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Technological infrastructure and international competitiveness

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The paper is probably the first written paper using the concept of 'the national innovation system' and it analyses how technological infrastructure differs between countries and how such differences are reflected in international competitiveness. It makes a critical review of new (in the 1980s) developments in the theory of international trade and confronts them with recent empirical results. It shows how competitiveness cannot be explained by wage rates/prices/currency rates. Technological leadership gives absolute rather than comparative advantage and technological leadership will reflect institutions supporting coupling, creating, clustering comprehending and coping in connection with technology. The analysis is rooted in historical context through references to Friedrich List and his criticism of Adam Smith and laissez-faire. Special emphasis is put on List's concept of mental capital. Finally, the analytical arguments are illustrated by the catching-up and forging ahead of first Germany and later Japan. The paper concludes that disequilibria in international trade will be persistent and that for laggard economy the free trade doctrine may be unduly restrictive. Another conclusion is that public investment in technological infrastructure and intellectual capital is crucial for successful economic development. It is pointed out that there is a need to couple education, science, trade and industry policy in order to build competitiveness.

1. International specialization and international competitiveness

Some recent OECD work has drawn a distinction between the study of trade performance on the one hand and studies of the 'evolution of factors affecting trade performance' on the other (OECD, 1981). The former type of study concentrates on factors, which modify 'the structure (volume, product composition, geographical distribution) of trade between countries in a quasi-objective way that is largely independent of the conscious action of individual countries'. Much of the academic literature on the economics of international trade is of this nature. The latter type of study concentrates on 'ways in which competition is waged between firms and the measures taken by governments to help them'. These studies are more characteristic of the literature of business economics and, one might add, of economic history and history more generally. In so far as they deal with technology at all, the first type of study treats it as a quasi-autonomous factor modifying traditional theories of comparative advantage based on relative factor costs. The second type of approach, however, treats technology as one (usually rather important) element in the competitive struggle between firms and nation-states, which may be manipulated by appropriate policies, both at the national level and the level of the firm (OECD, 1978).

In so far as it may be useful to make this conceptual distinction, this paper belongs clearly to the second category. It attempts some very elementary analysis of the influence of science and technology infra-structure on international competitiveness and it is concerned in particular with various ways in which a science-technology system may be organized, and how these have changed over time. It is argued that such changes have been an important element in the changing locus of international technological leadership and that this leadership has been a dominant element in competitiveness. However, it is an important part of the argument which will be developed, that there has in fact been some convergence between the two approaches distinguished above, as the theory of international trade has been going through a period of turmoil which without exaggeration could be described as a paradigm change, involving both a far more explicit recognition of the importance of technology in the explanation of past patterns of trade performance and much greater attention to the role of institutional factors.

2. International trade theories and technology

During the post-war period the traditional theory of international trade proved incapable of providing a satisfactory explanation of the observed patterns of commodity trade. Following the demonstration in 1953 of the 'Leontief Paradox' (Leontief, 1953), it became difficult to sustain explanations of the trade performance of such countries as the United States and the German Federal Republic in terms of the relative costs of labour and capital. Posner's seminal paper in 1961 opened the way to the development of an alternative paradigm, or at the very least a substantial revision of the established theory. Starting from the self-evident fact that a firm which introduces a new product may enjoy an export monopoly from the country of origin at least until imitators come into the market, he developed a set of concepts which became the basis for various 'technology gap' theories of foreign trade. As long as the 'imitation lag' was longer than the 'demand lag', technology gap trade could persist. Posner identified several mechanisms that might tend to maintain this gap for fairly long periods, including the quality and scale of commitment to R&D, the 'clustering' of technical innovations and dynamic economies of scale.

A few years after the appearance of Posner's paper, Hufbauer (1966) provided an excellent empirical illustration and validation of the theory with his study of international trade in synthetic materials. He measured imitation lags for many countries for some 60 synthetic materials and demonstrated a clear-cut relationship between trade performance and innovative leadership. He recognized that as a product matured, traditional cost elements could become increasingly important, so that 'low wage' trade could take over from 'technology gap' trade in mature technologies. Although he showed convincingly that innovation and early imitation explained the predominant position of the German and US chemical industries in trade performance in the early decades of the new synthetic materials industry, he did not attempt to investigate the source of these innovations other than by identifying the firm of origin.

