for further integration of the issues of foreign investment and cross-country technology flows in economic growth and trade theory.

As we have already indicated, the chapters in this section certainly do not cover the full spectrum of subjects which could be addressed under an 'international' heading. Particularly with regard to the problems confronting developing countries, the list of subjects could be vastly enlarged. Also the international finance side, in line with the rest of this book, has not been covered. The aim of this section, however, was to provide no more than a selective overview of topics and questions where technical change and economic theory in their international dimension are in need of 'revision'.

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Introduction

In contrast to many other fields of economic theory, international trade theory has traditionally kept the importance of technical change in explaining international trade flows or the international 'competitiveness' of a country or an industry at the centre of much economic debate. This can be explained to a large extent by the almost unique influence of 'classical' thinking in the area of international trade, with many contemporary trade theorists even expressing today, and particularly with regard to the technology assumption, strong doubts as to the actual contribution of 'neo-classical' thinking.

The fact that 'pure' neo-classical trade theory is still so prominent in international trade textbooks and is still held in such esteem by policy-makers (at least until recently) has indeed little to do with the way that 'factor endowments' (pure Heckscher–Ohlin–Samuelson) trade theory explains international trade flows. Its value as a *descriptive* theory—i.e. national differences in endowments of productive factors form the basis for trade—is regarded as very limited.

Like so many other fields of economic analysis, the 'strength' of the pure orthodox theoretical framework lies primarily in the relatively straight-forward normative implications—in terms of the gains from trade for both trading partners, as well as international factor price equalization—which can be built around the model. The fact that in order to do so it has to rely on a set of extreme 'heroic' assumptions is then generally justified in terms of cost–benefit analysis: the insights gained by such a simple but complete trade/welfare picture outstrip by far the disadvantages of more realistic but more complex and less clear analyses.

Such a view requires, however, first that a 'reasonably accurate' explanation is offered for the main interdependencies identified by the theory, and, second, that the distortions and imperfections of the real world lead only to minor or 'short-lived' aberrations with relatively little consequence for the normative or policy conclusions of the theory. In the case of 'orthodox' trade theory and rather uniquely amongst nearly all fields of economic inquiry there has been growing recognition from all sides that both conditions do not hold.

Nowhere is this more clearly illustrated than in the seminal review which Hufbauer (1970) presented nearly twenty years ago on the emerging and growing evidence and support in favour of the so-called 'neo-technology' accounts of international trade flows. In interpreting his neo-technology results, Hufbauer, himself author of one of the most detailed technology 'gap' trade studies on synthetic materials (1966), remained, if anything, rather schizophrenic. His 'neo-technology' results, while powerful in explaining the actual trade flows and admittedly closer to the real world, represented an approach which, in Hufbauer's words, was not 'geared to answering the traditional questions of economic inquiry'. And Hufbauer added with some irony: 'It can as yet offer little to compare with Samuelson's magnificent (if misleading) factor-price equalisation theorem' (Hufbauer, 1970, p. 192).

While Hufbauer's contribution was exceptional in its frankness, it was in no way exceptional in bringing out the dilemma between relevance and consistency with a general and established theoretical framework which has characterized the analysis of technical change in economic theory.

Some authors privilege the first criterion (relevance) and find in the evidence on technological change a powerful challenge pushing toward the search for a radically different theory. As Rosenberg puts it,

> in a world where rapid technological change is taking place we may need an analytical apparatus which focuses in a central way upon the process of technological change itself, rather than treating it simply as an exogenous force which leads to disturbances from equilibrium situations and thereby sets in motion an adjustment process leading to a new equilibrium [Rosenberg, 1970, pp. 69–70]

Conversely, other economists stress as a necessary condition for the theoretical consideration of the phenomena related to technological change precisely their tractability within the traditional model or simply consider the absence of any alternative as a sufficient condition for their neglect. In Bhagwati's words,

> the 'realistic' phenomena . . . such as the development of new technologies in consumption and production involve essentially phenomena of imperfect competition for which, despite Chamberlin and Joan Robinson, we still do not have today any serious theories of general equilibrium . . . Unless therefore we have a new powerful theoretic system . . . we cannot really hope to make a dent in the traditional frame of analysis [Bhagwati, 1970, p. 23]

These two positions illustrate in many ways also two archetypes of scientific strategies, the first focusing on the search for alternative models conforming more to reality and the second pursuing a gradual and progressive incorporation of an increasing number of phenomena into modified forms of neo-classical general equilibrium analysis. It may be useful to use such theoretical benchmarks to review a highly selected literature which presents a high variance in its 'degree of orthodoxy', scope

and realism of the assumptions.[1] We shall in this short review start from what could be called an 'incrementalist' analysis of technology-related phenomena broadly along the lines of the neo-classical approach.

The 'pure' theory: neo-classical extensions and the revisionists

Consider first the neo-classical 'pure' theory of trade in its simplest textbook form. There are generally four fundamental assumptions:

(i) *On technology*. Differences in technologies can be adequately represented by production functions. The latter are assumed to represent the real world, are well behaved, continuous, differentiable, exhibit non-increasing returns to scale, etc. Moreover, they are assumed identical across countries.

(ii) *On behaviours*. Perfect competition prevails throughout. Agents are maximisers under budget constraints.

(iii) *On demand*. Identical tastes across countries and well-behaved utility functions.

(iv) *On adjustment mechanism*. Adjustments are such as to guarantee *ex hypothesi* the clearing of all commodity and factor markets.

These assumptions lead to the following subsidiary assumption: hypotheses (i)–(iv) offer a reasonably accurate description of the prevailing 'state of the world' and the main interdepencies in the international arena, so that any possible distortions or imperfections of the real world lead only to minor or 'short-lived' aberrations with relatively little consequence for the interpretative and normative conclusions of the theory.

In its simplest form, the 'pure' theory of international trade then goes on to prove some of the most 'classic' theorems of economic theory: on relative specialisation determined by relative factor endowments (Heckscher–Ohlin–Samuelson theorem),[2] on factor–price equalisation, and the theorem of comparative statics on the effects of changing prices on factors' returns (Stolpher–Samuelson theorem) and of changing endowments upon commodity outputs (Rybczynski theorem).

We will not consider here the developments and refinements of all four above hypotheses,[3] but will limit our review to some of those contributions which do not entirely subscribe to the derived hypothesis that distortions are short-lived, and have tried therefore to modify some of the assumptions (i)–(iv). Typically, the scientific strategy is to hold the rest as true and work out the implications of the additional (more 'realistic') hypothesis. Assumption (iv) remains, however, *the* core proposition which is generally kept untouched, since the entire model, irrespective of how it is precisely defined, needs a link of some kind between relative scarcities and relative prices.

One way of relaxing the simplest technological assumptions has been by allowing production functions to be different between countries. Jones

(1970) analyses some of the implications: factor price equalisation does not occur any longer, 'differential rates of technical differences between countries come to dominate the determination of comparative advantages' (p. 84), but the Heckscher–Ohlin theorem on specialisation still applies in a modified form. Berglas and Jones (1977) embody in their model a mechanism of learning-by-doing characterised by 'local learning' (Atkinson and Stiglitz, 1969) on the techniques effectively in use. Findlay (1978) develops a steady-state dynamic model including technology transfers between an 'advanced' country and a 'backward' one. Chipman (1970) considers the case of moving production functions whereby technical progress is itself endogenous along Kennedy–von Weizsäcker–Samuelson lines (cf. Kennedy, 1964; von Weizsäcker, 1965; Samuelson, 1965). Purvis (1972) present a model with international technological differences and capital mobility, illustrating that in this case, contrary to the standard model, factor mobility and trade may be complementary. The issue of capital mobility is also considered by Ferguson (1978) and Jones (1980): interestingly, the patterns of trade turn out to be essentially determined by technology gaps and relative labour costs.

Another way of relaxing the standard assumption with regard to the production function is by introducing economies of scale. Since the analysis of the latter must be generally associated with behavioural assumptions different from the pure competitive model,[4] one may consider these two variations on the standard model together.[5] First, as Drèze (1960, 1961) and Ohlin (1933) himself, already fifty years ago, pointed out, economies of scale taken on their own can be an explanatory variable of trade patterns. Second, from a more normative point of view, they may well influence the welfare effects of trade so that a country may even lose from trade, as suggested originally by Graham (1923).

More recently several interesting theoretical developments have been produced in this area (see Dixit and Norman, 1980; Chapter 9). Krugman (1979, 1984a, 1982a) has explored the conditions under which Graham's arguments hold: they depend on the nature of the increasing returns (which are either 'national' or 'international') and the pattern of change in relative prices due to the transition from autarky to trade. Imperfect competition due to increasing returns *may* imply gains from trade for both trading partners (cf. Melvin, 1969, and Krugman, 1979a) but may also imply losses (cf. Kemp, 1969). In the case of 'imperfect competition' a large number of conclusions emerge which may be diametrically in conflict with the standard Heckscher–Ohlin–Samuelson model:[6] for example, factor prices will not be equalised, but, on the contrary, the price of the factor used intensively in the production of the export good may actually be high in each country (cf. Markusen and Melvin, 1980, p. 3). Similarly, factor mobility instead of substituting for trade (trade in factors as opposed to trade in commodities), as in the standard model, will be complementary to trade, with each country achieving an equilibrium where it is well endowed with the factor used intensively in the production of its export

good. As Markusen and Melvin (1980) note: 'In the Heckscher–Ohlin model this is, of course, the basis for trade whereas in the present model it is the result of trade' (p. 3).

In general, as shown by Markusen and Melvin (1984), sufficient conditions for the gains-from-trade theorems to hold are (i) on the behavioural side, marginal pricing, and (ii) on the technological side, the convexity of the production possibility sets.

The analysis of differentiated products, on the other hand, has led to attempts at synthesis between theories of monopolistic competition, intra- and inter-industry trade. Differentiation is supposed to come from a demand for a variety of product characteristics (cf. Barker, 1977; Dixit and Stiglitz, 1977; Krugman, 1979, 1980, 1981) or from different combinations of some fundamental attributes (cf. Lancaster, 1979) embodied in each product. Thus whereas intra-industry trade (see Grubel and Lloyd, 1975) is explained on the grounds of monopolistic competition, the explanation for the inter-industry trade flows will be left to the traditional Heckscher–Ohlin model. These models predict that intra-industry trade will be highest between similar countries in terms of per capita income and patterns of demand (Linder, 1961), whereas inter-industry flows will be more important the greater the difference between countries in terms of their 'endowments'.[7] An alternative (Ricardian) model of intra-industry trade is provided by Petri (1980), where intra-industrial specialisation for any given pattern of demand is determined by relative labour productivities and cost conditions within sector-specific and country-specific structures of production.

Another line of analysis of those market structures different from pure competition has been pioneered by Caves (1971, 1974) in an attempt to link instruments and concepts of industrial organisation (multinational corporations, oligopolistic competition, strategic behaviours) with a general equilibrium trade model. A growing literature on industrial organisation and international trade has emerged since.[8] While some of the results can be formally represented in terms of the traditional model with specific factors,[9] this line of enquiry has more clearly drawn attention to the significance of the link between industrial structures and trade flows (given whatever 'endowments') and to a different adjustment mechanism (international capital mobility in the form of multinational investment rather than intra-national, inter-sectoral mobility). This line of analysis allows therefore, at least in principle, the consideration of *country-specific* variables, both institutional and economic in nature which as such represent absolute advantages/disadvantages and hence also incentives/obstacles to the location of international capital (see Jones, 1980).

Under the broad heading of 'industrial organisation and international trade', one must also mention parts of the vast literature on the origins and effects of multinational corporations. Some of the studies are quite far in spirit and construction from the neo-classical assumptions listed above (e.g. Hymer, 1976): technological differences between companies and countries, country-specific absolute advantages and high degrees of 'imperfection' of markets in general and the market for technology in particular are implicit from the start. These features of the world are indeed the necessary structural conditions for the existence of multinationals. Other interpretative models try to incorporate also some neo-classical elements. This appears to be the case of Dunning's 'eclectic theory' (see Dunning, 1977, 1981a, 1981b; Buckley and Casson, 1976) wereby Heckscher–Ohlin mechanisms of adjustment in prices, quantities, and relative specialisation are considered as *one of* the processes at work, whose relative importance depends on the sectors, the degree of development of the countries, and the nature of the technology. Finally, other interpretations—such as Rugman (1980)—try to reconcile the existence of multinationals, intra-firm trade, etc., with traditional analysis. Rugman recognises the widespread existence of 'imperfections' (and thus the limited validity of assumptions (i) and (ii) above). However, he assumes that companies face and overcome these imperfections by *internalising* the relevant transactions. Therefore multinationals become some kind of 'second-best approximation' to the working of the standard model.

None of these theories has been thoroughly formalised. It is safe to say though that all of them, to different degrees, lead to conclusions at variance with the canonic model: factor prices are not generally equalised, there are oligopolistic rents, trade patterns do not depend only on countries' endowments, the degrees and forms of market 'imperfections' become a determinant on their own of productive locations and trade.

Some models adopt 'Ricardian' hypotheses on technology—with coefficients of production fixed and different between countries—while generally retaining general equilibrium assumptions on prices, determined through a market clearing process. Dornbusch, Fisher and Samuelson (1977) present a two-country Ricardian model with a 'continuum' of commodities and the patterns of specialisation determined by relative wages and relative productivities. Wilson (1980) extends the model to many countries and non-homotetic demand schedules. Jones (1979) considers the conditions under which technical progress may produce 'immiserizing growth' for either of the trade partners.

A simple but illuminating picture of the technology–trade relationship emerges from Krugman's North–South trade model (1979a, 1982). Starting from an innovative North and a non-innovative South, where the North's innovations take the form only of new products produced immediately in the North, but only after a lag in the South, Krugman (1979a) shows how new industries have to emerge constantly in the North in order to maintain its living standards since the new industries decline and disappear sooner or later in the face of low-wage competition from the South. In Krugman's model, this is because the North's wages reflect the rent on the North's monopoly of new technology: 'This monopoly is continually eroded by technological borrowing and must be maintained by constant innovation of new products. Like Alice and the Red Queen, the developed region must keep running to stay in the same place' (Krugman, 1979a, p. 262). In other words, while the North will be able to achieve some 'moving equilibrium' through a large enough rate of innovation, acceleration of technology transfer will narrow the wage differentials between North and South and might even lead to an absolute decline in living standards in the North. The most interesting aspect of Krugman's model is, maybe paradoxically, the set of simplistic and, from a traditional trade point of view, totally 'unrealistic' assumptions behind the model: there are no differences in factor endowments, because there is only one factor of production (labour); and all goods, old and new, are produced with the same cost function, leaving no room for differences in labour productivity. Neither neo-classical nor Ricardian trade explanations are relevant, there is no fixed pattern of trade, but trade is determined by a continuing process of innovation in the North and technology transfer to the South. Yet despite these simplifications, some of the conclusions, which emerge from the model are very appealing, not least because, as Krugman observes: 'The picture of trade seems in some ways more like that of businessmen or economic historians than that of trade theorists' (Krugman, 1979a, p. 265).

It is obviously very difficult to provide a synthetic assessment of these quite heterogeneous streams of literature, characterised as they are by very different directions and degrees of 'revisionism'. Three general conclusions, however, may be drawn.

First, there is probably little disagreement, even among neo-classical trade theorists, about the inadequacy of the 'canonic' factor proportions theory to explain *by itself* international trade flows. As Krugman (1979c) puts it: '. . . casual observation seems to militate against a simple factor proportions theory. The emphasis on factor proportions in international trade is . . . not the result of an empirical judgement' (p. 14).

Second, most of the studies we reviewed implicitly highlight the lack of robustness of the major Heckscher–Ohlin–Samuelson results in terms of both predictions and welfare implications. Relaxation of the least realistic assumptions (i.e. perfect competition, constant returns to scale, factor immobility, immediate and free diffusion of technology, existence of well-behaved production functions) leads, generally speaking, to indeterminate predictions in relation to the direction and volume of trade. Moreover, the factor-price equalisation theorem does not generally follow. In terms of welfare implications, depending on which assumption is relaxed, conclusions on the 'gains from trade' are sometimes in accordance and sometimes at variance with the orthodox model.

Third, and from our perspective of more direct interest, quite interesting results sometimes emerge, *despite* the continuing presence of highly restrictive assumptions. This set of conclusions could prove to be even more important when placed in an alternative theoretical framework: for example, the role of technology gaps, country-specific absolute advantages and different forms of industrial organisation; the importance of economies of scale and various types of learning; the absence of any general tendency towards factor-price equalisation.

It was already mentioned at the beginning of this survey that a core assumption shared by most of the models reviewed so far is a *scarcity* link between factors, commodities and prices, irrespective of the particular hypotheses on technology, forms of competition, etc. In this sense, the contributions reviewed above share all the points of strength and weakness of general equilibrium analysis. The strength, in our view, relates to the capability of handling with a simple and general theoretical device the question of *interdependence* among national and international markets. Not surprisingly, the main question addressed by the standard Heckscher–Ohlin–Samuelson theory and by most of its 'revisionist' developments concerns the *patterns of specialisation* of each country in relation to some country-specific characteristics.

The other side of this coin is that such analyses, undertaken in terms of equilibrium positions, take as given that (i) there are adjustment mechanisms which generally lead to such equilibria, and (ii) that these mechanisms based on price/quantity adjustments—as in the standard Walrasian model—lead to the clearing of all markets. Both points are difficult to accept on either theoretical or empirical grounds. The difficulties in accounting for the adjustment processes in the standard general equilibrium framework when neither the fantastic 'auctioneer' nor a complete set of contingency markets exist (see Hahn, 1984; Leijohnuyfud, 1981) are well known and discussed at greater length in some of the other contributions to this volume. There is, however, no reason to believe that such adjustment processes are any easier in the open economy case.

On more empirical grounds, it is difficult to believe that relative prices are explained by relative scarcities in a world generally characterized by various forms of static and dynamic economies of scale, continuous technical progress, national economies often characterised by some degrees of unutilised labour or labour *and* capital.

The very formulation of the standard model in its 'timeless' form becomes even harder to accept whenever one of the factors of endowment—capital—is as such a set of reproducible (and heterogeneous) commodities. The question has been discussed in a 'capital controversy',[10] with many points in common with the famous 'Cambridge Debate' on capital theory, focusing on the problems ranging from the heterogeneity of capital goods[11] to the measurement of that 'aggregate capital' which must appear among the 'endowments'.[12]

Another feature common to practically all the models reviewed so far is the behavioural assumption concerning maximising agents.[13] Particularly with regard to technical change, this assumption becomes rather questionable. As argued at greater length elsewhere (Dosi, 1984) and following Nelson and Winter (1982), it is difficult to maintain that maximisation procedures are an adequate representation of the global behaviours of the agents whenever one properly accounts for the fundamental features of

technical change (including uncertainty about choices and outcomes, patterns of search generally embodying tacit heuristics, various kinds of irreversibilities, etc.). It is not only or even primarily a matter of realism of assumptions. The fundamental point is that behaviours are directly relevant also in terms of the equilibrium positions towards which the system might tend to converge. In other words, even the 'static attractor' of the system may well be *path-dependent* and *behaviour-dependent* (cf. Nelson and Winter, 1982; Dosi and Orsenigo, 1985).

The less pure theory: the 'heretics'

The discussion so far has focused upon that stream of economic analysis concerned primarily with one theoretical question, namely *the determinants of specialisation*, and one functional mechanism, namely the adjustment processes induced in the latter by the *interdependences between markets*, both within each country and between countries. It is a line of enquiry which—despite the great differences in the assumptions on technology, demand, nature of the markets—links Ricardo, the neo-classical school and all those 'revisionist' contributions based on a general equilibrium framework. One of the fundamental premises of such a stream of thought is that trade (or the notional transition from autarky to trade) affects the inter-sectoral (and, sometimes, inter-national) allocation of inputs, quantities and prices, but *does not* affect the rate of utilisation of the stocks of inputs themselves (and thus the rates of macroeconomic activity).[14] This is straightforward in modern general equilibrium analysis where, as already discussed, full employment of all factors is assumed by hypothesis. It is equally true for that part of Ricardo's *Principles* concerned with international trade, based as it was on the assumption that

> no extension of foreign trade will immediately increase the amount of value in a country, although it will very powerfully contribute to increase the mass of commodities, and therefore the sum of enjoyments. As the value of all foreign goods is measured by the quantity of the produce of our land and labour, which is given in exchange for them, we should have no greater value if, by the discovery of new markets, we obtained double the quantity of foreign goods in exchange of a given quantity of ours, [Ricardo, 1951, p. 128].

Since in Ricardo's model production techniques are given, the assumption concerning an unchanged 'amount of value in a country' is precisely equivalent to an assumption of constancy of the rates of macroeconomic activity throughout the notional transition from autarky to trade. In the history of economic thought, however, one can identify also another group of contributions, highly heterogeneous in scope and nature, seldom thoroughly formalised, heretic in spirit and often produced by outsiders to the dominant economic tradition. In this composite group one may include early economists from the eighteenth and nineteenth centuries, such as the

Reverend Tucker, Count Serra of Naples, Ferrier, List, Hamilton, as well as parts of the analysis of Adam Smith. In more recent times one finds an equally heterogeneous set of writers ranging from some technology-gaps and product-cycle authors (Posner, Freeman, Vernon, Hirsch) to Kaldor, Cornwall and Thirlwall, broadly in the post-Keynesian tradition; 'structuralist' writers in development economics, especially within the Latin American tradition; economic historians, such as Gerschenkron and Kuznets; some modern French writers such as Bye, de Bernis, Lafay and Mistral. Obviously, these contributions are highly different in nature and scope. However, one may state that they have in common, explicitly or implicitly, one or several of the following assumptions:

(i) International differences in technological levels and innovative capabilities are a fundamental factor in explaining the differences in both levels and trends in export, imports and income of each country.
(ii) General equilibrium mechanisms of inter-national and inter-sectoral adjustment are relatively weak, so that trade has important effects upon the rates of macroeconomic activity of each economy. Putting it another way, the growth of each economy is often balance-of-payments-constrained and this constraint becomes tighter or looser according to the levels and composition of the participation of each country in world trade flows. The weakness of price/quantity adjustments between sectors and between countries has to do partly with the nature of technology (fixed coefficients, irreversibilities, etc.) and partly with the nature of demand (sticky baskets of consumption, etc.) As a result, what adjusts in the international arena is world market shares within each sector and, through that, the levels of macroeconomic activity generated by foreign demand.
(iii) That same weakness of general equilibrium adjustments is such that the intra-sectoral distribution of trade shares between countries and their evolution through time can be explained by a set of country-specific absolute advantages and without explicit reference, at least in a first approximation, to price/quantity adjustments between sectors and between factors' returns.
(iv) Technology is not a free good.
(v) The allocative patterns induced by international trade have dynamic implications which may either yield 'virtuous' or 'perverse' feedbacks in the long term.

These assumptions have generally been stated in a rather confused way by the early writers, who did not share the rigour and depth of any Ricardo or Samuelson, and were often motivated simply by policy issues such as protection versus free trade. Nonetheless, they had precious if confused insights into complex problems of economic dynamics which were later neglected in the cleaner but more restrictive formalisations of modern trade theory. For example, Tucker (1774) (quoted also by Hufbauer, 1970) assumes that there is a macroeconomic link between technological

advantages, international competitiveness and incomes, and discusses whether the product-cycle effects induced by the lower wages of the 'poor country' will eventually reverse the competitive position of the 'rich' *vis-à-vis* the 'poor'. His answer is reassuring for England: continuous technical progress, higher capabilities of accumulation and institutional factors will keep an absolute advantage there, despite the lower wages of the more backward countries. Ferrier (1805) deals with the relationships between trade and rates of macroeconomic activity in the light of the historical experience of the Continental Blockade, arguing that there is a direct negative link between import penetration and employment levels in the relatively backward country due to a generalised technological disadvantage and to the long term effects that de-specialisation in the most advanced products (in that case, manufactures) exerts upon the capability of progress and accumulation: '. . . I compare a nation which with its money buys abroad commodities it can make itself, although of a poorer quality, with a gardner who, dissatisfied with the fruits he gathers, would buy juicier fruits from his neighbours, giving them his gardening tools in exchange'. (Ferrier, 1805, p. 288).

Interestingly, Adam Smith was equally aware of the dynamic implications of trade and his position appears almost symmetrical to Ferrier's, from the 'advanced country' point of view. First, he argues, trade has a beneficial effect upon the rates of macroeconomic activities and employment because, in contemporary words, exports increase aggregate demand. This is close to what Myint (1958) later defined as a 'vent-for-surplus' model of trade. Second, the enlargement of the market due to international trade feeds back upon the domestic division of labour and thus on the trends in productive efficiency.

The argument of List (1904), German and nationalist, is directly against Ricardo and Say. The practical matter at stake, as known, was the political advocacy of protectionism and industrialisation. In List's view, there is nothing in the adjustment mechanisms on the international market (in List's terminology, the adjustments 'based on the theory of exchange values') which guarantees dynamic convergence between nations in terms of productive capabilities and incomes (the 'growth of productive forces of a Nation'). In several respects, this view involves much more than an 'infant industry argument', the idea being that the long-term position of each country depends jointly on its degrees of capital accumulation, its global technical and learning capabilities,[15] and a set of institutional factors (social consensus, factory discipline, political conditions). According to List, the adjustment processes set in motion by international trade might well be detrimental to the development of these aspects of the 'national productive forces'. Putting it in modern words, static and dynamic economies of scale and differing income elasticities of the various commodities will lead under free-trade conditions to divergence rather than factor-price equalisation, and to growth polarisation with the concentration of production in one country rather than welfare gains for both partners. In a similar perspective, these points have been emphasised in much of the early development/trade/dependency literature (cf. Prebisch, 1950), and in the historical analysis of the early industrialisation/opening of trade process in the United Kingdom.

More recently and along the lines suggested by Kaldor (1970, 1975, 1980), Thirlwall and Vines (1983) have formalised such views in a multi-sector North–South model and have studied the 'consistency conditions' between the two countries and the various sectors. The Kaldor–Thirlwall–Vines approach, while incorporating some ideas similar to earlier 'two-gap' models of development—whereby the growth of the industrialising countries is shown to be constrained by either saving/investment capacity or by the foreign exchange requirements[16]—embodies a general hypothesis that world growth is determined by 'asymmetrical' patterns of change in technical coefficients and demand composition. In this view, processes of inter-factoral and inter-commodity substitution in response to relative prices and excess factor supplies are of minor importance. What adjusts is the level of sectoral and macroeconomic activity.

An ambitious multi-sector model along similar lines is that of Pasinetti (1981), whose open-economy version determines the relative rates of growth between economies in terms of evolution of relative productivities and income elasticities of the commodities each country produces.

In all these models the difference in the income elasticity of the various commodities plays a fundamental role and is assumed to dominate upon the price/quantity adjustments in consumption baskets. Thus, as Thirlwall (1980) shows, the income elasticities enter into the determination of the foreign-trade multiplier of each economy (via import propensities and export elasticities to world income). The other factor is obviously technology. 'Polarisation' in innovativeness is shown to imply 'polarisation' in growth.

Interestingly, while both the Ricardian and neo-classical perspectives focus upon the determinants of the *patterns of specialisation*, the set of contributions reviewed above focuses on the relationship between trade, levels of activity and growth. In terms of adjustment mechanisms, both Ricardo and the neo-classical school hold the rates of activity constant and study trade-induced changes in relative prices and relative quantities; conversely, the 'heretic' stream often assumes away price/quantity adjustments and studies the link between trade and rates of activity in both the short and long term.

In order to highlight these differences, one may represent the early heretic model as follows. Imagine two countries, Portugal and England, producing two commodities, (wine and cloth) with only one production factor: labour. Suppose that, at the beginning, the two countries are absolutely identical: the same technical coefficients, same relative prices, same patterns of consumption, same absolute prices as expressed in their respective currencies whose exchange rate is equal to one. Suppose also the existence of a non-reproducible asset, say, gold, or alternatively

tradable shares representing titles of ownership over the productive activities. Finally, suppose that each economy has some surplus labour which can be mobilised without any extra cost whenever required. Clearly, the two countries, even if opened to the international markets, will not trade. Assume now an across-the-board improvement in the Portuguese technical coefficients which leaves *unchanged relative* productivities and *relative* prices. In the perspective of both Ricardo and the neo-classicals still no trade will occur. As Findlay puts it, '. . . greater technological efficiency cannot be the cause of trade if the relative difference is the same in both goods' (Findlay, 1973, p. 57).

On the contrary, in what could be called a Smith–Ferrier–List model of trade a *one-way* trade will occur with Portugal progressively gaining market shares on the English market in *both* wine and cloth. Correspondingly, gold or ownership titles will move from England to Portugal. The rates of macroeconomic activity will grow in Portugal and fall in England. The adjustment process to the Portuguese technological advance will not stop until the exchange rate will have entirely adjusted to the new purchasing power parity determined by the new levels of productivities in Portugal as compared to English ones. It is easy to define the dynamic counterpart of the model. Imagine a *continuous* flow of technical improvements in Portugal. One will observe a continuously increasing market penetration of Portugal on the English markets. The adjustment process takes essentially three forms.

First, the English currency continues to devaluate. Second, gold or ownership titles continue to flow out of England. Third, the rates of activity in Portugal continue to grow and the English ones to fall. Notably, the increasing technological gap is reflected in the changing world market share in *each* commodity, even if no international specialisation occurs. One could broaden the model, for example, by introducing a third commodity, whisky, which only England can produce due to some natural advantage. Then, under the above assumptions, England will slowly converge toward an absolute specialisation in whisky while her short-term rate of activity and her long-term growth will depend upon the levels and changes in the Portuguese propensity to drink whisky as compared with the English propensity to drink wine and wear clothes.

Needless to say, such a model embodies gross over-simplifications. However, it illustrates probably better the evidence on the free-trade adjustment processes following major technological polarisations than the Ricardian alternative. This is precisely what continental writers from the early nineteenth century had in mind: given the European backwardness *vis-à-vis* England, *laisser-faire* regimes would not have yielded mutual gains from trade, but rather would have reduced Europe to a condition more similar to India.

A major factor counteracting this link between polarisation in technology and in income levels is, of course, the international diffusion of technology. Indeed, most modern technology-gap models focus on the crucial time element between innovation and imitation abroad as the trade and income-polarising 'reversal' factor.

The basic assumption of modern technology-gap trade accounts is that technology is not a freely, instantaneously and universally available good, but that there are substantial advantages in being first. Thus in Posner's seminal model it is suggested that while technical changes and developments may influence some industries and not others, it is the technical change originating in one country and not in others which will induce trade 'during the lapse of time taken for the rest of the world to imitate one country's innovation' (Posner, 1961, p. 323).

A similar point is made in Freeman's case study of the plastic industry: 'Technical progress results in leadership in production in this industry, because patents and commerical secrecy together can give the innovator a head start of as much as 10–15 years' (Freeman, 1963, p. 22). Once imitation has taken place, more traditional factors of adjustment and specialisation would again take over and determine trade flows. In Hufbauer's words: 'Technology gap trade is . . . the impermanent commerce which initially arises from the exporting nation's industrial breakthrough and which is prolonged by static and dynamic scale economies flowing from the breakthrough' (Hufbauer, 1966, p. 23). There is, of course, nothing necessarily 'impermanent' about these static and dynamic scale economies. Coupled with new or improved product innovations they might well lead to a more or less continuous trade flow.

Product life-cycle theories (Hirsch, 1965; Vernon, 1966) provide an articulated trade picture along similar lines. They also integrate foreign direct investment and view technology as part of a wider set of market structure factors, including entry, product differentiation/standardisation, nature of demand. Vernon's original model is primarily demand-determined: high levels of income and sophisticated demand patterns induce innovative responses of domestic firms. More recently, the introduction of supply factors has dealt with some of the weaknesses of the original model (for a critical assessment see, Walker, 1979). The contributions here relate primarily to theories of innovation and can be seen as an extension of post-Schumpeterian 'evolutionary' models (see Nelson and Winter, 1982; Dosi, 1984) to the international field, where the emphasis is on the dynamic/biological nature of international competition.[17]

Another recent direction of investigation relates to the importance given to the import and export of technology in shaping a country's future trade pattern. It opens the way to a further integration of foreign investment theories (cf. Buckley and Casson, 1976, 1981, Dunning, 1981), technology transfer and catching-up models (cf. Cornwall, 1977; Gomulka, 1971, 1978; Kotzumi and Kopecky, 1980), and dynamic diffusion models (see Nelson, 1968; Nelson, Winter and Schuette, 1976; Nelson and Winter, 1982; Metcalfe and Soete, 1984) within a theoretical trade framework.

The empirical evidence

The picture which emerges out of the innumerable number of empirical trade studies is, as one might expect, far from uniform. Moreover, the correspondence between theoretical models and empirical tests is generally poor. As Deardorff notes in his thorough review of trade studies,

> Empirical tests of the theories are often faulted on the grounds that they test propositions that do not derive rigorously from the theories. The reason is not usually that empirical models are sloppy. Rather, the problem seems to lie in the theories themselves, which are seldom stated in forms that are compatible with the real world complexities that empirical research cannot escape. [Deardorff, 1984, p. 468]

We will organise our review of an even more selected literature with reference to the same themes and approaches discussed above.

A major stream of research, not surprisingly, has been concerned with the explanation of the so-called 'Leontief paradox' within a by and large, orthodox factor-proportions framework. As is well known, Leontief (1953) found that the composition of trade of the United States, clearly a capital-abundant country, was biased in favour of labour-intensive exports and capital-intensive imports. While the typical research strategy in the theoretical field was simply to neglect the potentially disruptive implication of such a falsification of the theory, the empirical strategy focused upon additional variables which could explain away the 'paradox'. This has been one of the analytical procedures which has drawn attention toward technology-related variables, typically labour skills and what has become known as 'human capital'. Many empirical studies, primarily concerned with the US case, found these latter variables to be significantly correlated with the American composition of trade (see, amongst others, Keesing, 1965, 1967; Baldwin, 1971; Harkness and Kyle 1975; Branson and Monoyios, 1977; Stern and Maskus, 1981). Moreover, Leamer (1980) has argued that a proper test of the Heckscher–Ohlin model must not be based on the factor content of trade but on the relative factor intensity of production as compared to consumption. Using this criterion, Stern and Maskus (1981) found that the Leontief 'paradox' did hold for 1958 but not for 1947 or 1971. These empirical findings and refinements seem, at first sight, comforting to the prevailing theory in its generalised version, including a 'technology-production' factor and extending the concept of capital not only to human capital but also to 'intellectual capital', defined as the 'capitalised value of productive knowledge created by research and development' (Johnson, 1970, p. 14). However, one must have severe reservations about these 'revisionist' attempts to accommodate the evidence with a traditional factor-proportion view of trade flows.

First, with regard to the conclusions based on Leamer's methodological suggestions, the results are far from 'non-paradoxical' and depend crucially on the chosen years. They therefore appear not particularly robust.

Second, as argued by Deardorff, the 'acknowledgement of additional factors of production cannot in theory explain Leontief's paradoxical results regarding capital and labour' (Deardorff, 1984, p. 481)

Third, the higher the distance of the underlying model from the original labour/land framework, the lower appears the plausibility of the basic assumptions. As already discussed in the previous section, one can hardly consider 'capital' as an endowment whenever it is actually produced under conditions of non-decreasing returns. It is even harder to define R & D as an endowment, for its 'size' depends on highly discretionary decisions of firms and public institutions.

Fourth, proper 'tests' of the Heckscher–Ohlin model must be based on direct *plus* indirect factor contents. As discussed at length by Momigliano and Siniscalco (1984), this correct procedure has been followed only by a few studies.[19] The majority of them simply consider direct product characteristics. This methodological difference matters. Thus Italy's trade performance is *negatively* correlated with the direct R & D content of each commodity but is *positively* correlated with the total content (direct plus indirect, via input/output flows) (see Momigliano and Siniscalco, 1984).

Finally, there is the question whether empirical analyses of trade flows can be usefully carried out at the level of intra-country, inter-sectoral studies only. This methodological issue has been raised at a general level by Leamer (1974) and Leamer and Bowen (1981). The problem stems from different technology-specific characteristics which are likely to influence trade flows and can be accounted for only in inter-country, intra -sectoral analysis.

Given all these methodological problems and caveats, it is fair to conclude that most of the empirical studies based on cross-sectoral analyses relating trade flows (either measures of comparative advantages or net exports) to a menu of product characteristics, while useful in presenting the possible *regularities* in the structural features of domestic supply and their statistical correlation with the patterns of competitiveness, are far from useful in highlighting any causal mechanism *explaining* international competitiveness and specialisation.[20]

The empirical validity of the endowment-based theory of trade remains therefore very much subject to debate.[21] As Hufbauer puts it,

> Leontief's findings dealt an apparently telling blow to the simplistic two-factor version. Various authorities have sought to repair the damage; their work in some respects resembles the tortured efforts of pre-Copernican astronomers. [Hufbauer, 1970, pp. 267–8]

A different line of empirical enquiry has been concerned with the patterns of relative inter-sectoral specialisations based on a simple Ricardian framework. MacDougall (1951–52) showed that the sectoral ratio of US to UK exports was well correlated with relative American and British labour productivities. These results, confirmed by Stern (1962) and Balassa (1963), do not, however, explain the *sources* of inter-sectoral

differences in productivity and—as has been argued—could be consistent also with a Heckscher–Ohlin model of trade.[22] On the other hand, they could also highlight the mechanisms leading to comparative advantages on the ground of sector-specific gaps or leads in technolgy.

Empirical studies using the technology-gap trade framework or product life-cycle theory, on the other hand, emphasise in the first instance the inter-country differences in innovativeness as the basis of international trade flows. Rather than inter-industry variations in the technological 'endowment' of a specific country, it is the variation across countries in innovativeness within each sector which seems crucial (see, among others, Freeman, 1963, 1965; Hirsch, 1965; Hufbauer, 1966; Tilton, 1971; Dosi, 1984). Most sectoral studies (e.g. on chemicals, plastics, process plants, electronics products, semiconductors; see the authors just mentioned) highlight the dynamic relationship between early innovative leads, economies of scale, learning by doing, oligopolistic exploitation of these advantages, and international competitiveness. As referred to in the introduction, one of the most ambitious attempts of inter-country and inter-sectoral comparison of technology-based and product-cycle-based models as compared to the other explanations of trade flows was carried out by Hufbauer (1970).

Hufbauer found that the commodity characteristics by country were related to a set of country characteristics including variables related to technology, economies of scale, product differentiation and patterns of domestic demand. Whereas some of the proxies used implied high levels of 'heroism', they pointed to the widespread existence of country-specific advantages/disadvantages related to technological innovation, national 'context' conditions and forms of corporate behaviour different from 'pure competition'.

Similarly, the findings by Gruber and Vernon (1970), while broadly in line with the Leontief 'paradox', highlighted the homogeneity in the structure of exports (and production) among the major industrial countries and their general correlation with per capita GDP. Walker (1979) critically analysed the sectoral evidence on product-cycle patterns of production and exports, finding that there are groups of products which do conform with the prediction of a shift from advanced to intermediate and backward low-wage countries, while other groups appear more in line with straightforward technology-gap theories, whereby the advantage remains over long periods in the most innovative country(ies).

Irrespective of whether the analysis deals with intra-country, inter-sectoral comparisons or inter-national, inter-sectoral ones, an important methodological issue concerns the proxies used for the technology variable.[23] With the exception of Davidson (1979), Pavitt and Soete (1980), and Soete (1980, 1981), most empirical studies use technology *input* proxies, such as R & D expenditure or R & D employment. Yet the exact relationship between technology input and technology output remains unclear. Most technology-gap models, however, by emphasising the crucial role of new products and process innovations, make explicit the need for using a technology output proxy instead of an input proxy in explaining international trade flows.

Some interpretative suggestions

As we have discussed at greater length elsewhere (Dosi, Pavitt and Soete, 1988), the empirical evidence on the composition and dynamics of trade flows can be interpreted within what we consider to be a more satisfactory interpretative framework based on wide–spread technological gaps among countries, generally non-clearing markets, 'Keynesian–Kaldorian' links between international competitiveness and macro-economic rates of domestic activity. We also tried there to account for a few 'stylized facts' on which this interpretation is based.

First, the international distribution of innovative efforts and innovative results is far from homogeneous, even with the OECD countries, The 'club of the innovators' comprises not much more than a dozen countries, has been relatively stable in its membership for almost a century—with only one major entry (Japan), and shows interesting patterns of evolution in the internal ranking of countries (e.g. Germany and the USA overtaking England at the turn of the century as the major source of innovations, a very quick catching–up process by Japan and to a lesser extent some European countries, such as Italy after the second world war).

Second, these differences in innovative capabilities correspond to equally wide differences in labour productivities. Remarkably, as much as one can infer from imperfect statistical evidence, these differences do not correlate with analogous differences in capital/output ratios. That is, differences in the 'production functions' rather than differences in 'endowments' appear to be the fundamental feature of the international system of production.

Third, cross-sectoral analysis shows a high sectoral specificity in the opportunities and propensities to innovate and patterns of inter-sectoral distribution of one country's innovative strength and weakness which defy traditional explanations (e.g. why is Switzerland strong in pharmaceuticals and Sweden in mechanical engineering?).

Fourth, as regards trade flows, one obviously observes long term changes in the patterns of national 'revealed comparative advantages' but these changes are often inter–linked with country-wide changes in world market shares which often occur in all (or most) sectors, although at different rates (e.g. the British generalised decline or the Japanese rise).

It is against this background of stylised facts that we have started constructing an alternative model of technology and trade.

Technology, we argue in line with several other chapters in this book, cannot be reduced to freely available information or to a set of 'blueprints': on the contrary, each 'technological paradigm' with its forms of specific knowledge yields relatively ordered cumulative and irreversible patterns of technical change, which are also *country–specific*.

A fundamental implication of such an analysis of technical change is also a theory of production whereby different ('better' and 'worse') techniques, products and firms co–exist at any point in time.

Thus, the main mechanisms of change over time are evolutionary processes of innovation and diffusion of unequivocally better techniques and products. This interpretation, partly modelled elsewhere (Dosi, Pavitt, and Soete, 1988) can account for the continuous existence of technology gaps between firms and between countries and for the conditions of *convergence* or *divergence* in inter-firm and inter–national technological capabilities, according to the degrees of opportunity, cumulativeness and appropriability that each technology presents.

In this view, the degrees of innovativeness of each country in any one particular technology are explained—as regards their origin—through the inter–play between (i) science-related opportunities, (ii) country–specific and technology-specific institutions which foster/hinder the emergence of new technological paradigms, and, (iii) the nature and intensity of economic stimuli, which stem from abundance of particular inputs, or, alternatively, critical scarcities of inputs, specific patterns of demand and levels and changes in relative prices. In this sense, the interpretation suggested here accounts for the taxonomic evidence presented by the particular theories of 'market–induced' innovations (e.g. product-cycles, demand-pull, relative-price inducements) and incorporates them in what we believe to be a more general view of the innovative process: certainly there is a wide variety of economic inducements to innovation, but these belong to the necessary although not sufficient conditions. Sufficiency is provided by the degrees of matching/mismatching between these generic market opportunities and the institutional conditions related to the scientific/technological capabilities available in each country, the 'bridging institutions' between pure science and economic applications, the expertise embodied in the firms, the patterns of organisation of the major markets, the nature and impact of public policies.

Over time, capital accumulation and technological accumulation are inter-linked so that irreversible improvements in input efficiencies and search/learning processes feed back on each other. In some respects, our analysis overlaps with the question concerning 'why growth rates differ' (cf. the next chapter by Fagerberg). However, our interpretation is the polar opposite to the traditional one (but consistent with Fagerberg's): instead of explaining differences between countries in terms of differential endowments, we argue that the fundamental inter-national differences relate to the country-specific conditions of technological learning and accumulation.

The model of trade, only briefly hinted at here, takes these regularities as its starting point, and is based on the general existence of technological differences—that is: differences in input efficiencies, in product qualities and in performance—between countries. These gaps, we argue, are the equivalent of the Smithian/Ricardian 'absolute advantages' and determine two fundamental processes of adjustment between and within countries.

First, inter-sectoral intra-national differences in technology gaps/leads yield a tendency toward relative specialisations in the sectors of 'comparative advantages'. This is the familiar mechanism of adjustment described in the Ricardaian and, under different assumptions, neo-classical literature.

Second, and at least as important, intra-sectoral gaps/leads between countries yield adjustments in world market shares, as suggested by some of the 'heretic' contributions reviewed above. This adjustment process relates to the notion of 'absolute' or 'structural' competitiveness of each country. It is an 'absolute' notion in the sense that it does not relate to any inter-sectoral comparison ('I am relatively better in this or that'), although it is obviously relative to other countries ('I am better or worse than country B or C').

The link between absolute advantages/disadvantages and world market shares (or per capita exports), within each sector and for each country as a whole is empirically quite robust: in previous tests (Soete, 1981, Dosi and Soete, 1983), different degrees of innovativeness and differential productive efficiency perform as a good predictor of the inter-national distribution of export flows in more than three quarters of the forty industrial sectors that we considered, despite the admittedly imperfect nature of our statistical proxies.

Moreover, country-wide changes in innovativeness and input efficiencies are a significant part of the explanation of the long term changes in national export shares in the world markets.

In our interpretation and in line with the arguments advanced by Pasinetti (1981), comparative advantages are obtained only as a by-product of both intra-national inter-sectoral changes in inputs allocations and changes in the absolute amount of inputs each economy employs to produce for changing shares in the world market. That is, from a dynamic perspective, revealed comparative advantages appear to be the *ex post* result of sector-specific and country-specific learning dynamics, and of the related inter-national intra-sectoral changes in competitiveness of firms and countries.

This analysis can easily be linked with a 'Keynesian' view of the determination of the rates of macroeconomic activity of each economy. Unlike neo-classical trade analyses—which impose market-clearing in the model—and unlike also Ricardian trade models—which, in order to identify equilibrium specialisations, generally assume steady-state growth, our interpretation requires changes in the levels of macroeconomic activity of each economy in response to changes in international competitiveness (i.e. relative changes in innovativeness, input efficiency, organisational competence of domestic firms, etc). Thus, the link between absolute advantages/disadvantages and world market share (or per capita exports) is theoretically consistent with a determination of domestic aggregate demand via the foreign trade multiplier.

Elsewhere (Dosi, Pavitt and Soete, 1988), with the help of a simple formal model, we show that international gaps in technology define the boundaries of both 'Ricardian' processes of adjustments in specialisations and 'Keynesian' adjustments in the rates of macroeconomic activity. From a dynamic point of view, it is the evolution in the innovative/imitative capabilities of each country which shapes the trends in the relative and absolute rates of growth of the *tradeable* sector of each economy.

These theoretical propositions are broadly consistent with the empirical evidence reported and presented in Pavitt and Soete (1981) and in the next chapter Fagerberg: the links between innovativeness and macroeconomic growth, in cross-country analyses over the past eighty years, appear to be rather strong, although the precise forms of that relationship depend on each particular phase of development (i.e. each particular 'regime of international growth', as hinted in Boyer's chapter).

Conclusions

There are as will be obvious from the review section still major gaps in our understanding of the role of innovation in international trade. One is only beginning to analyze (i) the determinants of different national capabilities to innovate, imitate, and, generally exploit competitively the innovative efforts: (ii) the nature and relative importance of the various adjustment mechanisms within and between countries following such innovative processes; (iii) the relationship between sector-specific patterns of competitiveness and 'general equilibrium' factors, in the broader sense, linked to relative prices, inter-sectoral capital and labour mobility, etc; (iv) the implications of economies of scale, dynamic increasing returns (see in particular Arthur's chapter in this book), oligopolistic forms of market organisation, international investment and all the factors which generally go under the heading of 'imperfect competition'; (v) the long-term relationship between innovation, trade and growth. All these issues are as much in need of empirical research.

Our own approach as sketched out above, can be summarized by the following propositions: *First*, the 'microfoundations' of international trade analysis, consistent with the available evidence, should be found in the extension of an 'evolutionary' interpretation to the international arena. *Second*, in such evolutionary dynamics, what appears to be, *ex post*, a 'comparative advantage' is in no proper sense the result of any 'endowment' but the outcome of processes of learning—innovation, imitation, organisational change—which have both sector and country specificities. *Third*, the innovative process, by allowing various sorts of (static and dynamic) increasing returns generally entails also forms of market interactions different from perfect competition. *Fourth*, these same properties of technical change imply the possibility of those *irreversible processes* discussed in Arthur's chapter, and, thus, also, from a normative point of view, the possibility of 'virtuous' or 'vicious' circles in innovativeness, competitiveness and growth. *Fifth*, the *micro*-economic and sectoral levels and changes in international competitiveness, determined under conditions of continuous technological learning and limited short-term substitution in both production and consumption, appear also to represent the micro-foundations of many *macro*-economic analyses, in particular those with some 'Keynesian' ascendancy whereby economic systems seldom hit any powerful scarcity constraint, but are limited in their growth by aggregate demand and foreign balance requirements.