This question was taken up in a series of studies at the National Institute of Economic and Social Research in the 1960s (Freeman *et al.*, 1963, 1965, 1968). These attempted to relate both the innovative and the comparative trade performance of firms and countries to various factors which Posner (1961) had identified, particularly the scale, location and quality of their R&D and the 'outputs' from that R&D, as measured by various indicators such as patents. The results of this work lent support to the view that the innovative leadership of German chemical firms over a long period was related to their exceptionally heavy investment in R&D and the same point also emerged in relation to the leadership of US firms in the world market for electronic capital goods. Patent statistics showed that technological leadership in these industries was broadly based and did not rest simply on a few chance inventions or discoveries. However, it was never suggested that the innovative successes of leading firms or countries could be explained simply in terms of the quantity of R&D performed. The studies also attempted to take into account firm strategies, institutional factors, such as the role of government research, of the education system and the inter-dependent relationship between various groups of firms, such as for example chemical firms, chemical process plant contractors and machinery suppliers. This paper represents an attempt to extend and generalize this approach, taking into account the results of more recent work.

Both the NIESR studies and Hufbauer's work were important also in underlining the relationship between imitation lags, dynamic economies of scale, process innovation, and a range of scientific and technical activities. Imitation lags could be prolonged if R&D threshold costs were high and the best competitive efforts of would-be imitators could be repeatedly frustrated if the innovators could maintain a flow of process innovations related to scale economies and new generations of products. Such mechanisms were later shown to be extraordinarily important in the semi-conductor industry by the studies of Golding (1972), Sciberras (1977) and Dosi (1981a). All of this empirical evidence pointed to the conclusion that technology gaps could be sustained over long periods. However, it related only to a few specific industrial sectors and could thus be dismissed as irrelevant for the greater part of foreign trade.

The first attempts to relate trade performance to some measure of technical innovativeness across a wide range of industries were made by Vernon, Keesing and their colleagues at Harvard in the mid-1960s (Vernon *et al.*, 1967). Their work pointed the way to a resolution of the Leontief Paradox, in as much as it demonstrated that there was a fairly strong statistical association between the ranking of US shares of world export markets by product group, the R&D intensity of those industries and other measures of the participation of highly qualified manpower. World export performance of the United States was exceptionally strong in several industries, which although they were certainly 'labour-intensive' rather than capital-intensive in the traditional sense, were characterized by very large inputs from highly skilled personnel. However, this work related only to the United States and attempts to extend it to a wider range of countries at the OECD in the late 1960s ran into severe difficulties because of the limitations of the R&D data, the problems of reconciliation of the R&D classification with trade classifications, and international comparability problems.

In any case, it was always conceptually unsatisfactory to use an 'input' measure (R&D expenditures or manpower data) as a surrogate for technological innovativeness. In the absence of any direct measures of innovative achievement (except those laboriously constructed for individual industries such as synthetic materials), patent statistics seemed to offer the best available 'output' indicator, as they were universally available for long periods. Some of the main problems associated with their use (lack of comparability of different national systems, reflecting variations in propensity to patent) were ingeniously circumvented by Pavitt and Soete (1980) through their use of the new statistics, which became available through the Office of Technology Assessment and Forecasting of the United States Department of Commerce.

The first systematic attempts to relate international trade performance to some measure of 'technological output' across the board and for a large number of OECD countries were made by Soete (1980, 1981). In his 'General Test of Technological Gap Trade Theory' he regressed variations in export performance across 22 OECD countries on variations in innovativeness for each of 40 industrial sectors. His results demonstrated the crucial role of the technology variable in explaining inter-country variations in export performance in the great majority of industries. Non-significant results were obtained for a few industries such as food, petroleum and stone, clay and glass in which natural resource endowment clearly plays an extremely important role. A second group of industries where results also were sometimes not significant were the typical mature industries of relatively low research intensity, such as textiles and ship-building. But the results were significant for 70% of the product groups at the 5% level and for half of them at the 1% level of significance.

In the face of such evidence and the lack of any comparable support in the empirical work to justify the traditional factor proportions theory of comparative advantage, it has become difficult[1] to ignore the importance of the influence of technology on trade performance. Indeed, already in the 1960s some of the leading traditional trade theories had begun to acknowledge the need for some revision of the mainstream theory, notably Harry Johnson, who developed the concept of 'human capital' within neo-classical trade theory (Johnson, 1968).

This major revision of the theory by its leading exponent meant that, after the Montreal Conference of the International Economics Association, both believers and

[1]Not impossible, as we know from other cases of paradigm change in the natural as well as the social sciences that 'rationality' counts for less than the emergence of a new young generation of practitioners (Easlea, 1973).

heretics could agree up to a point in stressing the importance of such factors as investment in education and industrial technical training, as well as R&D and other scientific and technical services. In the 1970s a number of economists provided further strong support for this view (see e.g. Horn, 1976; Wolter, 1977).

This did not necessarily mean that 'technology gap' and 'human capital' trade theories were in agreement about other fundamental issues such as the assumptions of perfect competition, attitudes to government intervention and so forth. In practice, despite Harry Johnson's revisionism a significant body of trade theory continued to neglect or ignore the issues raised by the neo-technology debate and to make somewhat unrealistic assumptions about the role of relative prices and of government in relation to trade competition. All the more importance therefore attaches to the other recent empirical and theoretical work by neo-technology trade theorists.

One stream of such work has concentrated on the relevance of 'non-price factors' in the explanation of trade competitivity and of international trade performance. Almost all such studies, whether based on interviews with buyers and sellers, or on more general statistical analysis, point to the conclusion that price is only one element in effective competition. It is of decisive importance for homogeneous primary commodities traded in internationally competitive markets or subjected to relatively simple processing or refining. But in most capital goods markets and for many consumer goods, empirical research points unambiguously to the conclusion that factors such as real or perceived quality variables related to design, technical service, reputation and marketing play an extremely important role, along with non-technical factors such as credit. Kravis and Lipsey (1971) report that their questionnaires showed that only 28% of US exporters attributed success to lower prices, while 37% suggested that the critical factor was product superiority and a further 10% product uniqueness.

Of German importers, only 7% said they were buying in America because of lower prices, whereas 63% explained their imports by non-availability of products at home. Rothwell's (1980, 1981) results for textile machinery and agricultural machinery showed an even greater emphasis on non-price factors. Only 4% of UK companies importing textile machinery in the 1970s gave lower prices as the reason, whilst over 80% gave reasons such as 'superior overall performance and design' or 'technically more advanced' or 'no suitable UK alternative'. In his study of the success of Japanese exporters in the world colour television industry Sciberras (1981) reported that evidence from consumer organizations in both Europe and the United States in the 1970s stressed superior product quality over a great part of the product range. For example, Juran reported in the Journal of the Electronics Industry (March 1979) that US sets failed at least five times as frequently as Japanese sets at that time.

At the aggregate statistical level the evidence is no less decisive. Posner and Steer (1979) sum up the results of their analysis as follows:

> Historically there is no doubt that non-price influences have dominated (in UK trade performance)—the proportion of the total change which they

> 'explain' is an order of magnitude greater than the explanatory power of price competitiveness.

The OECD secretariat paper on the notion of international competitiveness quotes the results of Kaldor (1978) and of the OECD Balance of Payments Division (OECD, 1981), which show 'perverse' relationships between measures of 'price competitiveness' and development of export shares during the 1960s and 1970s. Japan and Germany in particular managed to combine a deterioration of relative prices and labour costs per unit of output with improved export performance, whilst the UK in particular showed a fall in world export shares when her relative export prices and costs were apparently improving. These very strong long-term tendencies of the entire post-war period were deeply rooted and could only be counteracted by changes in relative prices to a limited extent.