The largest part of the theoretical analysis of these processes is still to be done. However, we would argue that these contain some of the most promising links between the evidence on trade flows and patterns and the interpretations of innovation, industrial evolution and patterns of growth discussed in the other chapters of this book.

Notes

1. Extensive reviews of the trade literature can be found in Bhagwati (1964), Chipman (1965/66), Stern (1975), and Jones and Kenen (1984), and more specifically on the issues related to technology and international trade, in Hufbauer (1966, 1970), Chesnais and Michon-Savarit (1980), Aho and Rosen (1980), Dosi and Soete (1983), Soete (1985) and Lyons (1986).
2. That is the Heckscher–Ohlin theorem, stating that the relative specialisation of each country is in those commodities which use intensively those factors which are relatively abundant in that same country.
3. Such as, for example, the analytical treatment of those cases with more commodities than factors, etc.
4. Of course this is necessarily so if the economies of scale are internal to each firm.
5. For a thorough review, see Helpman (1984). An interesting collection of some of the 'state-of-the-art' contributors in the field is in Kierzkowski (1984).
6. For 'imperfect competition' models see, among others, Markusen (1980), Lancaster (1980), Helpman (1981). Helpman and Razin (1980), Melvin and Warne (1973). The implications of economies of scale in a neo-classical, open-economy growth model are analysed in Krugman (1984). For an overview see Helpman and Krugman (1985).
7. This line of enquiry is in many ways an attempt at a synthesis between the Heckscher–Ohlin–Samuelson model and Linder's model (cf. Linder, 1961). For a model accounting also for multinational investment, see Helpman (1984).
8. cf. the special issue of *The Journal of Industrial Economies* edited by Caves (1980), Brander (1981), Jacquemin (1982), Brander and Krugman (1983), Dosi (1984), Momigliano and Dosi (1983), Caves, Porter and Spence (1980).
9. That is, a general equilibrium model with sector-specific and inter-sectoral immobile factors (see Jones and Neary, 1984).
10. On this issue, see, for a 'Cambridge view', Steedman (1979, 1980), Metcalfe and Steedman (1981), and the replies by Ethier (1981) and Dixit (1981).
11. Interestingly, the standard neo-classical way out of the difficulties with regard to capital measurement has been, in the closed economy case, through general equilibrium models of Walrasian ascendancy. This possibility is generally precluded in the field of international trade, since the specification of a long vector of 'endowments' implies nearly tautological conclusions. It is of little interest, as Corden puts it crudely, to have a 'theory' which says 'that Switzerland has a comparative advantage in watches because she is watchmaker-intensive or that the United States export 747s because she is intensive in firms or engineers capable of making 747s' (Corden, 1979, p. 9.). In trade-related capital theory the standard procedure is simply to assume that the measurement problem does not exist *ex hypothesi*: 'Suppose that . . . the common technology has no factor-intensity reversal . . .' (Ethier, 1981, p. 274).
12. This is not the place to discuss these issues. Suffice to make one remark. With time and reproducibility of capital (in the form of machines, etc.), the 'dynamic' equivalent of the timeless Heckscher–Ohlin–Samuelson model becomes one where the 'scarcity constraints' are the rate of growth of the labour supply and the saving rate. This strictly pre-Keynesian view of the growth process raises many questions: how does one account for all periods and countries in modern history characterised by structural unemployment of one kind or another? Do 'scarcity constraints' functionally define the system even in the presence of continuous technical progress and widespread economies of scale? Where is there proof that it is the rate of saving which determines the rate of investment and not vice versa such as in the Keynesian–Kaleckian view? Where is the evidence that countries characterised by higher saving propensities also present higher capital 'endowments' and relatively capital-intensive exports?
13. This is equally true for the models of 'pure' competition as well as those based on imperfect competition or oligopolistic strategic interaction.
14. Obviously, this assumption is necessary to base the analysis on unit functions, indifference curves, isoquants, etc.
15. For a reappraisal of List's view on the importance of the national techno-scientific system, cf. Freeman (1987).
16. See Chenery and Bruno (1962), Chenery and Strout (1966), Findlay (1973). For a thorough critical analysis of the debate on North–South differences, terms of trade, development, see Bacha (1978). A review of the trade/development literature, cf. Findlay (1984).
17. See Klein (1977, 1978). Klein's work focuses on individual firm behaviours in relation to industrial innovation. For an overview of this line of enquiry, see Graham (1979).
18. Some scattered and less convincing evidence exists also for Sweden (Bergstrom-Balkestahl, 1979) and Canada (Hanel, 1976). Thorough reviews can be found in Deardorff (1984) and Onida (1984).
19. To our knowledge, since Leontief (1953, 1956), the total factor contents has been used only by Carlsson and Ohlsson (1976).
20. One can interpret in this way also the results of those studies which include among the 'independent' variables a lot of factors of which only few can be derived by a standard factor-proportion model; cf. for example, Wells (1969), Moral (1972), Finger (1975b).
21. Romney Robinson: '. . . in models which demand that all phenomena be subsumed either under production functions or under factor availability, it means that there is nothing left on the supply side but factor proportions to account for price differences. Yet if different production functions were admitted, then the theory, confronted with evidence of trade contrary to that

indicated by factor supplies, could always take refuge in the plea: 'different production functions'. But that would reduce it to a banality. *Any* pattern of trade could be explained in such terms' (Robinson, 1968, p. 6–7).

22. See Falvey (1981) and Deardorff (1984). Bhagwati (1964) challenged the theoretical foundations of these 'Ricardian' tests. The critique is somewhat surprising in the light of the relatively little amount of *ad hoc* assumptions required to derive the tests from the theory, especially as compared to those necessary to the factor-proportion models.

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20 Why growth rates differ

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Introduction

This chapter focuses on the importance of creation and diffusion of technology for differences in economic growth across countries.

The question of how technology and growth relate is not a new one. The classical economists have discussed this question extensively, but attempts to study this relation empirically on a cross-country basis are much more recent. In fact, with one exception (Tinbergen, 1942), the first attempts were made in the mid- to late 1960s (Domar *et al.*, 1964; Denison, 1967). The next section discusses how this question is treated in some influential post-war studies on 'why growth rates differ' between countries. Generally, these studies either ignore technological differences between countries or treat them as accidental and transitory. Diffusion is assumed to take place relatively automatically, either as free knowledge or through the addition of new vintages of capital to the capital stock. The role of innovation is normally ignored, except in the case of the technological leader country, and then treated in a very superficial way. Thus the models underlying most of these studies can generally be characterized as 'convergence-to-equilibrium models'. No surprise, then, that these studies have difficulties in explaining phenomena such as 'changes in technological leadership' or the existence of 'laggards'.

The remaining part of the chapter develops and tests a simple model of 'why growth rates differ' which is more in line with the approach of this book. In the model, economic growth is assumed to depend on three factors: creation of new technology, diffusion of technology, and efforts related to the economic exploitation of innovation and diffusion. Contrary to many other approaches to the subject, this model allows for both convergence and divergence between countries. In the final part of the chapter, the model is tested on a sample containing data for twenty-seven developed and semi-industrialized countries between 1973 and 1983.

Lessons from previous research

Studies of why growth rates differ between countries may roughly be divided in three groups: (a) 'catch-up' analysis; (b) 'growth accounting'; and (c) 'production-function' studies. Let us consider these approaches one at a time.[1]

(a) 'Catch-up' analysis

The idea that differences in economic growth between countries are related to differences in the scope for imitation is normally attributed to Veblen (1915). Since then, several economic historians have analysed problems related to industrialization and growth from this perspective.[2]

More recently, Abramovitz (1979, 1986) and Maddison (1979, 1982, 1984) have applied this perspective to the differing growth performance of a large sample of industrialized countries. According to these writers, large differences in productivity levels between countries (technological gaps) tend to occur from time to time, mainly for accidental reasons (wars, etc.). When a technological gap is established, this opens up the possibility for countries at a lower level of economic and technological development to 'catch up' by imitating the more productive technologies of the leader country. Since these writers hold technological progress to be partly capital-embodied, they point to investment as a critical factor for successful 'catch up'. They also stress the role of demand factors, since demand is assumed to interact in various ways with investment and the pace of structural change in the economy. For instance, the deceleration of productivity growth in the last decade is partly explained in this way. They mention the importance of institutions, but do not discuss this in detail because of the methodological difficulties that are involved.

The works by Abramovitz and Maddison are to a large degree descriptive, and as such they are very useful. They convincingly support their arguments by comparing data for productivity levels and economic growth/productivity growth across countries, and these comparisons are sometimes supplemented by descriptive statistics/simple statistical tests. Other scholars working in this tradition have extended these tests in various ways and reached similar results (Singer and Reynolds, 1975; Cornwall, 1976, 1977). However, they all concentrate on diffusion processes and ignore innovation aspects. As pointed out already by Ames and Rosenberg (1963), writers in this tradition have great difficulties in analysing phenomena such as developments in leader countries[3], changes of leadership,[4] and the existence of 'laggards'.

(b) 'Growth accounting'

For many years, Kuznets and his colleagues devoted much effort to the construction of historical time series for GDP and its major components (national accounts). The post-war 'growth accounting' exercises grew more or less naturally out of this work. While national accounts presented decompositions of GDP, growth accounts attempted to decompose the growth of GDP. The first analysis of this type was carried out by Abramovitz (1956) in a historical study of the United States. What he did was to sum up the growth of inputs (capital and labor), using 'prices' or factor shares as weights, and compare the result with the growth of output as conventionally measured. The result, that about one-half of actual growth[5] could not be explained in this way and had to be classified as unexplained total factor productivity growth, surprised many, including Abramovitz himself:

> This result is surprising . . . Since we know little about the causes of productivity increase, the indicated importance of this element may be taken to be some sort of measure of our ignorance about the causes of economic growth. [Abramovitz, 1956, p. 11]

Abramovitz discussed briefly possible explanatory factors behind this large residual, emphasizing research, education, learning by doing, and economies of scale. From this, researchers have followed different paths in 'squeezing down the residual', as Nelson (1981) puts it. One has been to embody as much as possible of technological progress into the factors themselves, as suggested by Jorgensen and Griliches (1967).[6] Another, following Ambramovitz's suggestions, has been to add other explanatory variables, thereby reducing the unexplained part of the residual, which, following Solow (1957), is normally attributed to technical change.

Denison was the first to apply this latter methodology to the study of why growth rates differ between countries (Denison, 1967; Denison and

Table 20.1 'Why growth rates differ' (Denison)

	1950–62			1953–61
	US	Western Europe[1]	Italy	Japan
Growth[2]	3.4	4.7	6.0	8.1
of which:				
Labor	1.1	0.8	1.0	1.9
Capital	0.8	0.9	0.7	1.6
Residual (TFP)	1.4	3.0	4.3	4.6
of which:				
Technology	0.8	1.3	1.7	1.4
Resource allocation	0.3	0.7	1.4	1.1
Scale factors	0.4	0.9	1.1	2.0
For comparison:				
National income per person employed[3]	100	59	40	55

Sources: Denison (1967), Chapter 21; Denison and Chung (1976), Chapters 4 and 11.

[1] Belgium, Denmark, France, Germany, Netherlands, Norway and United Kingdom.
[2] The columns do not always add up because of rounding errors and other minor adjustments not reported here.
[3] In 1960 US prices (except Japan: 1970).

Chung, 1976). Regarding technology, Denison's work rests on a view very similar to the one which characterizes many 'catch-up' analyses,[7] but his conclusion differs from theirs. Some of his main results are summarized in Table 20.1. As is apparent from Table 20.1, the results indicate a close connection between the size of the residual and the level of development. This could, of course, be interpreted in support of the catch-up approach. But Denison attributes about two-thirds of the differences in residuals between the United States and the rest of the countries covered by his investigation to other factors (improvements in resource allocation and the exploitation of economies of scale). In fact, when these factors are adjusted for, only France and Germany among the Western European countries seem to catch up in terms of technology. In his 1967 study, he therefore concludes:[8]

> On the surface, to reduce the gap greatly would not seem very difficult if the businessmen, workers and governments of a country really wished and were determined to do so . . . In contrast to this *a priori* impression of possibilities, the historical record up to the early 1960s, at least, suggests that either the desire is lacking or imitation is a very difficult thing; most countries seem to have made little progress. [Denison, 1967, p. 340]

However, when Denison discusses the contribution from increased exploitation of economies of scale, what he mainly refers to is increased aggregate productivity caused by increased productivity in the production of durable consumer goods. But where does the technology used to produce consumer durables come from, if not from the United States? In fact, the 1950s and 1960s are exactly the periods when the production of consumer durables spreads from the United States to Europe and Japan. A similar argument can be made for structural changes. Without the growth of new industries based on imported technology, such as, for instance, consumer durables, would these changes have taken place to the same extent? Thus we will argue that Denison's conclusions rest on rather shaky assumptions, and that it is quite probable that he seriously understates the importance of diffusion of technology from the United States to Europe and Japan in this period.[9]

On a more general level, this illustrates a major weakness in growth-accounting analysis. As pointed out by Nelson (1973, 1981), most of the variables which the growth accountants take into account are interdependent, and without a theory of how these variables interact, decompositions cannot claim to be more than mere illustrations of the growth process.[10] To explain differences in growth between countries, it would be necessary to distinguish between 'active factors' ('engines of growth'), and more 'passive factors' which, though permissive to growth, cannot themselves be regarded as causal, explanatory factors, and the relations between the various factors would have to be determined and explained. Furthermore, the contribution of innovation to economic growth, not only in the United States but everywhere, would have to be worked out and integrated into the analysis.[11]

'Production-function' studies

As noted, the growth accounting exercises relate the growth of output to various input factors. Solow (1957) was the first to provide a formal theoretical framework for this type of analysis.[12] Following standard neo-classical equilibrium assumptions (perfect competition, full capacity utilization, full employment, no economies of scale, etc.), he assumed that production (Q) could be related to technology (A) and the factors of production (capital (K) and labor (L)) in the following way:

$$(1)\quad Q(t) = A(t)\, F(K(t),L(t))$$

Let small-case letters denote rates of growth. By differentiating, dividing through with Q, and substituting the partial elasticities of output with respect to capital and labor, El_{QK} and El_{QL}, into the equation, we arrive at:

$$(2)\quad q = a + (El_{QK})k + (El_{QL})l,$$

Since under neo-classical assumptions the partial elasticity of output with respect to labor, El_{QL}, equals the workers' share (s_L), and the partial elasticity of output with respect to capital, El_{QK}, the capitalists' share (S_K) of net output, the rate of growth can now be written as the sum of the rate of growth in the capital stock, weighted by the capitalists' share in net output, the rate of growth in the labor force, weighted by labor's share in net output, and the rate of growth of 'technology' ('total factor productivity growth' (a)):

$$(3)\quad q = a + s_K k + s_L l$$

Equation (3) obviously provides a theoretical justification for growth accounting, even if the underlying assumptions are much stronger than those which underlie most applied work in this area. But Solow's work did also represent the starting point for econometric studies of 'why growth rates differ' between countries. Chenery (1986) provides a summary of some of the main results from econometric applications of production functions on cross-country samples consisting of less developed, semi-industrialized or developed countries. Generally, these studies show that Solow-type production–function models explain very little of the observed differences in growth between semi-industrialized or less-developed countries. According to Chenery, the main reason for this is that the equilibrium conditions which underlie the neo-classical approach do not hold for these countries. He concludes that

> In particular, disequilibrium phenomena are shown to be more significant for the former (semi-industrialized) than for the latter (developed). Thus, although neo-classical theory is a useful starting point for the study of growth, it must be modified substantially if it is to explain the essential features of economies in the process of transformation. [Chenery, 1986, pp. 13–14]

Following this line of argument, several attempts have been made to extend the production-function approach by adding other explanatory

Table 20.2 Sources of growth in semi-industrialized countries 1964–73

	Regression coefficient	Contribution to growth
Growth		6.4
of which:		
Labor	0.766	1.8
	(3.73)	
Investment	0.135	2.7
	(2.96)	
'Residual'		1.9
of which:		
Exports	0.246	0.5
	(2.96)	
Manufacturing	0.809	1.5
	(3.68)	
'Constant'	−0.002	−0.2
	(0.132)	
R^2 (adjusted) = 0.75; N = 29		

Source: Feder (1986), Tables 9.9–9.10, Model V'.
The contributions do not add up because of rounding errors. The numbers in brackets are *t*-values.

variables, reflecting various types of disequilibria which exist within countries.[13] The main arguments in favor of this may be summarized as follows. Many countries, especially developing countries, are often assumed to have a 'dual' economy, consisting of a high-productive modern sector and a low-productive traditional sector. In this case, it is argued, a mere transfer of resources from the traditional sector to the modern sector should raise growth. A similar perspective is often applied to the relation between the export sector and the rest of the economy, because the export sector is often assumed to be more productive than other sectors. A recent application of this methodology to a sample of semi-industrialized countries may be found in Feder (1986). He estimates a neo-classical production function, with variables reflecting the development of exports and manufacturing production added, on a cross-country data set for the period 1964–73 (see Table 20.2). When compared with Denison's estimates for countries on a comparable level of development (Italy and Japan), some important differences emerge. First, the combined contribution of capital and labor explains about two-thirds of actual growth, compared to between one-third and one-half in Denison's calculations. Second, the contribution of capital is relatively more important in Feder than in Denison. Third, Feder does not distinguish between economies of scale and other factors related to re-allocation of resources. Fourth, Feder totally ignores the contribution of innovation and diffusion. The latter is, of course, the most striking. Following this approach, the question of 'why growth rates differ' between countries can be answered without any references to technology.

However, there are important methodological problems here. To what extent can the introduction of disequilibrium conditions be defended within a framework which assumes equilibrium from the start? The pure neo-classical growth model, as set out by Solow and others, pretends to explain economic growth from factor growth and technological progress. But the explanatory power of the model rests solely on the underlying equilibrium assumptions. If these assumptions do not hold, it is not at all clear how an estimated neo-classical growth model should be interpreted. For instance, in a situation where unemployment prevails, it is not obvious that growth in the labor force should be assumed to add anything to economic growth.[14] Furthermore, to what extent can structural changes, though facilitated by the existence of large, low-productive sectors populated by 'surplus labor', be counted as independent, explanatory factors of growth in the same sense as capital accumulation or innovative efforts? Why is it not the other way around, that structural changes are caused by capital accumulation, innovative efforts and growth? Thus neo-classical students of why growth rates differ seem to be faced with the following dilemma: either stick to the traditional neo-classical assumptions—this produces a logically coherent explanation that predicts poorly; or add additional variables that destroy the original equilibrium framework—then predictions become much better, but the model ceases to explain anything.

Chenery and others should be credited for having shown that the equilibrium conditions on which the production-function approach is built cannot be defended in studies of why growth rates differ between countries. However, they miss their point when they mix together a model built on equilibrium assumptions and factors reflecting disequilibrium conditions, without showing explicitly how the various factors interact and what the fundamental causal factors are. It is disappointing, also, that they normally[15] ignore the differences in technological levels and innovative performances across countries, which we believe to be one of the most fundamental disequilibrium mechanisms of the world economy. In our view, what needs to be done is to study 'why growth rates differ' from a theoretical framework which assumes disequilibrium conditions right from the start.

A technology-gap theory of economic growth

Essentially, the technology-gap theory of economic growth is an application of Schumpeter's dynamic theory of capitalist development, which was

developed for a closed economy, to a world economy characterized by competing capitalist nation-states. Following Schumpeter (1934, 1939, 1942), the technology-gap theorists[16] analyse economic development as a disequilibrium process characterized by the interplay of two conflicting forces: innovation, which tends to increase economic and technological differences between countries, and imitation or diffusion, which tends to reduce them. Thus, whether a country behind the world innovation frontier succeeds in reducing the productivity gap *vis-à-vis* the frontier countries does not only depend on its imitative efforts, but also on its innovative performance, and on the innovative performance of the frontier countries. Furthermore, even if a country behind the world innovation frontier may succeed in reducing the productivity gap through mainly imitating activities, it cannot surpass the frontier countries in productivity without passing them in innovative activity as well. In general, the outcome of the international process of innovation and diffusion—with regard to the economic development of different countries—is uncertain. The process may generate a pattern where countries follow diverging trends, as well as a pattern where countries converge towards a common mean.

To do full justice to the Schumpeterian theory outlined above, the world economy should be modelled both from the technology side, characterized by creation, diffusion and contraction of competing technological systems, and from the side of competing nation-states, characterized by different technological levels and trends, institutional settings, and internal structural disequilibria.[17] However, for the purpose of highlighting some of the reasons behind 'why growth rates differ', we will assume that a simpler approach may do.

Assume that the level of production in a country (Q) is a multiplicative function of the level of knowledge[18] diffused to the country from abroad (D), the level of knowledge created in the country or 'national technological activity' (N), the country's capacity for exploiting the benefits of knowledge (C), whether internationally or nationally created, and a constant (Z)

$$(1) \quad Q = Z\, D^{\alpha} N^{\beta} C^{\tau}, \text{ where } Z \text{ is a constant.}$$

By differentiating and dividing through with Q, letting small-case letters denote growth rates:

$$(2) \quad q = \alpha d + \beta n + \tau c$$

Assume further, as customary in the diffusion literature, that the diffusion of internationally available knowledge follows a logistic curve. This implies that the contribution of diffusion of internationally available knowledge to economic growth is an increasing function of the distance between the level of knowledge appropriated in the country and that of the country on the technological frontier (for the frontier country, this contribution will be zero). Let the total amount of knowledge, adjusted for differences in size of countries, in the frontier country and the country under consideration be T_f and T, respectively:

$$(3) \quad d = \mu - \mu(T/T_f)$$

By substituting (3) into (2) we finally arrive at:

$$(4) \quad q = \alpha\mu - \alpha\mu(T/T_f) + \beta n + \tau c$$

Thus, following this approach, economic growth depends on three factors:

- the diffusion of technology from abroad (imitation): the contribution of this factor increases with the distance from the world innovation frontier;
- the creation of new technology within the country (innovation);
- the development of the country's own capacity for exploiting the benefits offered by available technology, whether created within the country or elsewhere ('efforts').

The model developed above does, of course, present a very simplified picture of reality, especially with respect to diffusion. For a more thoroughgoing discussion of diffusion aspects, the reader is referred to chapters by Perez–Soete and Unger in this book. But the model differs from the one which until now has dominated most empirical work on technological gaps and economic growth in at least one respect: *it incorporates the effects of national innovative performance*. As pointed out by Pavitt (1979/80) and Pavitt and Soete (1982), the omission of the innovation variable in most applied work makes it difficult to explain diverging trends, whether represented by laggards or related to the questioned changes in technological leadership. However, the reasons for this neglect are probably not only rooted in the deep influence of equilibrium or convergence assumptions on current economic thinking, but also in problems related to the measurement of innovation and diffusion of technology across countries. The latter will now be considered more closely.

Productivity, patents and R & D

In the preceding section, we defined two concepts related to a country's level of economic and technological development, the total level of knowledge appropriated in the country (T), and the level of knowledge created within the country (N).

The first concept (T) refers to the total set of techniques in use in the country, whether invented within the country, or diffused to the country from the international economic environment. T cannot be measured directly. What can be measured, however, is the output of the process in which these techniques are used, or the level of productivity (Q/L). We have, therefore, as a number of earlier studies chosen to use Real GDP per capita as a proxy for T. However, since current prices and exchange rates are known to produce downward-biased estimates of Real GDP per capita for countries with productivity levels below the world productivity frontier; we adjusted the data on GDP per capita accordingly on the basis of results obtained by the 'United Nations International Comparison Project'.[19]

The second concept (N) refers to the country's own creation of technology, or its level of national technological activity. To find a proxy for this, we have to look outside the range of variables traditionally included in growth studies. It is customary to divide measures of technological activity into 'technology-input' measures and 'technology-output' measures (Soete 1981). Of the former type, expenditures on education, research and development, and employment of scientists and engineers may be mentioned; of the latter, patenting activity. Regarding the former type, these measures reflect to some degree both imitation and innovation, since a certain scientific base is a precondition for successful imitation in most areas (Freeman, 1982; Mansfield, 1982). Another problem with 'technology-input' measures is that data generally are of a poor quality, especially for non-OECD countries. Patenting activity, on the other hand, reflects the innovation process much more directly than 'technology-input' measures, even if the propensity to patent varies considerably across industries (Pavitt, 1983). Furthermore, data on patents exist for a large group of countries and long time-spans. Until recently, differences in national patenting regulations were considered to make it difficult to compare patenting activities across countries,[20] but this problem may be significantly reduced by limiting the analysis to patenting activities of different countries in one common (foreign) market (Soete, 1981). Contrary to Soete who used patenting in the United States as an indicator, this study uses patenting on the world market.[21] This has the advantage that it gives data for the United States.

Let us now take a closer look at the relation between the two concepts as well as the proxies chosen. What we should expect, following the technology-gap argument, is that the technologically most advanced countries, in terms of high levels of national technological activity (N), also are the economically most advanced, in terms of GDP per capita (T). Since the relation between own and foreign-produced technology should be expected to increase rapidly as the country moves towards the world innovation frontier, the relation between GDP per capita (T) and national technological activity (N) should be expected to be log-linear rather than linear, and steeper for patent-based than for R & D-based indices since the latter to a large degree reflects both imitation and innovation processes.

These hypotheses are tested on cross-sectional data (yearly averages) from the 1973–83 period. The sample consists of twenty-seven developed and semi-industrialized countries for which data are available (twenty-four for R & D). The following variables are used:

Table 20.3 The relation between productivity and technological activity

(1)	$T = 5.72 + 0.02\text{EPA}$ $(9.80)^*\ (4.49)^*$	$R^2 = 0.45\ (0.42)$, SER = 2.14, DW = 0.72
(2)	$T = -1.44 + 2.14\ \ln\text{EPA}$, $(-1.25)\ (8.06)^*$	$R^2 = 0.72\ (0.71)$, SER = 1.52, DW = 1.58
(3)	$T = -4.28 + 8.45\ \ln\ln\text{EPA}$, $(-3.07)^*\ (8.69)^*$	$R^2 = 0.75\ (0.74)$, SER = 1.44, DW = 1.79
(4)	$T = 4.16 + 0.32\text{RD}$, $(4.84)^*\ (4.98)^*$	$R^3 = 0.53\ (0.51)$, SER = 1.89, DW = 1.27
(5)	$T = 0.49 + 3.21\ \ln\text{RD}$ $(0.33)\ (5.18)^*$	$R^2 = 0.55\ (0.53)$, SER = 1.85, DW = 1.21
(6)	$T = 3.65 + 5.41\ \ln\ln\text{RD}$, $(3.33)^*\ (4.27)^*$	$R^2 = 0.45\ (0.43)$, SER = 2.04, DW = 1.03 N (1–3) = 27, N (4–6) = 24

* = Significant at the 1 per cent level at a two-tailed test.
SER = Standard error of regression.
DW = Durban–Watson statistics.
The numbers in brackets under the estimates are t-statistics. The numbers in brackets after R^2 are R^2 adjusted for degrees of freedom.

T = GDP per capita in constant 1980 US dollar (adjusted for differences in purchasing power of currencies)
RD = Civil R & D as % of GDP
EPA = External patent applications per billion of exports[22] (constant 1980 dollars)

The results are given in Table 20.3. First, whatever the form of the independent variable, a positive relation between productivity and national technological activity exists, significantly different from zero at a 1 per cent level. Second, as expected, the best results are obtained for log-linear models (log for R & D and double-log for patents, which implies a steeper curve in the latter case). Third, the correlation between productivity and patenting is much closer than between productivity and R & D. Fourth, in the case of productivity and R & D, the residuals show signs of serial correlation.[23] This indicates that countries on almost the same level of productivity tend to have correlated residuals, i.e. that the estimated level of R & D deviates from the observed level in a systematic way depending on the level of productivity (see graph 2 below).

Figure 20.1 plots the actual and estimated number of patents per billion of exports against GDP per capita (model 3 above). As can be seen from the figure, with some exceptions, the countries of our sample fit the regression line quite well. The main source of variance is Japan and a group of small, developed countries headed by Norway. Figure 20.2, which plots actual and estimated R & D against GDP per capita (model 5 above), shows that the variance in this case is larger. In addition to Japan and the group of small, developed countries referred to above, the variance comes

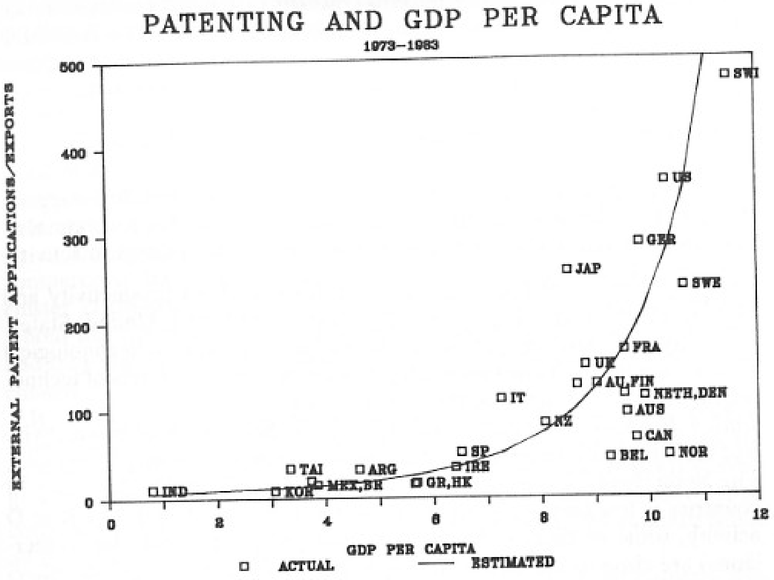

Figure 20.1 Patenting and GDP per capita (1973–83)

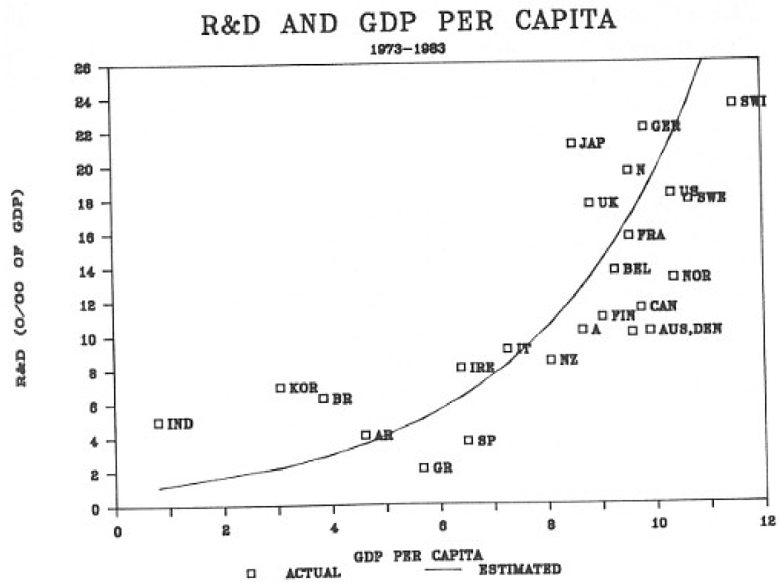

Figure 20.2 R & D and GDP per capita (1973–83)

from the semi-industrialized countries, which in most cases show much higher levels of R & D than should be expected, given their levels of GDP per capita. This latter phenomenon is in accordance with the assumption that a certain level of R & D is a necessary condition for imitation.

Patterns of development and growth

The general picture which emerges from Figures 20.1 and 20.2 suggests that the countries of our sample may be divided into three or four 'clusters' depending on the relation between productivity and technological activity.

Cluster A consists of four countries with high levels of productivity and high levels of technological activity: Switzerland, the United States, Germany and Sweden. These countries are the typical 'technological frontier' countries of our sample. Japan joins this group in terms of technological activity, but not in terms of productivity.

Cluster B consists of seven countries with medium levels of productivity and medium levels of technological activity: France, the United Kingdom, The Netherlands, Austria, Finland, Italy and New Zealand. This group of countries is less homogeneous than the other groups. In terms of R & D activity, some of them (France, the United Kingdom, and The Netherlands) are close to the leader countries, but they patent less, while others have more in common with the semi-industrialized countries or the countries in cluster C below.

Cluster C consists of five countries that have high levels of productivity, but relatively low levels of measured technological activity: Norway, Belgium, Canada, Australia and Denmark (Belgium is close to cluster B in terms of R & D, but not in terms of patenting activity). What most of these countries have in common, in addition to high productivity and low technological activity, is small size and an industrial structure based on natural resources.

Cluster D consists of the semi-industrialized countries of the sample (except India): Spain, Ireland, Greece, Hong Kong, Argentina, Brazil, Mexico, Taiwan and Korea. They have low levels of productivity and patenting, but their R & D efforts vary considerably.

Finally, Japan and India are in a sense 'freak cases'. Regarding Japan, the level of technological activity, measured through patents or R & D, is much higher than should be expected from the measured level of productivity. One way of interpreting this result is that it shows that the Japanese by the late 1970s had still not fully reaped the economic benefits of the country's high level of technological activity. In the case of India, this country fits the characteristics of cluster D in terms of technological activity, but the level of productivity is much lower.

Table 20.4 gives some further evidence on the patterns of growth of these countries in the last decade. This evidence confirms the type of interpretation of history that normally comes out of applied work on

technological gaps and 'catch-up' processes. The frontier countries in cluster A show on average the weakest performance in nearly every respect: cluster A countries have lower economic growth, lower level of investments, lower growth in the labour force and less structural change than other countries. The medium-technology countries in cluster B, and the small, natural-resource-based economies of cluster C, come second and third worst, respectively, in most respects: economic growth, investments and growth of labour force. (But cluster B countries compete favorably with cluster C in two respects—growth of patenting activity and structural change). However, all developed countries become 'laggards' compared to the semi-industrialized countries of cluster D. On average, cluster D countries have rates of growth of GDP, patenting activity and labour force between two and three times that of the developed countries, and they also have much higher levels of investments and faster structural change.

It is important to note, however, that there are large differences in growth patterns within cluster D: the Asian NICs show a much better performance in all respects than Latin American and European NICs, even if the latter countries still have better performance than the developed countries in most areas (though not patent growth). But the distance is not all that large, especially to cluster C countries.

The growth pattern of Japan is an interesting mix of the patterns discussed so far. In terms of level of technological activity (and growth of labour supply), Japan belongs to cluster A, and in terms of productivity and structural change to cluster B. However, when it comes to GDP growth, patent growth and investment behavior, Japan shares many of the characteristics of cluster D countries. In fact, the share of investments in GDP is even higher than that of the Asian NICs.

'Explaining growth'

There are at least three important problems that have to be considered in an econometric test of the technology gap model.

(1) Are all relevant variables included?
(2) If so, what is the relation between these variables?
(3) How to quantify the variables.

The first problem refers to the section on technology-gap theory. Briefly, what we did was to develop a model where economic development is shaped by two conflicting forces—innovation, which tends to increase productivity differences between countries, and diffusion, which tends to reduce them. The fundamental (causal) factors of our model of economic growth are growth in national technological activity, diffusion of technology from abroad, and growth in the capacity for economic exploitation of these factors. However, there are other variables that could be considered as relevant. The most obvious candidates, to be considered below, are

Table 20.4 Patterns of growth 1973–83

	GDP growth	Patent growth[1]	Structural change[2]				Development level		
			Investment share in GDP	Export share in GDP	Agriculture as share of GDP	Population growth	GDP per capita[3]	External patenting/exports[3]	R & D per capita
All countries	2.8	5.0	23.6	6.0	−3.6	1.4	1.0	1.0	
Cluster A	1.3	1.3	20.5	4.8	−1.0	0.8	1.4	3.0	2.0
Cluster B	1.8	4.6	22.1	7.3	−2.2	0.9	1.2	1.1	1.3
Cluster C	2.3	3.0	23.2	3.4	−2.0	1.1	1.3	0.6	1.2
Cluster D	4.4	8.1	25.6	7.5	−5.2	2.1	0.6	0.2	
of which:									
European NICs	2.7	1.1	23.2	8.8	−4.7	1.3	0.8	0.3	0.5
Latin-Am. NICs	3.2	0.8	24.3	3.2	−1.8	2.2	0.5	0.2	
Asian NICs	7.3	22.4	29.1	10.4	−9.2	2.9	0.5	0.2	
Japan	3.7	9.0	31.4	7.9	−2.6	0.8	1.1	2.2	2.1

[1] *Growth in external patent applications relative to the frontier country (Switzerland).*

[2] *Annual change in %.*

[3] *Average = 1.*

growth in labor supply (the neo-classical candidate) and changes in the sectoral composition of output and employment (the structural candidate).

The neo-classical candidate, growth in labour supply, has already been discussed at some length. Our argument was that the existence of excess labour, or growth of labour supply, though permissive to growth, cannot be regarded as a causal factor of growth in the same sense as the technology-gap variables, especially not as long as unemployment prevails.[24] It is also questionable what role should be attributed to factors reflecting structural changes within the economy, even if one accepts the 'dual-economy argument' of large and persistent differences in productivity between sectors. To some degree, such changes should be regarded as effects, rather than causes, of economic growth. However, if institutional obstacles for transfer of resources from one sector to another exist, this may restrain growth. Thus, what we will do is to test the basic technology-gap model with and without variables reflecting structural changes, in order to decide to what degree these variables add something to the explanatory power of the model.

The next step in testing the theory is to find reliable proxies. This has already been discussed at some length in the previous sections. Following this discussion, we use growth in external patent applications (PAT) and growth in civil R & D (RDG) as proxies for growth in national technological activity, and GDP per capita, adjusted for differences in purchasing power of currencies, as a proxy for the total level of knowledge appropriated in a country, or 'productivity' (T). Since we have more observations for patents than R & D, we will use the latter only to test the sensitivity for shift of proxy. As in most other studies, the investment share (INV) was chosen as an indicator of the growth in the capacity for economic exploitation of innovation and diffusion. This is, of course, a simplification since institutional factors obviously take part in this process. But the share of investment may also be seen as the outcome of a process in which institutional factors take part, i.e. differences in the size of the investment share may reflect differences in institutional systems as well. For structural changes, we used changes in exports and agriculture as shares of GDP as proxies.

The problem of interdependence between variables relates to the discussion in the preceding section on patterns of growth. Obviously, one of the impressions from this discussion is that the different factors that shape growth to some extent are interrelated. For instance, the fastest-growing countries of the sample, the Asian NICs, have a larger 'technological gap' *vis-à-vis* the technological leaders, higher growth in patenting activity, invest more and show faster structural change than most other countries. The opposite is true for the 'technological leaders' of cluster A. But the preceding section also shows that countries follow different patterns of development and growth. The Latin American NICs, for instance, have a 'technological gap' comparable to the Asian NICs, but they invest much less, their level of patenting activity grows much slower, and they show less structural change. In fact, their growth of patenting activity is inferior to all other groups of countries. Similar examples of different development patterns, though less spectacular (except Japan, of course), may be found among developed countries. Thus, even if it is difficult to deny that the variables to some degree may be interdependent, as most economic variables in fact are, we hold it as unlikely that this will cause multi-collinearity.

However, the problem is not only one of multi-collinearity, but also of interpretation. Therefore it is necessary to consider the possible feedbacks from the dependent to the independent variables, as well as the forms of interaction between the latter. We will limit this discussion to the basic model as outlined earlier. For theoretical reasons, we hold it as unlikely that differences in development levels and growth in national technological activity across countries can be analysed as mere reflections of, or be shown to depend strongly on, differences in economic growth or investments between countries. This is also supported by empirical evidence (Clark, Freeman and Soete, 1982).[25] An interaction between the two technology variables cannot be ruled out *a priori*, but seems less likely in light of the discussion above of differences in growth patterns between countries on comparable levels of development. The same holds for investments when related to the two technology variables. The most probable form of interdependence, therefore, runs from economic growth, interpreted as a demand variable, to investments. However, even if this may be true to some extent, available evidence suggests that differences in growth of domestic demand alone cannot explain the huge and persistent differences in investment ratios between countries (Fagerberg, 1986).

The following variables were used:

GDP	=	Average annual growth of GDP at constant prices
T	=	GDP per capita at constant 1980 prices (dollars) adjusted for differences in the purchasing power of currencies
PAT	=	Average annual growth in external patent applications (abroad)
RDG	=	Average annual growth in Civil R & D (inflation adjusted)
INV	=	Investments as a share of GDP at constant prices
AGR/EXP	=	Annual average change in agriculture (exports) as a share of GDP(‰))

The results of the test follow in Table 20.5 below. Generally, the results give strong support to the basic technology-gap model as a model of 'why growth rates differ' between countries. The degree of explanation is very high, above 80 per cent, and all variables turn up with the expected signs, significantly different from zero at the 1 per cent level. The results were not very sensitive to the choice of innovation proxy. Since Japan is often regarded as a special case, we also estimated the model with a dummy for Japan, but this did not influence the results.

Table 20.5 The model tested (27 countries, 1973–83)

1. Basic model							
GDP =	0.38	− 0.24*T*	+ 0.12PAT	+ 0.20INV			R^2 = 0.83 (0.81)
	(0.25)	(−3.74)*	(4.02)*	(3.47)*			SER = 0.85
							DW = 2.12
2. Basic model with dummy for Japan							
GDP =	−0.60	− 0.22*T*	+ 0.11PAT	+ 0.23INV	− 1.22JAP		R^2 = 0.84 (0.81)
	(−0.35)	(−3.40)*	(3.84)*	(3.67)*	(−1.24)		SER = 0.84
							DW = 2.24
3. Test for effects of changes in agriculture as a share of GDP							
GDP =	0.47	− 0.25*T*	+ 0.12PAT	+ 0.20INV	+ 0.005AGR		R^2 = 0.83 (0.80)
	(0.26)	(−2.88)*	(3.68)*	(3.35)*	(0.10)		SER = 0.87
							DW = 2.10
4. Test for effects of changes in exports as a share of GDP							
GDP =	0.81	− 0.24*T*	+ 0.14PAT	+ 0.20INV	− 0.07EXP		R^2 = 0.85 (0.82)
	(0.53)	(−3.85)*	(4.54)*	(3.65)*	(−1.74)**		SER = 0.82
							DW = 1.85
N = 27							
5. Test for shift of innovation proxy							
GDP =	0.43	− 0.16*T*	+ 0.11PAT	+ 0.16INV			R^2 = 0.75 (0.71)
	(0.28)	(−2.48)**	(3.21)*	(2.90)*			SER = 0.80
							DW = 1.41
GDP =	−1.01	− 0.17*T*	+ 0.18RDG	+ 0.16INV			R^2 = 0.75 (0.71)
	(−0.72)	(−2.54)**	(3.27)*	(2.97)*			SER = 0.80
							DW = 1.78
N = 22							

* = Significant at a 1 per cent level (two-tailed test).
** = Significant at a 10 per cent level (two-tailed test).
R^2 in brackets = R^2 adjusted for degrees of freedom.
SER = Standard error of regression.
DW = Durbin–Watson statistics.
N = Number of observations included in the test.

The results do not support the hypothesis of structural changes as independent, causal factors of economic growth. Both variables turn up with signs opposite of what should be expected, in the case of exports significantly different from zero at the 10 per cent level. The latter may be interpreted in support of the view that the influence of change in outward orientation on growth depends on international macroeconomic conditions, i.e. that the slow growth in world demand in the 1970s restrained the growth of outward-oriented countries.

Table 20.6 Actual and estimated differences in growth *vis-à-vis* the frontier countries, 1973–83

	Actual difference in growth	Estimated difference in growth	Explanatory factors: Diffusion	Innovative activity (growth)	Investment (level)	Export orientation (change)
Cluster A	—	—	—	—	—	—
Cluster B	0.5	1.0	0.4	0.4	0.3	−0.2
Cluster C	1.0	1.0	0.2	0.2	0.5	0.1
Cluster D	3.0	3.1	1.4	0.9	1.0	−0.2
of which:						
European NICs	1.3	1.2	1.0	−0.0	0.5	−0.3
Latin Am. NICs	1.9	2.3	1.5	−0.1	0.8	0.1
Asian NICs	6.0	5.7	1.6	2.9	1.7	−0.4
Japan	2.4	3.5	0.5	1.0	2.1	−0.2
All countries	1.5	1.7	0.7	0.5	0.6	−0.1

Table 20.6 decomposes the differences in growth between the frontier countries (cluster A) and the others (model 4). The following picture emerges:

(1) Differences in growth between the frontier countries and the other groups of developed countries (Japan excluded) were rather small in the period under consideration, about 1 per cent as a maximum (cluster C – cluster A). The model attributes this difference to a combination of factors, although technological factors seem to have greater significance for cluster B than for cluster C countries, while investments seem to matter more for the latter.

(2) The model attributes the higher growth of Japan, when compared to the frontier countries (around 3 per cent), mainly to Japan's high growth in national technological activity and the high level of investments in the country.

(3) Within the group of semi-industrialized countries, two distinctly different growth patterns may be observed. The European and Latin American NICs grow on average 1.5–2 per cent faster than the frontier countries, primarily because of diffusion of technology, but partly also because of a higher share of resources devoted to investments. The Asian NICs, however, grow on average about 6 per cent faster than the frontier countries, and 3–4 per cent faster than the other NICs. The model attributes this latter difference to the rapid growth of the Asian NICs' own technological activities, in combination with high levels of investments.

Concluding remarks

Most studies of 'why growth rates differ' between countries have in common the fact that they ignore innovation and lack a systematic theory of what causes growth to differ. Thus, while useful as descriptions, they do not really explain differences in growth performances across countries.

This chapter has developed a simple, testable model of economic growth based on Schumpeterian logic. Both this logic and the subsequent test point strongly in the direction of a close relation between economic growth and growth of national technological activities, a fact that is normally forgotten. Thus, to catch up with the developed countries, the results obtained here suggest that semi-industrialized countries cannot rely only on a combination of technology import and investments, but have to increase their national technological activities as well.

However, the limitations should also be stressed. For instance, the technology-gap model developed here has little or nothing to say on how to achieve higher growth in innovative activity or other efforts related to the exploitation of innovation and diffusion. Furthermore, sectoral as well as inter-temporal differences in the international process of innovation and diffusion, and the relation between these changes and similar changes in the institutional system, are ignored.[26] To do full justice to the theoretical perspective which underlines the model developed in this chapter, nothing less than a multi-sector, multi-country evolutionary model of technological and institutional change would be required.[27]

Appendix

Methods

Growth rates are calculated as geometric averages for the period 1973–83, or the nearest period for which data exist. Levels and shares are calculated as arithmetic averages for the period 1973–83, or the nearest period for which data exist. Changes in shares are calculated as total change in the share between 1983 and 1973, divided by the number of years (normally ten, sometimes less) $((s(t_1) - s(t_0))/n)$.

Sources

Real GDP per capita, 1980 market prices in US dollars, growth of gross domestic product at constant prices, agriculture, exports and gross fixed capital formation as a share of GDP:

OECD countries: *OECD Historical Statistics 1960–1983*.

Taiwan: *Statistical Yearbook of the Republic of China 1984*.

Other countries: *IMF Supplement on Output Statistics and UN Monthly Bulletin of Statistics*.

For Switzerland and New Zealand, data for Agriculture as a share of GDP were not available, so the data for these countries are estimates (based on employment).

External patent applications:
OECD countries: *OECD/STIU DATA BANK*.
Other countries: World International Property Organization (WIPO); *Industrial Property Statistics* (various editions) and unpublished data.
The OECD data are adjusted WIPO data. Data for the non-OECD countries are compiled from published WIPO statistics except for Hong Kong, Korea and Taiwan 1975–83 where data are compiled by WIPO from unpublished sources.

The R & D data are estimates based on the following sources:
OECD countries: *OECD Science and Technology Indicators, Basic Statistical Series (vol.B, 1982) and Recent Results (1984))*.
Other countries: *UNESCO Statistical Yearbook* (various editions) and various UNESCO surveys on resources devoted to R & D.
Military R & D expenditures were, following the OECD, assumed to be negligible in all countries except the United States, France, Germany, Sweden and the United Kingdom. The R & D data for these countries were adjusted downwards according to OECD estimates. The estimates were taken from OECD, Directorate for Science, Technology and Industry; 'The problems of estimating defence and civil GERD in selected OECD member countries' (unpublished). For other countries, civil and total R & D as a percentage of GDP were assumed to be identical.

Growth of labor force (population between 15 and 64):
OECD Historical Statistics 1960–1983, *OECD National Accounts* (various editions), *UN Monthly Bulletin of Statistics* (various editions), and *Statistical Yearbook of the Republic of China 1984*.

Notes

1. The purpose of the following is to discuss some main characteristics of postwar research in this field, not to give a complete survey. For survey articles covering the whole or parts of this field, the reader is referred to Choi (1983, Chapter 3), Nelson (1981), Chenery (1986) and Maddison (1987).
2. See, for instance, the works by Gerschenkron (1962) and Landes (1969).
3. '. . . the forces animating growth in the lead countries are more mysterious and autonomous than in the follower countries . . .' (Maddison, 1982, p. 29).

4. See, however, Abramovitz's instructive, but inconclusive discussion of possible factors influencing change of leadership (Abramovitz, 1986, pp. 396–405).
5. According to the numbers presented by Abramovitz, US GNP growth over the period 1869/78 – 1944/53 equalled 3.5 per cent, of which 1.8 per cent could be attributed to growth of inputs, and 1.7 per cent was left as unexplained. Similar, if not identical, results were reported by Solow (1957), Kendrick (1961) and Denison (1962).
6. Jorgensen and Griliches originally claimed that the residual could be eliminated altogether, but later retreated from this position. See the debate between them and Denison (Denison, 1969; Jorgensen and Griliches, 1972) on this subject.
7. cf., for instance, the following programmatic remark by Denison: 'Because knowledge is an international commodity, I should expect the contribution of knowledge—as distinct from the change in the lag—to be of about the same size in all the countries examined in this study' (Denison, 1967, p. 282).
8. However, in his 1976 study of Japan, he acknowledges that in this case, 'There was, in other words, a major element of 'catching up', . . . (Denison and Chung, 1976, p. 49).
9. More recently, Kendrick (1981b) has published a study of the growth of nine OECD countries between 1960 and 1979 based on Denison's methodology. But contrary to Denison's analysis, this study attributes a large part of the final residual to 'catching up', especially in the period 1960–73.
10. '. . .some of the recent studies seem to imply that somehow the growth accounts really explain growth. I do not see how they can. A growth accounting is not a tested theory of growth' (Nelson, 1973, p. 466).
11. It should be noted that Kendrick (1981b), in his study of nine OECD countries between 1960 and 1979, includes the contribution to growth from cumulative national R & D outlays. However, according to Kendrick's calculations, this contribution was almost negligible.
12. The purpose of what follows is only to discuss some problems related to applications of neo-classical production-functions to cross-country samples. We do not in any way attempt to survey the development of neo-classical growth theory or the theoretical controversies that followed. For a good (but old) survey of growth theory, see Hahn and Matthews (1964). Pasinetti (1974) provides an exciting introduction to the development of the neo-classical growth theory and the subsequent controversy from a post-Keynesian point of view.
13. For reviews of this literature, as well as empirical evidence, see Choi (1983), Chapters 5–6 and Chenery (1986).
14. Of course, the labor-force variable may still turn up with the expected sign significantly different from zero at the chosen level of significance. But this may simply reflect that the growth of labor force is positively correlated with other variables that affect growth positively, as, for instance, the level of development.

    The correlation between growth in labor supply (*POP*) and GDP per capita measured in *PPPs(T)*, a much-used proxy for the potential for technology transfer, for the twenty-seven countries included in our sample (see the next sections) was (the numbers in brackets are *t*-statistics; one star denotes significance of test at the 1 per cent level):

$POP = 3.16 - 0.23T, \quad R^2=0.56(0.55)$
(9.54) (-5.70)

15. It should be noted that there are a few examples of researchers who have estimated neo-classical growth models with some kind of 'development-level' variable included (Chenery, Elkington and Sims, 1970; Parvin, 1975).
16. The major contributors to this development were Gomulka (1971) and Cornwall (1976, 1977), but the main arguments were outlined much earlier by Posner (1961), even if Posner's main concern was specialization, not growth. Krugman (1979) has recently constructed a formal model of north–south trade based on similar arguments. For a more thoroughgoing treatment of these aspects, see the preceding chapter by Dosi and Soete in this book.
17. For a general discussion of some of these issues, see Clark, Freeman and Soete (1982), Perez (1983), and the chapters by Freeman–Perez and Boyer in this book.
18. In the present context, knowledge means 'technological knowhow' (knowledge and skills on how to produce goods and services).
19. The UN study (Kravis *et al.*, 1982) provides estimates for Real GDP (Nominal GDP adjusted for differences in the purchasing power of currencies) and Nominal GDP for thirty-four developing, semi-industrialized and developed countries for the year 1975. Since many of the countries included in our sample are not covered by the UN study, we used one of the short-cut methods developed there to estimate a relation between Real and nominal GDP per capita (r and n) for a sample of countries comparable to ours, and then used this estimated relation to predict Real GDP per capita for the countries of our sample. The estimated relation was (with a dummy for Jamaica (an extreme deviant) included):

$$\ln r = 1.14 + 1.229 \ln n - 0.042 (\ln n)^2 - 0.372 \text{ JAMAICA}$$
(1.52) (5.70)* (-2.82)* (-3.49)*

$N=27$
$R^2 = 0.99(0.98)$
(The numbers in brackets under the estimates are t-statistics; one star denotes significance at the 1 per cent level)

20. Nevertheless, Soete (1981) found quite a close correlation between levels of domestic patenting and R & D expenses in a cross-country study covering the business enterprise sector in nineteen OECD countries.
21. That is: total patent applications of residents in country x in all countries which report patent applications to WIPO (World Intellectual Property Organization) less patent applications by residents of x in country x.
22. For the sake of comparison with other variables, we will in this section deflate the total numbers of patent applications filed in other countries (external patent applications) by exports. The argument in favor of using exports as a deflator instead of GDP or population is that this adjusts for differences in export orientation, which could have biased the index (as a measure of innovating performance) upwards for countries where the share of exports in GDP is high, and downwards for countries where the share of exports in GDP is low, as, for instance, the United States and India.
23. The data are organized in descending order of GDP per capita (as it was in the early 1960s, though). This implies that the Durbin–Watson statistics can be given a special interpretation: it shows whether countries on approximately the same level of GDP per capita tend to have correlated residuals.

24. This is not to deny that limitations in labour supply may restrict the growth of certain countries in certain periods, but this is not considered relevant in the period under consideration here (1973–83). Cornwall (1977), however, holds that it was not relevant in the pre-1973 period either.
25. On this point, see also Fagerberg (1987).
26. For a discussion of some of these issues (determinants of innovation, sectoral differences in innovation patterns, national systems of innovation and policy issues), the reader is referred to Parts IV–V of this book.
27. To the best of our knowledge, no attempts to construct international models along these lines have yet been made, but it certainly represents a path worth following. For a general discussion of evolutionary modelling, see the chapter by Silverberg in this book.

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21 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 unidirectional process, development will be seen as a race along a fixed track, where catching up will be merely a question of relative speed. Speed is no doubt a relevant aspect, but history is full of examples of how successful overtaking has been primarily based on running in a new direction.

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

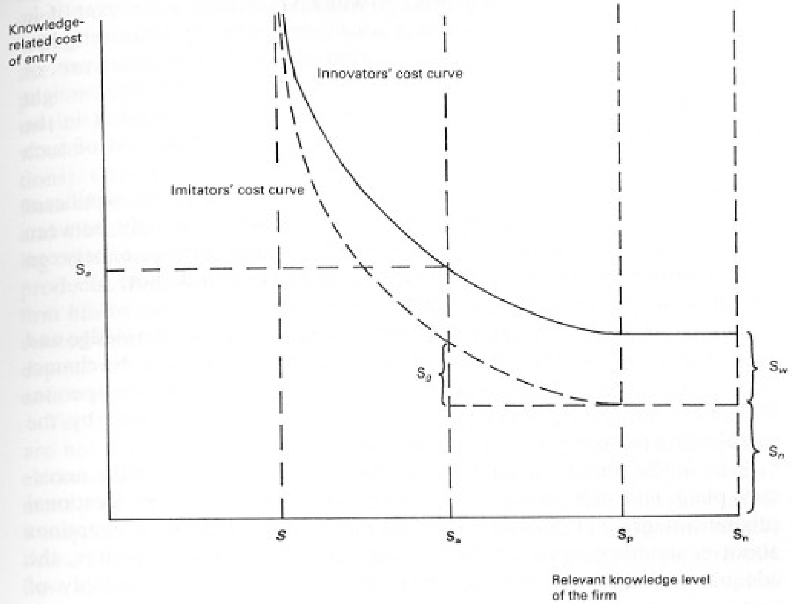

Figure 21.1 Varying knowledge-related cost of entry for different innovating and imitating firms.

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).

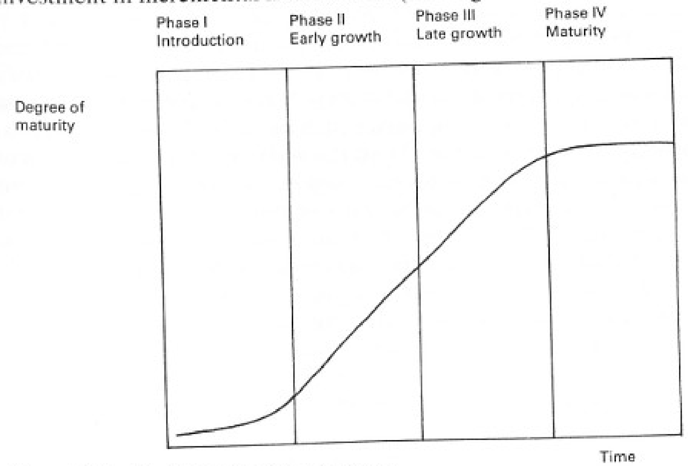

Figure 21.2 The life cycle of a technology

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

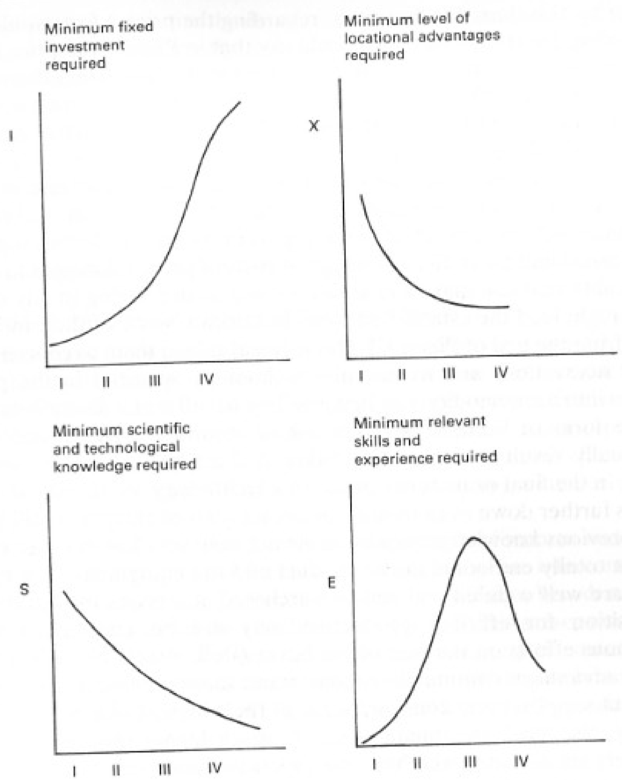

Figure 21.3 Variation in the components of the cost of entry over the four phases of the technology life cycle.

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 micro-electronics 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 occurring 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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22 Industrial structure, technical change and microeconomic behaviour in LDCs

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Introduction

The conventional analysis of import substitution industrialisation has by now produced a considerable number of studies accounting for the failure and successes achieved by many countries through that route. In spite of the broad coverage of these analyses there are still several major areas of dynamic analysis waiting to receive better attention. Two of these are the dynamics of competition (and what it implies with respect to the process of innovation) and the process of technological learning. It is my belief that the dynamics of competition and learning in less developed countries (LDCs) need to be better understood before we attempt to model the entrepreneurial reactions and attitudes towards innovation that would be necessary to accommodate together the micro and macro objectives of the new industrialisation strategies in those countries.

By examining the underpinnings of traditional import substitution industrialisation analysis in these two dynamic areas, we may be able to show that the very basic requirements of some of the new, more aggressive industrialisation policies, such as export promotion and/or technological leapfrogging with regard to microelectronics and biotechnology, are—and in line with the arguments set out in the previous chapter—very difficult to attain.[1] The most obvious factor missing to guarantee the success of these policies is that of the Schumpeterian entrepreneur, for whom the jump in quantum and quality of the 'domestic supply' required is so enormous that it seems unrealistic. Furthermore, the evolutionary sequence of entrepreneurial build-up of technological capabilities stressed by authors such as Nelson and Winter (1982) and Katz (1984) within the context of less developed countries suggests a gradual process not easily amenable to leapfrogging or to the sudden change to the export-oriented industrialisation argument. Here we intend to show that past experience with regard to entrepreneurial behaviour during import substitution industrialisation supports neither the demands nor the expectations now raised by the new strategies. In addition, we will argue that the user–producer interactive scheme of industrial innovation, as emphasized in various other contributions to this book but in particular in the chapter by Lundvall, is also rather weak in most LDCs due to the lack of a sufficiently strong capital-

goods sector as well as the poor development of the institutional framework essential to the creation of the national system of innovation.

The chapter is divided into two sections. The first one summarises the characteristics of the industrial structure that developed during import substitution industrialisation: the preference for expanding the consumer-goods industries in oligopolistic markets, facilitated by the use of imported technology, and generating few incentives or rewards for entrepreneurial risk-taking. In the second section, the issue of technology transfer and related topics of technological change such as diffusion, packaging and learning are explored to explain the relatively slow development of technological capabilities taking place during this process. Some conclusions that bear on the prospects of the new strategies are briefly summarised at the end.

Industrialisation, entrepreneurship and the market system in LDCs

The choice of domestic production to substitute for imports implemented through import substitution industrialisation in most LDCs has meant the creation of two major negative results. One is a far less than competitive environment biased towards the development of consumer-goods industries (of relatively high profitability in spite of their inefficiency); the other is the continuing dependency of the economy on imports of production goods. Given the inefficiency of consumer-goods industries to compete in external markets through exports, a limit to the imports capacity of production goods has appeared as a result of foreign exchange constraints. Consequently, most LDCs have ended up with a stagnant, inefficient and non-integrated industrial sector.

The way in which such results were achieved, we will argue, must be analysed in a more rigorous manner than that conventionally adopted by simply attributing them to market inefficiencies induced externally to the proper (ideal) mechanisms that *ought* to conform to the neo-classical market paradigm. The fact that those results are more the rule than the exception demands from us an attempt to construct new forms of analysis. Here we adopt an approach similar to that suggested by some of the evolutionary writers reviewed in the rest of the book. The thread of the argument evolves around the way in which technical change is incorporated into and determines the industrial structures of LDCs during the process of import substitution industrialisation.

Such an outcome is far from being conducive to an equilibrating situation. For many countries, and especially the advanced countries, the proposition sustained in the introduction and in other chapters of this book may well be accepted: that the world is much more stable and ordered than what can be deduced on the grounds of the prevailing theory.[2] However, it is hard to conceive of such an automatic adjustment taking place in the LDCs in present times, and even less so if the market system is still assumed to guide the adjustment process into the near future.

Ever since the beginning, the price system has been denied its basic allocative function as the guiding post reflecting scarcity, quality and choice of priorities for the development of new industrial activities in LDCs. For one, the import substitution industrialisation strategy relied on a protection system to fix domestic prices, and that system gave rise to and *perpetuated* a set of pricing practices that discriminated against production goods and exports, favouring the continuing extension of the mix of consumer goods domestically produced. The profitability of the latter was not necessarily related to their efficient production, and was enhanced through a double mechanism that offered both high domestic prices to the protected consumer goods, while at the same time allowing those producers to import production goods at international or subsidised costs. These are in the end the main causes accounting for the failure of the import substitution industrialisation strategy to solve the balance-of-payments structural constraints which it was originally supposed to correct.

Although most people would agree on the poor implementation of protection in most countries,[3] there is still controversy about its future uses and about the extent to which the pure market system can be expected to substitute for it efficiently.

The major assumption behind the liberalisation proposals is usually related to the fact that in the absence of protection efficiency will appear everywhere (i.e. the old virtues of the market system will take over only if imperfections of this sort are removed), a result which is very unlikely to occur; more probably, some domestic industries will disappear in the face of open competition from imports. Whether the trade balance will as a result turn positive is unclear. More importantly, however, the validity of the infant industry argument will need to be retained if the logic of future industrial development of LDCs were to suggest priority to the production-goods (and particularly capital-goods) industries. This priority would seem to be reinforced when considering the diffusion of the new micro-electronics technologies, since these may have a considerable impact on the design, the production and the functioning of many capital goods.

The importance of developing a domestic capital-goods industry seems generally accepted as a necessary condition to enhance a country's capacity to develop successful innovations. This is well argued in the analysis of the innovation process as the result of effective user–producer interactions, as illustrated in Lundvall's chapter. It is also implicit in the taxonomy of technological trajectories developed by Pavitt (1984), and most clearly so in respect of the supplier-dominated group of industries. In both these accounts one discovers a key role for the machinery-producing sector in the development of the patterns of specialisation that are observed for most of the Scandinavian and Western European industrialised countries.

However, the user–producer approach also argues that inertia tends to consolidate the existing user–producer networks, an inertia that leads to decision-making on the basis of past experiences. This inertia develops not only within national systems of innovation, but also with regard to relationships involving domestic user firms and foreign producers well established in the international machinery or technology markets. This is a picture extremely familiar to many LDCs. Thus the permanent links reinforced through imported capital goods and technology create a degree of technological dependence that may not be overcome unless very specific policy measures are targeted to that end.

Several agents perform crucial roles that lead one to neglect the strategic importance of an endogenous user–producer interaction. Most of all, the entrepreneurial function is poorly performed from the view of a longer-term perspective of the host economies. This applies to transnational corporations (TNCs), locally owned firms and state enterprises. The subsidiaries of TNCs assume the technological leadership in the economy and become the major source of advanced technology, constituting the main vehicle to transfer technological changes originating from and conforming to the conditions in advanced countries. The TNCs replicate internally to each LDC the oligopolistic market structure of their countries of origin,[4] supplying their previous importers of finished goods with locally assembled goods using imported inputs and imported technology.

With regard to technology, private firms under local ownership have reacted less actively than TNC subsidiaries. They have chosen, even more significantly than the TNC subsidiaries, to concentrate on the most traditional niches of industrial production; food products, clothing, textiles, furniture, wood products and metal products, most of which are usually dominated by local firms. Their technology acquisitions are not differently guided from those of the TNCs, i.e. they search for the well-known and most reliable technology source, which means for the most part imported technology.[5] Price and the use of imported inputs and equipment are not particularly scrutinised, inasmuch as they can pass the costs involved on to the consumers. If these firms had previously been involved in foreign trade, it is yet more likely that their industrial activity and their technology acquisitions would have been limited to assemble or replicate the imported good.[6]

As industrialist the state has also acted rather poorly. First and foremost, the state has usually entered industries where private enterprises have not been interested due to the large amount of investment needed (e.g. steel) or where low-priced intermediate inputs (e.g. petrochemicals, fertilisers) or low-priced basic goods (e.g. maize and other staple goods for the basic diet) have not offered attractive returns to private investors. For the most part, state industries have developed rather inefficiently due to the absence of any competition, and have also been forced to offer those products at subsidised prices to the consumer-goods producers. In other words, not only can the origin of inefficiency be rooted in the inputs at the beginning of the production system—inefficiency which is then transmitted to the rest of the system—but in order to finance these inefficiencies, the state has developed structural deficiencies which it will be difficult to correct in the future.

On the technology side, much like the private sector, state enterprises have in general been passive importers of technology and capital goods. The state-owned enterprises choose their technology under criteria that do not conform to any conventional paradigm. According to James (1986, p. 21), the technological choices of state-owned enterprises are substantially at odds with the traditional theory of the firm. Management decision rules are highly simplified, poorly informed and subject to a variety of subtle motivations of unclear direction.[7] From a different perspective, though, the relatively high capital intensity of most of the industries where the state dominates should provide an interesting opportunity to develop a capital-goods industry.

The short-sighted guidance of the state has been verified again in recent periods, such as in the mid-1970s, when shortages of foreign exchange in many LDCs had already been clearly associated with their heavy dependency on imported production goods. Not long after, explicit policy proposals had appeared making state purchases a key instrument for the development of local capital-goods industries (see, for instance, the Mexican NAFINSA-UNIDO, 1977, programme), and the oil revenues of the late 1970s and early 1980s were wasted in imports of production goods along the same pattern that had characterised most of the previous import substitution industrialisation pattern. Similar behaviour was observed in some of the other oil-rich countries where the state controls the industry (e.g. Venezuela, Ecuador and some of the Arab countries).

Technology transfer and learning in LDCs

In spite of the substantial literature dealing with the transfer of technology and the involvement of TNCs in LDCs,[8] there are still several major issues that have attracted relatively little attention: the determinants and variety of technology transfer, the degree and extent of local learning *vis-à-vis* the continuing dependency on imported technology, the integration of local industry to domestic capital-goods producers, and the role of technology in the international division of TNCs activities. These issues are explored in the remainder of this chapter.

Technology transfer is an old but still inadequately tackled subject in most of the development literature. In so far as there has been in general poor treatment of the innovation and diffusion process in advanced countries, giving rise to the recent suggestions along post-Schumpeterian lines mentioned earlier (the evolutionary approach of Nelson and Winter, and the taxonomy of trajectories of technical change of Pavitt), there is a need to adjust the conventional view of technology transfer as a spontaneous, linear, static, neutral and homogeneous process that does not distinguish between sectors of activity, firms and countries involved. Some of the empirical studies in the early 1970s were already pointing to the necessity of recognising these different characteristics, sectoral conditions and consequences.[9] However, in so far as these were primarily sectoral and country-specific-type of analyses, these studies could not test for explanations on a more generally applicable basis. This remains one of today's major challenges.

In the first instance, one may be able to explain in a more comprehensive manner the determinants of technology transfer: why do firms engage in licensing? According to the dominant foreign investment theories (see in more detail the chapter by Chesnais), firms will choose the direct foreign investment mechanism as their first option, preferring foreign investment for its greater rent-extracting potential, and turning to licensing only if that potential cannot be realised (Caves, 1983, p. 204). Accordingly, it is mostly the circumstances that are relatively unconducive to foreign investment that need to be looked at when determining when licensing will occur (James, 1986, p. 13).

A number of factors may influence the preference for licensing rather than direct investment. According to Caves (1983, p. 224),

> arm's-length licensing is encouraged by risks to foreign investors and barriers to entry of subsidiaries, by short economic life of the knowledge asset, by simplicity of the technology, by high capital costs for the potential foreign investor, and by certain types of product market competition that favour reciprocal licensing.

Thinking of technology transfer as transactions taking place in an organised market (in the sense used in Lundvall's chapter), and taking into consideration some of the factors encouraging the licensing, it would be plausible to expect market imperfections with regard to price-fixing; the extent of knowledge transferred; the degree and timing of diffusion likely to follow the knowledge transferred; and the conditions of packaging involving other elements of technology. The predominant role of TNCs in the technology transfer process adds further questions about the proper working of a market system as such, especially when the transfer is between parent and subsidiary firms.

The way in which prices are fixed for technology transfer contracts hardly resembles the demand–supply static scheme relating prices and quantities. The technological knowledge involved usually represents a whole set of 'indivisible' information which cannot be broken up into marginal quantities. Furthermore, prices, usually in the form of royalties, will be fixed rather arbitrarily, representing merely a compensation of past efforts invested in accumulating the know-how or experience related to the technology transferred. In other words, most of the time there will not be additional or marginal costs associated with the transfer operation.[10] If anything, there is an opportunity cost in the sense that the proprietor might have wanted to exploit the business himself directly, as argued by the direct foreign investment model reviewed above.

Nor is there a well-organised information system to compare the various possible suppliers. Thus even the arm's-length type of licensing may lead to a negotiated price fixed by mutual agreement from both parties, and even though the purchaser may not have complete information to consider less costly alternatives, these may not be of much relevance when he counts on transmitting that price to his domestic, captive (due to protection) customers. The degree of irregularity in price-fixing[11] was probably best illustrated during the first half of the 1970s, when most governments in LDCs were able to introduce legislation limiting royalty payments to less than half the previous percentages, without seriously inhibiting the licensing processes.[12]

One difficult aspect that will influence the technology price is the extent of diffusion of the knowledge transferred versus the exclusive appropriation by the licensee. Virtually all technologies will be subject, sooner or later, to a considerable degree of diffusion. The transfer of technology itself represents the initial step of a diffusion process that may further expand through copying, subcontracting and the like. In fact, access to technology has not been high in the ranking of barriers of entry in the last decade, and less so for older industrial activities where technology has matured.[13] Yet it is difficult to assess *a priori* the number of years during which a firm may be able to profit from the use of technology obtained on an exclusive basis; this period should be, in principle, the only one for which the licensor might have the right to a royalty in exchange.

The assessment of the extent of knowledge involved in the transfer of technology has remained a difficult issue both from a neo-classical perspective and the more explicit assumption of perfect information and from the technological development perspective. Perhaps the most significant contribution to the first is the well-known Arrow paradox on the lack of complete information when acquiring information (Arrow, 1962). If complete information existed, the need to acquire it would naturally disappear.

As far as the relationship between technology transfer and the accumulation of technological capability is concerned, there have been a large number of empirical studies showing a highly diversified pattern in this relationship, depending on the nature of the contract, the firms involved, the sectors of activity, and so on.[14] One needs also—as emphasised in the preceding chapter by Perez and Soete—to distinguish between transfer of knowledge merely related to the proper operation of the specific technology involved and the more ambitious transmission of the 'paradigm foundations' that may enable the licensee to produce for himself the new technologies implicit or likely to develop along the technological trajectory that may be anticipated for that industry or type of products.

Technology transfer studies have generally failed to account for the phenomenon of technological packages. Some studies, especially empirical sectoral studies,[15] have identified a variety of conditions linked to the technology packages. For some sectors, it is the packaging of technology elements as such (trademarks, patents, know-how, etc.) that is crucial. For other sectors, where technology diffusion has been general, technology acquisitions, if any, take place on the basis of single technology elements.

For other sectors, where the principle of producing and/or operating the equipment has not experienced such widespread diffusion, the package often includes the supply of capital goods. As we have already mentioned, and following Pavitt (1984), there will be a good number of sectors where technological trajectories will be crucially dependent upon (among other things) the complementary relations between producers and users of capital goods.

One major shortcoming of technology transfer studies in this area has been the inadequate (sometimes totally absent) treatment of capital goods as a crucial input into the transfer package, something increasingly recognised as important in the discussion on innovation and technological trajectories in advanced countries,[16] but probably even more important for LDCs in so far as it may inhibit their chances to initiate the development of their capital-goods industries. In this respect, earlier suggestions to treat the capital-goods industry both as a source of technology and as the locus for the accumulation of technological capacity (Rosenberg, 1976; Stewart, 1978) have been for the most part ignored. And recently, the sudden upsurge of literature advocating both export-oriented strategies and microelectronics as a vehicle into exports or leapfrogging in the context of the international process of industrial restructuring (see, e.g., Soete, 1985) has further obscured the crucial link between technological capacity and the development of the capital goods industries.

The social costs associated with the poor development of capital-goods industries are not properly captured by the price system used by the firm when comparing between domestic and imported capital goods. Two major social costs absent from that system are the chronic trade deficits of countries that do not produce capital goods and the lack of their own technological capability to innovate, adapt or copy technologies that are closely associated with the capital-goods industry. The rising trade deficits of the Latin American countries, for instance, are structural in the sense that they are derived from the interplay between two forces: the dependence on imports of production (and especially capital) goods in order to grow, and the lack of an export capability also associated to a large extent with a limited technological capability that could permit a more suitable exploitation of local resources. The successful experience of South East Asian exporters, on the other hand, seems to rest largely on the development of a capability to improve, adapt and innovate in order to take advantage of local conditions. What is probably most important to note here is that the development of such a capability may have been more related to the development of their capital-goods industries than generally recognised.[17]

Capital-goods production has been considered in the past as one of the main vehicles for the acquisition of a technological capability, as argued above. But the link becomes even stronger when one considers the present surge of innovations in microelectronics, since many of them take place as a result of the matching of microelectronics applications to capital goods.

Such applications cannot take place without the latter. In other words, if the diffusion of earlier electromechanical vintages of capital-goods production towards LDCs was taking place at a relatively slow pace, the development of capital goods based on the new technologies (or the upgrading of the previously developed machine producers)[18] will face much stronger bottlenecks if national policy does not play an active role. The discussion of an appropriate protection policy, to apply in a highly selective fashion that gives pre-eminence to learning objectives, becomes of relevance again.[19]

The need to have a strong technological national policy does not necessarily mean the introduction of wider state intervention across all industry. It certainly is necessary to make a careful and selective assessment of which sectors are likely to suffer most from the application of the new technology. The same can be said about the export prospects linked to the new technologies. Here the assessment of export-oriented strategies will need to include an estimate of the extent to which the new technology facilitates or opposes international sourcing. It has been argued that a declining trend in sourcing is to be expected given the benefits that may be derived from relocating production near the final markets.[20]

The analysis takes us beyond the microeconomic framework into issues of international trade, international location and the strategic responses of firms according to the structure of their markets—topics dealt within more detail in other chapters of this book. At the same time, though, the analysis calls for a more integrated analysis of the North and the South than what has been attempted so far. Here we introduce only a short list of arguments that point to some additional difficulties to be faced by LDCs in their attempt to follow open routes of industrialisation on an integrated basis with countries in the North.

If one is to give serious consideration to some of the recent trends of industrial restructuring in industrialised countries and their implications for LDCs, the outcome is more likely to be pessimistic in tone. Three major trends are commonly stressed in some of the recent literature: the locational effect of new technologies; the organisational changes accompanying the applications of microelectronics; and the protectionism of major importing countries as they face trade imbalances along their restructuring process.

The reconcentration of industrial activities close to the final markets has been a matter of recent observation both at the macro and micro levels. As discussed in more detail in Chesnais's chapter, the US economy has turned into a net recipient of foreign investment[21] in the 1980s in the search for one of the few remaining dynamic markets. At the micro level, both the application of microelectronics to production and the Japanese transformation of organisation systems have shifted the source of comparative advantage away from traditional concerns with relative labour cost, which represented the major attraction to base production in LDCs, to systems gains through savings of time, total quality control and lower inventory costs. These systems gains are better achieved if production of all parts and

components takes place within a reasonable proximity.[22]

In order to expect a leapfrogging achievement from LDCs in this type of organisational innovation, it is necessary to assume that the institutional mismatch affecting all (or most) countries as a result of the new technologies (as repeatedly projected by Perez, 1985) will not confront LDCs as acutely.

Rather, we would need to assume that these countries may be able to jump a step further into the integration of the new organisation systems without having transited through the previous one and, in some cases, are able to start totally from scratch. Past experience with state enterprises and local entrepreneurial behaviour in times of relatively easier conditions seems, however, to deny such expectations. There only remains some hope that newly attracted TNCs may respond to internationally shaped demands, a result not likely to occur on a large scale for the reasons set out above and, in any case, possibly not a desirable trend either.

Finally, even if a few LDCs may find the necessary conditions to appropriate for themselves the new technological and organisational paradigms while retaining some of their traditional sources of comparative advantage (labour cost, natural resources, energy sources, etc.), the protectionist sentiment clearly prevalent in the major DC markets is going to limit a widespread effect of this type. In recent years, for instance, the United States has been increasingly introducing protection in sectors where its trade deficit has become more important or where the impact of imports is closely related to certain regions within the United States. Examples of such sectors are the automotive (though in the form of Japan's 'voluntary' export restrictions), clothing and textiles, shoes, steel and other industries.[23]

The EEC has also introduced protection for some of these sectors. In the absence of protectionism, these sectors would be among the most obvious sectors for LDCs to fit their future competitive advantage, if they could only couple with success some of the traditional factors of comparative advantage with the application of new technologies. But more likely the protectionist trends are here to stay, if not to be implemented even more widely.

Possibly one of the few open alternatives left to LDCs may be to resort again to greater integration among themselves. If the possibilities for enlarging North–South trade relations may not be so bright as argued above, there is always some room to enlarge the scale of operations by bringing together the markets of neighbouring countries. This is further stimulated if the countries involved are not too distant developmentally from each other, and if they consequently perceive the mutual gains for each in developing certain healthy complementarities. The bad experiences of Latin American integration efforts attempted on a large scale in the past, such as the Andean Pact and the Central American Common Market, have not prevented a more modest (though probably more promising) initiative for common projects recently launched by Argentina, Brazil and

Uruguay.[24] Notwithstanding the optimism with which these initiatives may be contemplated, the very selective number and type of neighbours that can be brought together in such conditions determines the limited scale on which these arrangements could take place in reality.

Conclusions

The LDCs find themselves on the verge of a new vicious circle, whereby the international conditions of competition are dramatically altered by the effect of new technological and organisational innovations which demand a new and even more active role from entrepreneurs than what was experienced in the recent past. Both neo-classical economics theory and conventional development economics theory have traditionally lacked a serious treatment of the imperfections that characterise entrepreneurial behaviour, while they both seem to rest on the unrealistic assumptions that if market signals (in the neo-classical view) or the infrastructural and incentives systems (in the conventional development view) are rightly devised, a sufficiently large supply of nationalistic and longer-term-oriented entrepreneurs will develop. The standard diffusion model, on the other hand, mistakenly assumes a mechanistic process whereby profit incentives move accordingly to the stage of diffusion and, in common with the other theories, entrepreneurial skills may never be in short supply. The latter assumption is particularly inadequate to the common LDC environment. The painful adjustment process taking place in many LDCs during the recent period has shown that entrepreneurs of this sort are as scarce as any other of the economic factors.

The conditions derived from the new innovations have not prevented the appearance of new strategies or the reshaping of old strategies for LDCs without a careful consideration of the new environment. Export-oriented strategies continue to be advocated, rather naïvely ignoring that they may be in direct conflict with two of the most direct results of those innovations: the relocation into industrialised countries of products where LDCs were developing a comparative advantage in terms of the older technological methods, and the rising trend of protectionism in the industrialised countries. The export-oriented or outward-outlook strategies in vogue have also failed to consider—for either exporters of new products or exporters who may incorporate the new technologies in their production in LDCs—the underlying marriage required between capital goods and microelectronics, which involves contradiction in the need to develop the capital goods industries *before* the marriage may take place. Needless to say, the development of capital goods and its qualification as the focus of technological capability accumulation have implicitly disappeared as a priority in the mainstream interpretations of outward-looking strategies.

Finally, our review of the sources of market imperfections detected for technology transfer operations suggests that those imperfections may become even more pronounced for transfers involving the new technological innovations. Imperfections associated with price, quantity of knowledge, diffusion patterns and related aspects will continue, or may be worse, in the future. But probably most importantly, the conditions given rise to technological packages are going to deteriorate for LDCs, including the package of imports of capital goods, which in our view remains an important priority for the technological development of LDCs.

Notes

1. A somewhat similar approach is taken in other recent works, such as Schmitz (1984).
2. This is argued in spite of the limitations of conventional theory to account for the dynamic adjustment taking place over the long run with technical change acting at the same time as a disequilibrating factor—in a static sense—and a source of order for the directions of change.
3. Some important exceptions must be noted with respect to countries such as Japan (see, for instance, Weiss, 1986), South Korea (see Westphal *et al*, 1981) and Brazil. With regard to the latter, a recent study discovered the development of certain technological capabilities as a sequential process having to do with, among others, protection policies systematically maintained for at least two decades (Katz, 1984, p. 32). Other factors are size of market and plants, dynamism of the technological frontier, and the type of production processes.
4. The 'follow the leader' reaction observed in oligopolistic markets, as pointed out by Vernon (1973), and stressed in James's recent survey (1986, p. 9).
5. For some of the writers heavily devoted to empirical studies, large, locally owned firms are in fact on much the same footing as domestic subsidiaries of TNC as far as technological behaviour is concerned (see, for instance, Katz, 1984, p. 25). They may only retain a different type of technological behaviour when comparing domestic, family-owned firms and state enterprises. We also found supporting evidence of this sort in our Mexican food-industry study (Unger and Márquez, 1981).
6. For the late latecomers to import substitution industrialisation, as opposed to Gerschenkron's depiction of Germany, Russia and Italy, Hirschman generalises: 'their industrialization started with relatively small plants administering "last touches" to a host of imported inputs, *concentrated on consumer rather than producer goods*, and often was specifically designed to improve the levels of consumption of populations who were suddenly cut off, as a result of a war or balance-of-payments crisis, from imported goods to which they had become accustomed' (1986, p. 9; author's emphasis).
7. References given by James (1986) cover studies on India, Brazil and Tanzania. For the Mexican context, Villarreal and Villarreal (1978) have also given evidence of the same nature.
8. Most of these studies have concentrated on Latin American countries and a few Asian countries. See, for instance, Vaitsos (1974), Chudnovsky (1974), Katz (1976), Fajnzylber and Martínez Tarragó (1976), and Lall (1983).

9. See the works of Nadal (1977), Cooper and Maxwell (1975), Wionsczek, Bueno and Navarrete (1974), IDRC (1980), Unger and Márquez (1981), Rattner (1977), etc.
10. The knowledge transferred could thus be characterised as a public good, as suggested by Fransman (1985).
11. For Fransman, the price of knowledge is indeterminate, ranging between a minimum level determined by the cost of producing that knowledge to a maximum amount determined by the buyer's estimate of the cost of the next best alternative (1985, p. 577). Alternatively, one could think that the maximum is determined by the buyer's perception (usually being a producer himself) of the limits of his market to bear higher costs.
12. In the Mexican case, for instance, a 3 per cent limit on royalties on sales was then imposed, while there were pre-legislation contracts on a 10 per cent basis (see Nadal, 1977). Not surprisingly, the AC are again pressing against royalty limits and in favour of the extension of patent rights periods, given the ongoing and further expected technological transformations of industry, and the competitive fears they raise. And at the other end, in LDCs facing recently depressed growth and investment, concessions are accordingly being granted under elusive arguments. For instance, since 1982 the Mexican authorities have relaxed the 3 per cent limit 'in order to permit the transfer of better [sic] technology' (Gustavo Gómez Bustos introducing G. Funes paper to the Austin meeting, April 1986). The limit is now relaxed up to 10 per cent again, though the assessment of the 'quality' of the technology involved is not specified.
13. The few typical exceptions may be electronics, biotechnology and new materials technologies, which are supposed to be in the earlier phase of their technological trajectories. Most other sectors are seen in the phase of wider diffusion of their technological principles and applications, which serves to explain the upsurge of some low-wage efficient LDC competitors.
14. Similarly to Pavitt's affirmation that 'most technological knowledge turns out not to be 'information' that is generally applicable and easily reproducible, but specific to firms and applications, cumulative in development and varied amongst sectors in source and direction[1] (1984, p. 343), the transfer of technological knowledge has to be examined in the context of a wide variety of specific conditions before we can assume that it will increase the technological capabilities of a firm or an industry. Among the interesting empirical studies, one should mention Katz (1984), Westphal *et al.* (1981), Lall (1983) and Unger (1985).
15. See Cooper and Maxwell (1974), Mercado (1980), Nadal (1977), Unger and Márquez (1981), Unger and Saldana (1984), Cortés (1977), Katz (1976, 1984), Vitelli (1985).
16. See, for instance, Pavitt's qualification to the evolutionary models on the basis of distinguishing the variety of conditions around the complementary relations between producers and users of capital goods.
17. Among the few exceptions, there is a recent reference explaining Singapore's advantage as the location for MNC production of computer disk drives as a direct consequence of the country's well-developed machining industry (James, 1986, p. 6).
18. Numerically controlled machine tools are a case in point where conventional machine-tools producers may be displaced if they do not respond actively (see the case of Romy of Brazil in Katz, 1984, p. 31–3). See also Jacobsson (1985).

19. A similar suggestion is found in Katz (1984, p. 30). In this respect, the strategic reserve of certain microelectronics activities to domestic firms, imposed for instance on the microcomputer industry of Brazil, seems coherent from a national, long-term perspective, in spite of the concern raised by user firms or individuals who may base their criticisms on short-term cost comparisons.
20. Thus, a reconcentration trend in the North is forecasted for sectors as dissimilar as automobiles (Jones and Womack, 1985) and clothing (Hoffman and Rush, 1984), even though in both cases the influence of microelectronics is at the forefront. See also Chesnais's chapter.
21. For an updated account of this process, see Scholl (1986).
22. The automobile industry, one of the traditional leaders in the search for post-costs reductions through world-scale distribution of components plants (what was known as the trend towards the world car), has recently shown a reversal trend to reconcentrate both in Japan and the United States. For a striking comparison of costs in favour of Japan's integrated plants over others in lower wage areas, see Jones and Womack (1985, p. 400).
23. I have given an account of recent protectionist moves for certain selected sectors in Unger (1986). Other references can be found there.
24. Though this is a recent initiative and no firm results can be reported yet, it shows in principle the will to define jointly policies and projects for specific sectors. For a list of projects agreed, see *Journal de Brazil*, 8 December 1986, p. 14.

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23 Multinational enterprises and the international diffusion of technology

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Introduction

The last chapter in this section discusses some contemporary aspects of the relationships between science and technology and international investment (generally designated as foreign direct investment (FDI)), with special emphasis on the world-wide operations of multinational enterprises (MNEs). It is concerned with recent or ongoing changes in the overall pattern of FDI; in the international sourcing, creation and transfer of technology by MNEs; and finally in inter-firm technical cooperation agreements also involving such firms.

Considerable research and policy-oriented discussion have been directed towards the international dissemination or *transfer* of technology by MNEs (for a review and the appropriate references, see, *inter alia*, Caves, 1982). Rather *less* research and discussion have been devoted to the international *sourcing* of technology, and more broadly of scientific and technological knowledge, by MNEs, although this deficiency has now begun to be recognised by some (cf. Dunning and Cantwell, 1986; Bertin, 1986). This chapter will show that the international sourcing of technology includes, of course, the organisation of corporate R & D on an international level with laboratories in several countries, but covers also a wide variety of processes and mechanisms through which MNEs can organise the centralisation and appropriation of technology and technical knowledge. Today such mechanisms include a variety of inter-firm technical cooperation agreements which large corporations belonging to the MNE category are setting up with other enterprises, notably small, knowledge-intensive firms in 'high technology' industries, as well as with universities.

The chapter relates the new developments in the technological strategies of MNEs, both the ones they develop individually and those they organise through collective action, to the changes which have occurred internationally since the mid-1970s, notably: (i) the emergence and rapid generalisation of 'international' or 'world' oligopoly as the dominant form of supply structures in all R & D-intensive and scale-intensive industries; (ii) the world economic situation which has dominated since 1975; and (iii) last but not least, the important changes in science and technology with which the whole of this book is concerned.

Two theoretical traditions and a step towards a synthesis

The focus of the analysis is essentially on international investment and the MNEs. The setting of the analysis, however, is the wider process of internationalisation. This notion designates the wide set of economic mechanisms and relationships whereby previously fairly separate national economies become increasingly interrelated and interdependent with one another in all areas of economic activity. These mechanisms and relationships include the export and import of goods and services; outward and inward flows of direct investment and financial capital; outward and inward flows of embodied and disembodied technology; international movement of skilled personnel and transborder information flows; and, of course, the internationalised monetary and financial system.

The reference to the notion of internationalisation warrants a few indications concerning the theoretical underpinnings of this chapter. The conceptual approach which underlies the analysis is at the junction point between the most significant Anglo-Saxon work on foreign direct investment and the MNE, and the dominant French approaches towards the analysis of 'internationalization' (de Bernis, 1977), 'accumulation at world level' (Amin, 1970; Palloix, 1975), or 'world capitalism' (Michalet, 1976).

The approaches used by American and British scholars are essentially based on an extension of the decision to invest abroad either of the theory of the *firm* (Coase, 1937, as extended by Hymer, 1970; Horst, 1974; Buckley and Casson, 1976, with 'internalisation' and the interplay between 'markets' and 'hierarchies' (Williamson, 1975) as the key concepts, or else of the theory of *industrial organisation* and market structure theory (*inter alia*, Bain, 1956; Scherer, 1970; Caves, 1971; Knickerbocker, 1973; Vernon, 1974; and, more recently, Newfarmer, 1983, 1985). Here the extension of domestic oligopoly beyond national boundaries, prior to the emergence of global or international oligopoly, represents the main unifying trend in the analysis. Within the Anglo-Saxon tradition, Dunning's 'eclectic theory' 1981) represents an attempt to combine the two trends and impose a recognition of the *specificity* of the MNE as opposed to the traditional view of FDI, while seeking at the same time to bridge the gap between the theory of international investment and that of international location and trade.

French approaches are all different blends of what may be broadly defined as a 'neo-marxist' tradition. In contrast to the Anglo-Saxon approaches, all the French approaches essentially involve an extension at an international level of the theory of capitalist development (cf. Dobb, 1963; Sweezy, 1946), with the accumulation of capital and the related processes of (industrial) concentration and (financial) centralisation of capital as the key concepts. In all neo-marxist approaches government, e.g. the state, is also given a prominent central role as an institution shaping all aspects of modern capitalist society (cf. Mandel, 1975).

The blending of the French and the Anglo-Saxon approaches consists basically in the recognition that while MNEs are obviously active agents in the process of internationalisation and even architects of some aspects of the process, and *must consequently be analysed in their own right*, they are, nonetheless, *responding to an overall set of factors* over which they have in fact *little or no control*, and which *all stem from the basic mechanisms* driving the historical process of capitalist development. One of these mechanisms is the development (in a contradictory, antagonistic and unequal manner) of the forces of production, among which science and technology play an increasingly quite central role (see, *inter alia*, Rosenberg's essay on 'Marx as a student of technology', 1982, and Harvey, 1982, Chapter 4).

Once they are set against the background of the process of concentration and centralisation of capital and a situation where forces of production (notably those directly shaped by science and technology) have overrun national boundaries, a number of observations and concepts derived from the economics of technical change, the theory of the firm and the economics of industrial organisation and market structure acquire their full intelligibility and become necessary components of a global analysis. Set against such a background, empirical observations relating, for instance, to the close relationships between R & D intensity, industrial concentration and the scale of FDI in R & D- and scale-intensive industries take on a new dimension and can be interpreted as expressing a real *objective* constraint on firms in such industries to adopt the *world market* as the *only possible market* on which they can deploy and fully reap 'ownership advantages'.

The merging of the Anglo-Saxon approaches with the understanding derived from the extension at the world level of the process of capitalist development must *not* be interpreted, however, as implying a one-way process. For instance, while it is hard to establish a sound foundation for the analysis of global or international oligopoly without an understanding of the way in which the concentration and centralisation of capital will begin to take place at the international level with its tendency to englobe the advanced capitalist countries as a whole, through a process of 'mutual raiding' (Erdilek, 1985), international cross investment (Mucchielli and Thuillier, 1982), acquisitions and mergers, *conversely* the analysis of *firm behaviour in conditions of international oligopoly* (each firm backed by its home country government in one way or another), represents the *only way* of making *progress towards a better understanding* of the working of 'monopoly capital' and 'inter-imperialist rivalry'.

Similarly, once the concept of *internalisation* is set against the background of the twofold process of industrial concentration and financial centralisation of capital (as defined and distinguished in the marxist approach), and MNEs are defined in relation to their *group* structures and their *combined* industrial and financial attributes, it becomes possible to appreciate fully what Dunning has to say about the *organisation* of 'market failure' by large firms:

> Where, for example, enterprises choose to replace, or not to use, the mechanism of the market, but instead allocate resources by their own control procedures, *not only do they gain* but, depending on the reason for internalisation, *others* (notably their customers and suppliers prior to vertical integration, and their competitors prior to horizontal integration) *may lose*. Internalisation is, thus, a powerful motive for takeovers or mergers, and a valuable tool in the strategy of oligopolists. [Dunning, 1981, p. 28]

In the same order of ideas, Dosi (1984) points out the importance of not considering internalisation as a passive response to 'market failure':

> It would be misleading to consider internalization simply as an effect of and a reaction to some kind of 'market imperfection'. It is probably more accurate to consider it as one of the inner trends (and one of the 'rules of the game') in oligopolistic rivalry towards the transformation of the untraded features of technical change into proprietor assets which, as such, also represent entry barriers and differential advantages *vis-à-vis* other competitors.

The 'distinctive nature' of the multinational enterprise

A reference has been made to the financial dimensions of MNEs. This is a somewhat underlooked dimension of their scope and power, which has however been the object of a fair amount of attention and research in France and more recently in the United Kingdom (different French approaches include Morin, 1974, Pastré, 1980, Chesnais, 1979, and Grou, 1983; in the United Kingdom see Scott, 1979, 1986). These features are complementary to and indeed often an outcome of conglomerate organisation and are expressed *inter alia* in the 'portofolio' approach to assets, including industrial assets and the scale and significance of operations made by industrial MNEs as lenders in short-term international money markets (eurocurrencies) (Cohen, 1980). In this approach MNE must be viewed as a specific form of 'finance capital' (Hilferding, 1910; Lenin, 1915), e.g. a form which is predominantly engaged in industrial activity but in ways which are increasingly shaped by purely financial strategies as developed by financial analysts, financial market operators and bankers (see Minsky, 1982). This characteristic will be enhanced by the transformation of parent companies into 'holding' corporations, but is present today in all large multidivisional and multinational firms. It is a central factor in the emergence of the 'hollow corporation' as coined by *Business Week* which is now at the centre of debate in the United States (see Cohen and Zysman, 1987).

If due recognition is given to this dimension, and if the particular capacity of the MNEs to use world-based information technologies and systems to their own best advantage is also recognised (Antonelli, 1984), then Dunning's account of the 'distinctive nature' of the MNE (Dunning, 1981, p. 27) is a very acceptable one, namely that MNEs enjoy three combined and cumulative sets of advantages:

(i) those which large firms may have over others 'producing in the same location' and which 'stem from size, monopoly power and better resource capability and usage';
(ii) those pertaining to the advantage a branch plant or subsidiary can derive from belonging to a group, thus benefiting from many of the endowments of the parent company, 'for example, access to cheaper inputs, knowledge of markets, centralised accounting procedures, administrative experience, R & D, etc., at zero low marginal cost; or the *de novo* form will normally have to bear the full cost. The greater the non-production overheads of the enterprise, the more pronounced this advantage is likely to be'; and
(iii) the particular type of advantage 'which arises specifically from the multinationality of a company, and is an extension of the other two. The larger the number and the greater the differences between economic environments in which an enterprise operates, the better placed it is to take advantage of different factor endowments and market situations'.

If these three aspects are used in combination, the MNE will be viewed as a firm possessing a very wide range of opportunities simply not offered to smaller domestic or regional firms, for *entry* into as well as *exit* from given activities and markets; or again for 'internalising externalities', in our case, for instance, the results of government or university-financed and executed R & D. These firms also have special opportunities for reaping 'appropriable rents' or quasi-rents (Klein *et al.*, 1978), and for exerting forms of monopolistic or monopsonistic 'market power' (falling short of outright monopoly or monopsony) which can allow them to impose quasi-integration-type contractual arrangements of an essentially *predatory* nature on smaller supplier firms, including specialised 'knowledge-intensive' small firms.

But such firms are also oligopolists, in their home markets of course, and also today in international markets, where oligopoly prevails in all 'science-based' and in many 'scale-intensive' industries. The market power of each firm is bounded by that of the other rivals which make up the oligopoly. 'Mutual recognition' and oligopolistic reaction and interaction, which are the hallmarks of oligopoly, will take place in all spheres of activity, including technology, and may lead to situations where in the area of R & D and the development manufacturing and marketing of high-technology products a considerable amount of cooperation between oligopolists occurs. Once international oligopoly sets in, as is the case today, the 'endogenous generation of market structure and technological performance' (Nelson and Winter, 1982) will likewise start to become an international process. Before turning to these hypotheses in the later part of the chapter, we first discuss other important, albeit more traditional, aspects of the relationships between science and technology, FDI and MNEs.

Patterns of international investment in the 1980s

Major changes in the overall international pattern of foreign direct investment began to occur in the early 1970s. The fact that they started by *coinciding* with the deep changes in the world economic situation, before being later *accelerated* by the developments of the 1980s—in particular the collapse of profitable direct investment activity in most developing countries from 1981–2 onwards (the only exception being the Asian NICs) and the progressive extension of the new paradigms in science and technology and also manufacturing processes (notably Japanese—see Sciberras, 1980, for colour TV, and Jones, 1987, for automobiles)—helps to *explain the delay there has been in recognising the new international patterns* of FDI and in isolating them prior to adequate analysis.

The new patterns are the following: (i) a decline, later followed by a severe reduction, in the flow of FDI towards 'market economy' developing countries, in contrast with the People's Republic of China which has received the largest fraction of DC-orientated investment during the 1980s (UNCTNC, 1987); and (ii) more important still, the *recentring or reconcentration of the flow of FDI within the OECD area*, along with two major related changes, namely (a) the progressive shift in the role of the US economy from a 'home' to a 'host' country for FDI as European and later Japanese MNEs have developed their investment in the US market, and (b) the emergence since the late 1970s of Japan as a major 'home' country for MNEs and a large source of FDI directed towards the United States but also towards Europe.

The second, if not the first, of these two major developments was fairly foreseeable. It was announced in a Hymer and Rowthorn (1970) article, in which the authors predicted the emergence of global oligopoly as a result of the growth of European and Japanese FDI. The central finding of the Hymer–Caves strand of analysis (see also Knickerbocker, 1973) is that once a major firm in a concentrated industry has started to invest and manufacture abroad, its oligopolistic rivals are obliged to follow suit. While this may *start* as a rather unilateral process of oligopolistic rivalry between large firms based in the same economy (as it did in the 1950s and 1960s in the case of US-based foreign direct investment), *as soon as accumulation and the concentration and centralisation of capital have developed (or developed again) in other countries*, regions or poles of the internationalised capitalist world economy, the situation will *necessarily* increasingly be one of mutual cross-investment by MNEs, into one another's home markets and domestic technology bases.

This is the process that occurred increasingly in the 1970s and 1980s as a result of large-scale FDI by OECD-based MNEs into the US economy. Since the earlier 1980s, the United States has for the first time this century become a net importer of capital again. Part of this capital has had purely financial destinations, but a significant fraction has taken the form of investment into US manufacturing industry either through mergers or 'green-field' investment. At the same time as inward foreign direct investment has grown, outward US investment has somewhat declined. Consequently, if intra-Europe FDI is deducted from the European total, Europe and the United States now host approximately the same level of foreign investment (Fouguin, 1986). As in the case of trade flows, where Japan's imports are much lower than its exports, notably in high-technology industries, Japan's place in multipolar international investment is significantly different from that of Europe and the United States. Compared with Europe and the United States the level of foreign direct investment into Japan still remains extremely low. By contrast, Japanese *outward* foreign investment has been growing rapidly and will quite certainly be further accelerated by the changes in foreign exchange rates. Up to now a large part of Japanese investment in Europe and in the United States has been through joint ventures and inter-firm cooperation agreements of various sorts, one dimension of which is, as in the case of several US-based joint ventures, technical cooperation and the joint development of new technologies, and another the desire to overcome political and social sensitivities towards the entry of Japanese firms within the markets and domestic supply structures of US and European industry. When these sensitivities disappear, however, the preference of Japanese firms for majority-owned affiliates tends to reassert itself, as in the case of the United Kingdom (Dunning, 1985).

Trade, foreign investment and international flows of technology: the paucity of sound knowledge

In many instances, foreign direct investment has clearly recognisable trade-substituting effects: delocated production within a country replaces the exports previously made to that country from the MNE's home base. In other instances, foreign direct investment will create trade, along with new forms of dependencies and interdependencies. This is the case in particular when firms investing in a foreign economy continue to source capital goods and intermediary products from their home economy (as is often the case for Japanese firms at the moment) or when MNEs use affiliates to ship products (generally intermediary goods) to the parent company or to other affiliates.

An indication of the magnitude of the trade-substituting impacts which a unified theory would have to give an account of is given by UK data which show that in the case of the fifty largest corporations in 1981–2 the relation between overseas production of sales and export both as a percentage of sales was 3 to 1. Recent US Department of Commerce data show likewise that in 1983 the overall ratio of sales by the foreign affiliates of US MNEs to exports from the United States was a little over 2 to 1. This represents a drop in comparison to earlier periods and is due to the fall-back in US foreign direct investment since the end of the 1970s. However, in R & D-intensive industries where internationalisation has developed for many decades through direct investment rather than through exports, such as pharmaceuticals and chemicals, the ratio remains much higher: nearly 5 to 1 in pharmaceuticals and 3 to 1 in chemicals.

Even if the trade-substituting effects of foreign direct investment are quite substantial in some industries, in retrospect it is quite clear that the spectacular growth of exports and of internationalisation through trade would never have taken place on the scale it did in the absence of foreign direct investment. The trade-barrier-jumping capacity of foreign direct investment probably represents the strongest available deterrent to trade barriers, both tariff and non-tariff barriers. Foreign direct investment when coupled with trade also has a capacity to lower industrial entry barriers which trade alone does not possess. In the transitory period preceding the emergence of situations of world or international oligopoly in 'global market' industries and sectors, FDI in *combination with trade* succeeded in *lowering entry barriers*, reducing domestic concentration levels and weakening positions of domestic or regional oligopoly. In Europe notably, FDI increased United States competition significantly and had a positive effect on the competitiveness of European firms (Dunning, 1982). The need to *combine* the discipline stemming from low trade barriers with that resulting from *foreign direct investment* must be stressed. When foreign direct investment takes place behind high trade barriers, foreign affiliates, as shown by many industrial and country case studies and highlighted in Unger's chapter, tend to adapt themselves to reigning conditions of production and competitiveness and become a part of domestic oligopolistic supply structures. This, for instance, occurred in Spain in the 1960s and 1970s and of course in large Latin American countries like Brazil and Mexico (Connor, 1977, and Unger's chapter).

Another important theoretical issue in this area is the *relationship between intra-industry investment and intra-industry trade*. Discussing the case of industries in which 'there are a number of countries each home to a group of highly innovative firms' (e.g. in our terminology industries of the R & D-intensive, international oligopoly category), Dunning and Cantwell observe that:

> Over the last 25 years, this is the kind of industry that has been characterised by the rise of the cross-hauling of investments between those countries harbouring the strongest firms. Such countries become hosts to the greatest levels of international production as well as being homes to MNEs of their own. This phenomenon is known as intra-industry trade and production; and, we might add, intra-industry technology trade and diffusion as well. [Dunning and Cantwell, 1986]

This, of course, remains an extremely general statement and amounts to a *plea for research* into those now extremely frequent situations where *intra-industry trade and intra-industry FDI occur simultaneously*, along with related two-way international flows of technology. In 1978, Dunning had already indicated that 'any theory of intra-industry trade must now take account of intra-industry investment. *We are only at the borders of research in this area*' (Dunning, in Giersch, 1979, p. 70, author's emphasis). Nearly ten years later we are still about at the same point: trade analysis *continues* to be carried out *separately* from that of investment. This was again the case for recent research at OECD during the structural adjustment study (OECD, 1987b), with resulting limitations on the usefulness of the findings. The latter confirm the continuation and strengthening of trends noted in earlier studies, but they would require an integration of the international investment variable to become really *meaningful*. The findings are the following (OECD, 1987b)

(i) 'OECD trade had increasingly involved products characterised by significant economies of scale in production, extensive product differentiation or close links to the science-base. Thus, from 1962 to 1985, the share of scale or production-intensive and science-based goods in total OECD manufacturing trade (exports plus imports) increased from 53 to 65 per cent, with growth rates of the latter category being particularly high in the most recent period.'

(ii) The growth of trade has mainly entailed specialisation within industries. Using an index of intra-industry trade, based on the ratio of gross trade to net trade, the study finds that 'with the important exception of Japan, this index increased significantly for all the countries listed, the average for the group as a whole *rising by more than two-thirds* over the period 1959–1985'.

(iii) This pattern of specialisation was accompanied by major shifts in the geographical structure of trade. 'Thus, throughout the 1950s and 1960s, trade occurred primarily between industrialised countries, sharing broadly similar factor endowments and patterns of demand. Trade grew particularly rapidly between closely located countries, mainly the United States and Canada on the one hand and the European OECD countries on the other'.

(iv) Perhaps the most interesting finding, however, is the one concerning recent trends in the NICs which by 1985 accounted for fully 8 per cent of OECD manufactured imports. Regarding these countries, the study finds that 'the extension of interdependence to new trading partners did not weaken the major tendencies affecting the structure of manufactured trade. Thus, by the end of the period, nearly 40 per cent of OECD imports from the NICs were not in labour or resource intensive products, but in products characterised by significant scale economies or extensive product differentiation. And intra-industry trade—which had been a marginal factor in OECD trade with developing countries in the late 1960s—accounted for fully 31 per cent of the NIC's manufacturing trade with the OECD area in 1985: confirming that they too were increasingly drawn into the dynamic functions of trade'.

Such situations simply *cannot* be explained independently of FDI and the effects it has on the structure of trade. These effects are not limited to trade substitution (*inter alia* Vernon, 1979), but extend to other less well recognised phenomena, in particular:

(i) the role FDI plays in gradually homogenising the organisation of production (pattern of industrial output and levels of productivity) in those countries in which the overall effect of such investment, through the combined influence of MNE strategies and host government policy, is (as in the Asian NICs) to integrate previous DCs into the 'North';

(ii) the role of international sub-contracting (Germidis, 1981) and other long-term commercial arrangements bearing on the supply of manufactured inputs to industrial production; and, of course,

(iii) 'intra-firm' trade, e.g. trade between affiliated firms within multinational corporate structures (Helleiner, in Giersch, 1979).

It is this type of structural impact, along the particular forms of integration of domestic economies into the world market it entails, which some authors have viewed as leading potentially to what Michalet (1976) has called 'le capitalisme mondial', i.e. a world wide set of economic relationships possessing systemic features, which might supersede the present pattern of national economies and international market relationships. In other recent work (Chesnais, 1988), we have argued that the end of Bretton Woods and the subsequent international monetary system, the onset of deep economic and trade instability (whether one decides or not to use the term economic crisis), along with the full restoration of the 'cumulative oppressive power' of *rentier* money capital (Keynes, 1936, pp. 375–76), have offset the emergence of any such system. Very strong liquidity preferences by money capital have been accompanied by increasingly 'footloose' strategies by MNEs and a premium on the part of FDI to industries and countries where *exit* barriers (Porter, 1985) are low. Contemporary microelectronics technology has given additional scope for such strategies by MNEs and wrecked previous industrialisation policies in almost all developing countries and most Latin American NICs (see Kaplinsky, 1987 for automobiles; Mytelka, 1988 for garments, as well as the chapter below by Unger). But this does not modify the essential fact that the structure of international trade *cannot be analysed independently of FDI and the worldwide strategies of MNEs*.

The internationalised sourcing of technology: an under-researched dimension of MNE operations

The organisation by MNEs of the *creation* and/or the *acquisition and appropriation* of technology on an *international* level, across national boundaries, is by no means a new phenomenom. It dates back to the period when attention was almost exclusively concentrated on the international *transfer* (i.e. dissemination) of technology by and in particular *within* the MNE. If little is known about world-wide sourcing operations by MNEs for technology, this is mainly because it has been the object of little research (see also Bertin, 1986): MNEs were thought of as simply (or mainly) transferring technology *outwards* and not also transferring it *inwards*. Discussing overseas R & D spending by MNEs, Caves (1982), for instance, simply mentions in passing that the 'basic research of MNEs is much more footloose than is applied research, and that some of it goes abroad to seek out particular scientific specialists'.

In a number of industries (cf. the studies produced at OECD in the late 1970s, Michalet and Delapierre, 1978; Chesnais, in OECD, 1979; Burstall, Dunning and Lake, 1981) there is evidence that MNEs, for instance, the European MNEs in pharmaceuticals and food processing and the US MNEs in the electrical, electronics and computer industries, were early to understand that foreign direct investment and internationalised group structures could form the basis not only for internalised transfer of technology conducive to the most advantageous exploitation of 'firm-specific advantages' across national frontiers, but also for the *sourcing and centralisation of scientific and technical knowledge and resources on an international scale*. The findings of a recent US survey (Fusfeld, 1986, pp. 132–3) regarding the motivations of US MNEs for setting up foreign laboratories have provided further information regarding the strategies of MNEs in this area. The most frequently quoted objective has been the desire to 'have a window on foreign science', first and foremost in Europe. Other objectives include access to special skills not easily available in the home country, developing new sources of technical concepts or simply establishing on an international stage of operations of corporations concerned with science and technology.

The telecommunications and computer and data processing industries have probably been those where the world-wide organisation of corporate R & D and sourcing of scientific and technical resources has experienced the greatest development. As early as the mid-1970s several large firms had a kind of international technical system with a foot in several national systems, but with identifiable autonomous features of their own, ensuring the international flow of technology within international group structures. IBM has, of course, often been studied in this respect (see Michalet and Delapierre, 1978). By the mid-1970s IBM had set up a world-based set of R & D activities organised independently of its manufacturing and marketing affiliates, in which the tasks assigned to laboratories did not necessarily match those of the subsidiary's production units to which given laboratories belonged formally. Few laboratories within the IBM group were engaged competitively or simultaneously in research, and then only in the exploratory stage before any heavy development expenses were involved. Their work was organised so as to maximise complementarities. At the end of the 1970s, IBM had three laboratories performing fundamental research, two in the United States and one in Switzerland. Development

tasks were distributed on a world basis among all the other laboratories, i.e. fourteen major laboratories in the United States and eight in other countries: by order of establishment, The Netherlands, Germany, United Kingdom, Japan, Sweden, Austria, Canada and France.

To ensure that the R & D undertaken in affiliate laboratories geographically far removed from each other was consistent, IBM had set up a vast telecommunications network for regularly pooling all the group's technological resources, where laboratory computers were interconnected on a world-wide basis and a single data bank set up at the corporate R & D headquarters. In this respect again IBM has been exemplary. In particular since the emergence of world-wide telecommunication networks, its experience has been studied and partially followed by an ever more important number of firms. This is confirmed by the findings of the survey undertaken by Antonelli (1984) covering forty US and European MNEs, where replies show that among the seven main reasons given by firms for adopting the new international telecommunication equipment in their operations and undertaking the organisational changes required in corporate structures were the new possibilities offered for the 'international implementation of R & D capacities generated by increased interaction among affiliates and headquarters and greater division of labour, according to the technical requirements and scientific endowments of countries and affiliates'.

The centralisation of external scientific and technological knowledge is not limited to 'science-based' or R & D-intensive industries, but has been equally important in industries such as food processing, where innovation relies heavily on inter-industry transfers of technology. In our study of the technological activity of MNEs in this industry, we laid particular stress on the *horizontal coordination and management of inter-industrial technology transfers* by firms such as Unilever, Nestlé or CPC International and the role of engineering departments (Chesnais in OECD, 1979, Chapter XI).

The need to organise the sourcing of technological resources on an international basis and, in particular, to establish 'a window' on the world's most advanced science base, namely that of the United States, explains, of course, why large European firms, rapidly followed later by Japanese ones, have followed the road taken by the US MNEs in the preceding period. In the 1970s and 1980s non-US MNEs have increasingly sought to create laboratories in the United States as part of their investment in the US economy, in some instances as an important, if not a major component of the overall objective of this investment. This is particularly true in the chemical and chemicals-related industries, in particular in *pharmaceuticals*, where the need to gain direct access to the US science and technology base in the field of biotechnology has been a motive for much of the US investment made by non-US MNEs, which has generally taken the form of take-overs of existing firms, along with the acquisition of their R & D facilities which the new parent firms have often expanded. The process of 'international cross-investment in R&D', in the form of laboratories and other forms of scientific investments, including research contracts with universities, has been documented up to 1982 by Burstall in the case of the pharmaceutical industry (Burstall and Dunning, 1985). Since 1982, further European and Japanese investment has occurred in the United States, Japanese investment has grown in Europe, as has US and European investment in R & D facilities in Japan. Most firms still normally conduct the most sensitive and demanding types of work in centres located in their country of origin. Only still relatively few of the world's top thirty pharmaceutical MNEs have laboratories of the highest capacity situated elsewhere, but almost all now have some kind of 'window' open on the scientific capacity in their main competitors' home economies. This is all the more true since the emergence of biotechnology in the United States at the end of the 1970s and the expansion of inter-firm technological co-operation agreements, *inter alia* with the small genetic engineering firms, as a new mechanism for the acquisition of technology external to the large established MNEs (Chesnais, 1986; US Congress Office of Technological Assessment, 1984).

Increased pressures for an external technology sourcing by firms and the growth of inter-firm technical cooperation

Discussing the international flow of technology and technological balances of payments, the authors of the OECD Science and Technology Indicators No. 2 note that

> problems of interpretation are raised not only by the mixed contents of the TBPs, but also by the elusive character of certain international flows of technological knowledge, i.e. those for which there is no visible form of payment (among others: cross-licensing, transfer of knowledge to a subsidiary, international co-operation of a non-commercial type). [OECD, 1986a, p. 54]

Today, on account of the rapid growth of inter-firm agreements, probably a very large part of outwards and inwards transfers of technology by firms now take this non-visible form.

In discussing the contemporary growth of inter-firm agreements it is important, of course, to keep a sense of *historical perspective*. International cross-licensing between large firms, which remains a fairly basic form of technical cooperation agreement in concentrated R & D intensive industries, was already a significant feature of the chemical and heavy electrical equipment industries in the 1930s (Newfarmer, 1978, 1985). Little-publicised technical cooperation has been a long-standing feature of the relationships between firms like Siemens and Philips, ICI and DuPont, or the three Swiss pharmaceutical majors in Basle.

Today, in addition to the deeply troubled world economic situation, there appears nonetheless to be *two series of major driving forces* explaining why present trends probably represent a qualitative development which

will not be easily reversed. The first series of factors relate to the *point reached in the overall process of internationalisation*, along with the implications this has for firms, in the form of a continually growing requirement to wage what the business management literature calls 'global competition'. In all R & D-intensive industries, as well as in industries where scale economies are decisive, competition (e.g. oligopolistic rivalry) now takes place: (i) between a relatively small number of large firms (ranging from three in large commercial aircraft, and two or at best three in large civil aircraft engines, to ten or so in automobiles or in the main segments of the electronics sector); (ii) in a world arena which includes the respective home and host markets of rival MNEs as well as third markets, within and outside OECD; and (iii) through a wide array of means by which firms can gain access to technology and markets (notably 'reserved' government procurement markets). Such rivalry implies 'mutual recognition' and a variety of combinations between *competition* and *cooperation*.

The second set of factors concern contemporary developments in science and technology which help to explain why the access to a wide science and technology base that was an *advantage* in earlier phases is now a *necessity*. The overall trend is one where: (i) basic scientific knowledge is playing an increasingly crucial role in opening up new possibilities of major technological advance, or, to put it in another way, where the knowledge base of technology of firms is increasingly founded in basic science; (ii) many recent breakthroughs have occurred as a result of cross-fertilisation between scientific disciplines; (iii) technology has acquired stronger systemic features. These features are the hallmark not only of spectacular developments in space technology, telecommunications or military systems, but also of more mundane, albeit revolutionary, technologies in CAD/CAM, new materials, etc.

Ongoing paradigmatic changes in science and technology are accentuating all three aspects. Major innovations are based even more strongly on scientific knowledge; synergies and cross-fertilisation, both between scientific disciplines and between scientific and technological advances, play an ever more important role, notably through the advances continually occurring in computing technologies. The massive entry of computing into instrumentation has further strengthened the role played by the latter. The extension of the systemic features of technologies to a larger number of areas is a necessary and inevitable outcome and expression of these developments. Alongside these processes and as an expression of their developments. Alongside these processes and as an expression of their pressure on firms, there has been a general tendency towards increases in R & D costs and outlays. This has been particularly noticeable in computers, electronics and components and pharmaceuticals, but would also be identifiable in areas such as new materials if detailed company data on costs were available.

In combination these developments in science and technology have created what Fusfeld (1986, p. 143) calls a 'capability squeeze' on firms, marked by: 'the increase in the number of technical fields relevant to corporate growth' and 'totally new requirements for significant technical advances'. These pressures can be met *partly* by increasing *in-house R & D* within corporate structures, both nationally and internationally, or by the establishment in cooperation with other firms of joint-venture corporations solely dedicated to R & D. In other cases, they will require the *external acquisition of knowledge*, know-how and skills located in *other* organisations, whether universities (when the knowledge is still close to basic research) or firms. These are the processes lying behind the observations made by Dunning and Cantwell (1986) that:

'there has been a historical shift away from technology being viewed by the firm as a specific and single purpose input towards the development of integrated technological systems which require coordinated governance for their economic deployment. The rise of such technological interdependence means that it is no longer appropriate to think simply in terms of a sequence which runs from technology creation to transfer and diffusion. The successful creation and application of new technology has become much more dependent upon the earlier dissemination of related technologies within the firm, and of the parallel technologies developed elsewhere by other firms.'

A wide range of interfirm agreements

The external acquisition of technology can be organised either through 'arm's-length' operations, notably straightforward licence agreements, through mergers and hierarchies (Williamson, 1975) (e.g. the outright acquisition of the firms possessing the desired technology or accumulated scientific and technical knowledge), or on the basis of a *wide range of inter-firm agreements* falling 'between markets and hierarchies', (Mariti and Smiley, 1983). The range of the main types of agreements established by firms with a view to producing, acquiring and/or commercially exploiting technology in common are set out in Table 23.1.

A. University-based cooperative research projects are collective R & D undertakings established and financed by firms in universities with or without public support. The distinctive characteristics of this type of agreement are location of the R & D in academic structures and extensive support and direction by firms (as opposed to governments) even if some public support is offered.

B. Government–industry cooperative national or international research projects are collective R & D undertakings with strong government backing, located in firms but also in universities and public research institutes. Here government initiative and financial support (national as in the case of Alvey or by the EC as in that of Esprit), and a much greater variety in the location and execution of R & D, are distinctive features.

C. Research corporations are *private joint-venture companies* financed on

Figure 23.1 Inter-firm R & D, technology and manufacturing co-operation agreements and the R & D, to marketing spectrum

Pre-competitive stage Research and development cooperation			Competitive stage Technological cooperation			Manufacturing and/or marketing cooperation		
A	B	C	D	E	F	G	H	I
University based cooperative research financed by associated firms (with or without public support)	Government industry cooperative R & D projects with universities and public research institute involvement	Research and development corporations on a private joint-venture basis	Corporate venture capital in small high-tech. firm (by one or by several firms, otherwise competitors)	Non-equity cooperative research and development agreements between two firms in selected areas	Technical agreements between firms concerning completed technology *inter alia*: * technology-sharing agreements; * second-sourcing agreements; * complex two-way licensing; * cross-licensing in separate product markets	Industrial joint venture firms and comprehensive R & D, manufacturing and marketing consortia	Customer–supplier agreements, notably partnerships	One-way licensing and/or marketing agreements (including OEM sales agreements)
Many partners	Several partners		Few or very few partners			Few or very few partners		

Source: Chesnais in DSTI, 1986, *Technical Co-operation Agreements Between Firms: Some Initial Data and Analyses*, on the basis of typologies by Hacklisch (1986) and Ricotta and Mariotti (1986).

a shareholder basis by a number of firms, generally MNEs. Programmes focus on generic technology relating directly to the competitive interests of the joint-venture partners. The research results are proprietary and form a kind of pool of patents and know-how for partners.

D. Agreements involving the use of corporate venture capital (CVC) are used by large corporations, notably MNEs, to make small but strategic investments in new innovative processes, still belonging to small firms. Used in combination with R & D contracts, such investments prepared acquisition without interfering immediately with the activities of the small, innovative firms; these remain autonomous in their R & D and management decisions (Ricotta and Mariotti, 1986).

E. Non-equity cooperative research agreements are flexible forms of cooperation of limited duration, without shareholder participation, established between a very small number of firms (usually only two) to deal with specific technical problems. If the R & D is successful it can either be exploited commercially by the participating firms each in their own business, or lead to the establishment of a separate joint venture.

F. Technological agreements bearing on existing 'proven technologies' can take a variety of forms, depending on the specific characteristics of industries and technologies. They include: (i) technology-sharing agreements bearing on complementarity technologies; (ii) second-sourcing agreements between large MNE producers, otherwise competitors (as in semiconductors), involving access to proprietary technology; (iii) two-way exchanges of licences in directly complementary areas with clauses providing for the continuous exchange of improvements and developments; and (iv) two-way exchanges of licences or of scientific and technical knowledge produced by firms as a 'by-product' of their main lines of scientific and commercial specialisation.

G. Comprehensive R & D, manufacturing and marketing consortia are joint ventures with a number of partners, formed with the aim of creating, testing, producing and commercialising a product all the way from the R & D to the final market.

H. Customer–supplier partnerships, notably between MNEs, which represent 'the formalisation of a link that reflects a significant reliance of the partners on one another. It may or may not involve an equity interest or an exclusive relationship . . . It responds to the intensifying *systemic* dimension of components and provides a mechanism for leveraging critical technical and financial resources for the partners (Hacklisch, 1986).

I. Licence agreements and technology transfers forming part of a long term relationship between two firms, as in OEM agreements.

In search of useful interpretative analytical frameworks

The information base concerning inter-firm technical cooperation agreements includes a variety of industry case studies, some very detailed (Mowery, .1986; Hacklisch, 1986; Payne, 1986), others more limited in scope; a motley collection of statistical data bases; one or two Ph.D. theses containing some empirical testing (Hladik, 1984); articles written from the standpoint of the theory of the firm (Mariti and Smiley, 1983), and a rapidly growing but fairly heterogeneous literature by business management economists (Harrigan, 1985; Ricotta and Mariotti, 1986; Doz *et al.*, 1986). At present, there is really only one conclusion to be drawn from this material—that inter-firm agreements occur within a very wide variety of concrete situations, on the basis of a wide range of corporate strategies and with very differing consequences for the future of firms and the maintenance and/or strengthening of domestic technology bases.

Progress towards the development of appropriate conceptual frameworks for the interpretation of the existing data and the elaboration of new and hopefully more significant and/or easily usable studies than many of those made at present can take place along several alternative paths, on the basis of the different approaches discussed in earlier sections. The main theoretical question (which to our knowledge has not yet been really tackled) bears on the explanation of why MNEs, after giving priority to internalised modes of creation and dissemination of technology, have moved towards a much greater recourse to cooperation with other firms, e.g. why, *after* moving from the *market* to *hierarchies* (Williamson, 1975), they are now moving from *hierarchies* to the interfirm *organisation mode* (Imai and Itami, 1984).

Whatever the approach chosen, one essential condition must be satisfied, which is an adequate *understanding and account of technology and innovation*, along with the *particular constraints*, they place on firms to enter into agreement and the *particular advantages* which can be created by the *successful centralisation and appropriation of technology through such agreements*. While a purely scientific and technological interpretation developed independently of any theoretical basis *can only yield descriptive results at the best*, conversely no proper analysis of agreements can sidestep the economics of innovation and technical change.

Not many studies have yet succeeded in combining the reference to a well-defined economic approach with a sufficient detailed analysis of the technological constraints and opportunities pressing towards the establishment of agreements. Teece (1986) offers one example written from the standpoint of the theory of corporate strategy. Teece's central hypothesis is that:

> in almost all cases, the successful commercialisation of an innovation requires that the know-how in question be utilised in conjunction with the services of other assets. Services such as marketing, competitive manufacturing, and after-sales support are almost always needed.

In some cases, firms (notably MNEs) will have internalised the specialised complementary assets through previous investments and mergers. In others, firms (notably small and medium enterprises or purely domestic or regional firms) will lack one or several of the necessary complementary assets and will be forced to find adequate partnerships and/or establish cooperation agreements. Other factors shaping corporate strategy are technological and rest on contemporary innovation theory as developed *inter alia* by Abernathy and Utterback (1978), Nelson and Winter (1982) and Dosi (1986). They concern in particular: (i) the appropriability regime, e.g. the degree to which an innovation can be protected (ranging from 'tight' regimes where technology is extremely difficult to imitate, to very 'weak' regimes where it is almost impossible to protect); and (ii) the degree to which a dominant design has been developed and imposed by one or several firms in an industry or, on the contrary, where there is a state of technological flux (a pre-paradigmatic stage with respect to dominant design).

In the Teece approach, as in all similar approaches influenced by the work of Porter (1984), the key strategic issue is the struggle 'to avoid handing over the lion's share of the profits from its innovation to imitators and/or owners of specialised and co-specialised complementary assets'. Which are the precise key assets required will obviously *vary* from industry to industry or even from product to product, while the degree of external dependence of firms and the risk that they fare badly in the distribution of value added and the flow of rent from innovation will obviously depend on their size, diversification and degree of multinational expansion.

Another analytical framework is the one developed by Bertin (1986) for the interpretation of data from the AREPTIT-SPRU questionnaire to MNEs concerning the *inward* as well as the outward transfer of technology through agreements involving patents (see Bertin and Wyatt, 1986, for a full account of this study). According to Bertin, MNEs must attempt to avoid two pitfalls: 'one is the transfer of advanced or sensitive technology to partners who might turn into dangerous competitors in the future; the second is the acquisition of such technology from a partner who may gain some type of control of a significant share of the firm's activity through its use'. In the face of rising R & D costs and the need to acquire technologies outside the firm, MNEs may be expected to develop strategies along two contrasting models:

In the *first model*, the firm holds a competitive position which is strongly centered in a main field of activity. It allocates the major share of its R & D expenses to this main field. It restricts itself to few transfers of technique, mostly with internal partners—subsidiaries or associates, whether foreign or domestic.

In the *second type*, closer to what we know as the industrial conglomerate model, the firm holds no such definite and strong competitive position or it has several distinct ones. Accordingly its R & D is not as specialised and it turns to external as well as internal partners for frequent technical transfers to complement its own research activity or to valorise its own technical output.

MNE strategies will also be shaped by certain features of the technology concerned, its availability (along with possible limitations set by sellers), the cost of acquisition and the expected returns. Bertin tests his model and comes up with results which show *extremely strong industry-specific features*, partially outriding the initial assumptions:

(i) External transfer partners play a significant role in industries of the world-oligopoly type, such as automobiles and electronics. What is rather new is that such partners are also significant in the chemical industry. The increasing cost of research may exercise a strong influence on the firm's strategy, as suggested in various interviews, compelling the firm to increase technology exchange with competitors.

(ii) This is especially true of the electronics industry where more than two-thirds of firms have the same partners on sales and purchases of technology; the importance of cross-licensing is one possible explanation for this result, assuming a small number of suppliers of new technology.

(iii) Except for world oligopoly sectors, internal partners are given a strong preference in what could be called the core activities of MNEs . . . External partners are preferred in activities where they offer new potentialities for growth in the near future (markets) or in the distant one (new research fields). Uncertainty and heavy costs of entry are grave concerns in new fields of activity such as new materials, communications and advanced computing. These concerns induce firms, even the largest ones, to look for extensive external technical contacts and joint-ventures in research.

A taxonomy with the role of government, supply structures and key features of technology as parameters

As can be anticipated from the earlier sections of this chapter, our own attempt at establishing an interpretative analytical framework of taxonomy does not take the individual firm at its starting point of a theory of corporate strategy, but seeks to interpret inter-firm technical cooperation agreements in the context of the main 'exogenous' factors shaping the individual firm's environment: the progress of internationalisation, the tendency towards concentration and centralisation, the overall fall in the rate of return to capital (OECD, *Economic Outlook*, 1986c), the role of government, and the pace and direction of technological change.[1]

Ever since beginning to work on inter-firm technical cooperation agreements, we have been struck by *the extremely strong industry and/or technology-specific differences* in the type and range of agreements met within different industrial sectors (see OECD, 1986b). These must be related, of course, to the particular features of technology in different

Table 23.2 Main parameters shaping the types of agreements most frequently used by firms in different categories of industry

Main parameters / *Types of agreement*	Role of government in structuring the industry and its markets	International supply structure	Degree of novelty and sophistication of technology	Location of R & D and of 'technological capital' accumulation	Size of investment and rate of capital depreciation	Degree and nature of the systemic attributes of final product	Representative industries
Industrial consortia and international joint ventures aimed at world markets	Important or very important; industries considered as strategic	Highly concentrated (tending towards monopoly or duopoly)	New or very new and/or very sophisticated technologies	Large firms with privileged relations with government large public R & D labs	Very large investments with very long depreciation periods	Strong systemic with high technological content	Space launchers and satellites; long distance civil aircraft; jet engines; weapons and military systems; telecom. equipment
Complex international agreements pertaining to engineering, technology, financing and manufacture for domestic or regional market projects	Important in DCs, limited in advanced countries (except for export credits and foreign policy support during commercial negotiations)	World oligopoly with or without a dominant firm with trends towards cartel-type situations or fairly organised oligopolistic rivalry	Fairly well-known technologies requiring large accumulated know-how	Large firms belonging to the world oligopoly; engineering firms and heavy equipment manufacturers	Large investments and long or very long depreciation	Systemic with medium or low technological content	Large-scale bulk non-ferrous metal electrical power stations (including nuclear); large-scale public infrastructures
R & D joint-venture firms leading to patent pools open to corporate partners	Large buyer and/or purveyor of R & D funds	World oligopoly without a dominant firm and with very acute rivalry	Constantly and rapidly evolving technology	Large firms belonging to the world oligopoly	Large investments in particular in R & D requiring cooperation in generic technology	Not very systemic but sometimes significant technological complementarities	Electronic components
Technology sharing agreements; complex two-way licensing,	As above	As above	As above	As above	As above	As above	Electronic components
cross-licensing in separate product markets; second sourcing agreements	Weaker role	Medium to strong oligopolistic rivalry	Technology changing rapidly after a period of slow development	Ditto	Large investments still within the scope of large firms	Tech. complementarities and/or specialisation in sub-markets	Pharmaceuticals; specialised chemicals (high-grade plastics, composites)
R & D contracts between large and small firms, with or without the use of corporate venture capital	As above	As above	Rapidly evolving technology on the basis of radical paradigm change	Small knowledge-intensive high-tech firms with specialised skills; univ. or public laboratories	Investments in innovation not very costly but with very high risk	As above	Biotechnology; specialised electronics and software; certain new materials

sectors, and also to the nature of supply structures, the role of government in support, the very existence of certain industries, the subsidisation of R & D, and the establishment of non-tariff protection around 'reserved' public procurement markets (Chesnais 1987).

We have also observed that inter-firm technological cooperation across national frontiers invariably *combines* several dimensions or, again, *meets several objectives*, notably access to technology in combination with guaranteed access to certain semi-protected or threatened markets. In many industries, the exchange of technology is also an effective way of consolidating 'mutual recognition' and 'mutual forbearance' between oligopolists and of laying the basis for a strengthening of entry barriers, possibly paving the way for quasi-cartel-like behaviour. In instances where the main objective is access to technology, the type of agreement chosen will depend on the nature of the firm or institution where the technology is located and the steps to be taken to appropriate it. As a result, Table 23.2 has been built using six parameters:

(i) The first concerns the role played by governments in shaping the structures of the industry (through R & D subsidies, large-scale procurement, open involvement in the organisation of the industry, and the division of tasks between firms).

(ii) The second parameter relates to the international supply structure (e.g. situations of near monopoly on duopoly: concentrated world oligopoly with a dominant firm (e.g. computers); concentrated world oligopoly with several firms of near equal strength; loose world oligopoly in combination or not with concentrated oligopoly in domestic or regional markets, etc.).

(iii) The *speed* of technical change, and the degree to which it has a *novel* or *radical* character and is therefore likely to have appeared outside established firms requiring them to resort to external acquisition.

(iv) The country location of the largest R & D outlays and the institutions (firms, government agencies and their laboratories, universities) within which the accumulation of technology has been proceeding. In combination, (iii) and (iv) *influence* the easiness or, on the contrary, the obstacles to *external appropriation*.

(v) The level of R & D and capital investment thresholds and the pressure they put on firms to cooperate.

(vi) The extent to which R & D- and scale-intensive products have *systemic* features, authorising a division of tasks and hence cooperation between firms in their conception and manufacture: this is an important dimension of some type of cooperation well illustrated by Mowery's study (1986) of the aircraft and engine industries.

Using the taxonomy: two examples

Industrial consortia and international joint ventures aimed at world markets (for instance, the General-Electric–SNECMA (France) joint ventures for the development production of the CFM 56 jet engine, see Baranson, 1976, and Mowery, 1986) are the form in which inter-firm cooperation (with which governments are also generally involved directly or indirectly) invariably takes place in industries such as *space products* (launchers and satellites), commercial *aircraft* of the large inter-continental categories, *jet engines*, and increasingly the *defence* industries, where international inter-firm agreements backed or initiated by governments have become more and more frequent.

This form of cooperation involves a carefully negotiated division of industrial responsibilities and workloads, financial risk, assets and profits. Agreements are almost invariably publicised in detail since they often involve the use of public funds. Membership is defined in terms of *percentages* of assets and liabilities and a precise definition of industrial roles.

The use of industrial cooperation as the preferred, if not exclusive form of cooperation can be directly related to

(i) the 'strategic' and 'political' character of the industries concerned;

(ii) the way in which the pace and nature of world demand (including the size of the market and the particularities of market access), coupled with the extremely high costs and complexity of scientific and technical requirements for production, have created a situation where only a very limited number of producers are active, and where the threat of *outright* or *near-monopoly situations* is a real one and where alliance is the only choice open to almost all countries and to practically all firms; but also

(iii) where the strong *systemic*, but at the same time *high-technology features* of the end product allow a division of tasks, either among equals or near-equals (as in the case of the main participants in Airbus industries or Ariane), with all the complex problems of rivalry and coordination which this raises, or between firms in an unequal situation with one firm acting as prime contractor with sole final responsibility (as in the Boeing, TWR or Hughes Aircraft-led US consortia).

The semiconductor industry is one of those where the *greatest number and widest range of forms of agreements are used* by the large firms. The situation reflects, in part, the pace of technological progress in the industry (cf. Dosi, 1984, for a complete interpretation of the early 1980s). The close network of agreements which the major firms have established among themselves must, however, be related to the specific *supply structure of the industry*. The internationalisation and diversification strategies followed by all large electronics firms now place major manufacturers in a situation of oligopolistic rivalry generally involving competition on a combination of

identical and/or complementary product markets. Electronics and in particular semiconductors are industries *par excellence* 'characterised by strong oligopolistic and technological competition' where 'MNEs . . . need a direct presence in all those countries which hold leading positions in the development of the industry and of associated technology' (Dunning and Cantley, 1986). As a result one finds:

- at the *stage of precompetitive R & D* a number of *national* alliances between oligopolists belonging to the same country: e.g. the Japanese example of the large industry—MITI projects, e.g. VLSI, the '5th generation computer project' (Sigurdson, 1986) which the United States and Europe have recently tried to imitate (e.g. the three US cooperative arrangements in microelectronics, the Semiconductor Research Corporation (SRC), the Microelectronics Center of North Carolina (MCNC), and the Stanford University Center for Integrated Systems (CIS), which belong to category A of Table 23.1; the UK Alvey, the Esprit project (examples of category B), or again the new private R & D joint-venture corporations (type C), such as the European Computer Research Center (ICL, Bull and Siemens) and, of course, the US Microelectronics and Computer Technology Corporation (MCC);
- at the *competitive stage* a considerable focus *on F-type agreements*, between oligopolists *of different nationality* bearing on already developed technologies. In semiconductors alliances very rarely take the form of consortia of joint ventures, but rather of *bilateral* agreements between oligopolistic rivals. Faced with continually increasing R & D costs, MNEs see at present considerable advantages in sealing mutual recognition through agreements involving a two-way exchange of technology, thus reducing some R & D outlays and at the same time raising the stakes for non-participants in the agreements. In combination and on account of their number, their bilateral agreements create a web-like network of agreements, at various points of which one finds (in a sort of nodal position) the firms which have established the largest number of linkages.

The most carefully documented research on this industry (Hacklisch, 1986) shows that technology-sharing agreements, second-sourcing with technological exchange and joint and/or complementary development accords are the forms of agreement most frequently encountered in semiconductors. Technology-sharing agreements generally involve a two-way exchange of comparable, but *complementary* technical expertise. Major examples are the US–Japan agreements in which US design capabilities have been shared in exchange for Japanese competence in CMOS fabrication technology. A major finding by Hacklisch is that 'The respective strengths of US companies in design and software microprocessor technology and of Japanese firms in CMOS are a prime characteristic in a number of US–Japan agreements in the area of MUCs/MPUs'. Examples given include the Intel–Oki, Intel–Fujitsu, Motorola–Hitachi, Zilog–NEC and Zilog–Toshiba agreements.

The pooling of patents (which will occur if corporations like MCC are successful) and reciprocal licensing confront potential competitors, notably smaller firms or firms contemplating entry into the industry, with formidable competitive stakes and entry barriers. The situation in semiconductors today presents both *similarities* and important *differences* with earlier examples of the 1930s (in heavy electrical equipment and chemicals). Technology-sharing and exchange between the largest firms in the industry are quite certainly increasing the advance of these firms over those which cannot hope to be parties to the most important types of partnerships. They represent one of the factors lying behind the continual increase in concentration at world level. At the same time, however, and this, of course, is the novel aspect, rivalry continues to be extremely acute within the small group of leading world firms, notably between the main US and Japanese manufacturers. This particular combination of cooperation and competition is one of the foundations for the fear sometimes expressed by some observers in the United States (cf. Reich and Mankin, 1986) that the technology agreements set up with US firms are, in fact, providing Japanese firms with an accelerated access to the technology of their US competitors.

Concluding remarks

These must necessarily be extremely brief. The first concerns our belief that there is need for a multi-form theoretical and analytical attack in all the areas discussed from the third section onwards, where important lacunae in our knowledge, due to gaps in theory which urgently require bridging, have been identified.

The second observation concerns the overall message stemming from our analysis, which is not extremely optimistic for developing countries (see also the chapter by Unger), nor indeed for the smaller or less developed OECD countries (Walsh, 1987). Much more research would be required to understand the medium and long-term effects of a situation where the *largest* and *most advanced firms*, technologically speaking, are exchanging *between themselves*, vital, *complementary* technologies. On the basis, however, of available data in the light of the understanding built up by earlier work on *barriers to entry* (Bain, 1956) and *technology gaps* (OECD, 1970), it can safely be stated that such cooperation creates *formidable new entry barriers* at the heart of the industry and with respect to its 'core technology' base (US National Research Council, 1983); thus creating new conditions of interfirm and intercountry dependencies, in the form of a whole new web of dependent technological links *vis-à-vis* the industry leaders. This is felt even by advanced small and medium-size OECD countries. It is certain to affect developing countries very strongly in the future. As Dunning and Cantwell (1986) have put it:

> The change in the international environment has further compelled a move towards *integrated technological systems*. The advantages which stem from *such centralised co-ordination* has helped to strengthen the position of many MNEs *vis-à-vis* uninational firms, who are constrained to follow seriously only those activities in which their own countries have an existing or potential locational advantage. [author's emphasis]

The identification of such systems and the development of appropriate corporate strategies, (see the work of LAREA, GEST (1985) on 'Technology cluster Strategies') has already begun to create yawning new technological and industrial gaps between firms and countries, even within the most advanced OECD countries. The capacity on part of firms and countries to recognise (i) that core technologies may lie at the heart of technology *systems* (see Gille, 1978 and also with application to the Japanese situation Imai; 1984); (ii) that centralised coordination must start from a sound and firm domination of technological advance in these core core technologies; and (iii) that successful competition requires appropriate diversified large company industrial group structure, (of which the Japanese 'keiretsu' represents today the most successful example, see Freeman, 1987), *may represent* in coming years one of the most powerful instruments of *inequal development* at work in the world economy.

Note

1. *All* these factors of course are *endogenous* to the overall movement of the capitalist economy. The term 'exogenous' is used simply to designate the incapacity of any given firm, however large it may be and however much it contributes to their acceleration, to control the factors shaping the overall international economic, technological and political context in which it operates. The environment becomes increasingly 'exogenous' (e.g. constraining) as the size of firms become smaller, but *even the largest* MNE can never do more than *adapt*, with major advantages over small firms, *to the changes and challenges of the environment.*

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