3. Technological leadership and trade performance

These last results are of the greatest interest for our present purpose since they demonstrate that long-term shifts in world export shares between the leading manufacturing countries are not primarily explicable in terms of traditional price competition theory, but must be explained in other terms. The studies, which have been discussed so far, have provided fairly conclusive evidence that 'technology' broadly defined has played a very important role. But that evidence relates mainly to competitive performance sector by sector. This applies even to studies, such as those of Soete, which have looked across the board at all sectors of industry. His results and those of similar studies show that firms (and the countries in which they are based) tend to do well in their trade performance if they are relatively more successful than their competitors in developing new products and improving old ones, and in improving the manufacturing technology by which such products are made. They do not show why it is that in certain historical periods particular countries tend to do exceptionally well in export performance not just in one or two industrial sectors, but in many simultaneously, indeed sometimes in almost all of those sectors which are not dominated by natural resource availability or long-term traditional fashion-based factors. It was such general shifts in country performance, which lent credibility to such general explanations as relative prices (sometimes brought about by deliberate exchange rate policies) or low wages.

But if such older general explanations do not stand up to empirical testing or explain only a small part of the observed long-term changes in international trade patterns, then what can technology theories offer which might help to explain shifts in world technological leadership, shifts which are not just randomly distributed across industries or between the various industrial countries or in proportion to their earlier shares of world production or world trade, but occur in waves or long historical periods? What too can they offer to help explain why, when many countries are striving to catch up with the world technology leaders, only a few succeed and then only after a very long period? It is to these and similar questions that we now turn, since they have the greatest interest from the standpoint of international competitiveness as well as the new trends in international trade theory.

What has already been said about Posner's theoretical framework and about the NIESR studies of innovation and trade performance have suggested that 'catching up' and overtaking established technological leaders could pose formidable problems for imitators and aspirants for leadership, since they must aim at a moving target. It is no use simply importing today's technology from the leading countries for, by the time it has been introduced and efficiently assimilated, the leaders have moved on and the relative position of the various countries may be unchanged or even worsened from the standpoint of the followers. It cannot be simply assumed that 'catching-up' is an easy and almost costless process, based on the simplistic assumption that new technology is equally and freely available to all comers. This is one of several very unrealistic assumptions of perfect competition theory, which must be finally discarded if any progress is to be made in understanding the factors affecting international competitiveness. On the contrary, as has already been pointed out much of the empirical work on technology and international competition points to such problems as high R&D entry barriers, major bottlenecks in acquiring requisite skills, very significant dynamic economies of scale, high cost of the most recent and desirable patents, licences and know-how and so forth.

It is for these reasons that 'overtakers' face such difficult policy issues as the scale and direction of investment in technological infra-structure, as well as the infant industry problem which has pre-occupied them since the days of Friedrich List. It is for this reason too that great interest attaches to the achievement of those firms and those countries, which have succeeded in overcoming these entry barriers and overtaking the established leaders. This surely lies behind the great worldwide interest in those factors, which might explain the recent (1960s–1970s) astonishing performance of the Japanese economy or the rather less successful efforts of the Soviet economy, except in the military-space field. Much might be learned also from the earlier experience of Germany and the United States in overtaking and surpassing the one-time technology (and trade) leaders of the nineteenth century. Finally, something also is surely to be learned from the successful (and unsuccessful) attempts of the Newly Industrializing Countries (NICs) to break into the circle of leading industrial countries.

In developing such an analysis it is far less possible to make use of international statistics, whether with respect to trade or technology. This is for several reasons, both practical and analytical. On the purely practical level, the problems of reclassification of the immense volume of international trade statistics to reconcile them with the only available measures of technological output—patent statistics—are so formidable as to virtually preclude any major retrospective extension of the type of work accomplished by Soete, except perhaps in terms of some very broad sectors or over a long period. Pavitt and Soete (1981) have indeed already demonstrated that the type of approach, which they pioneered, can be used at the aggregate level to investigate long-term changes in the relative inventive performance of the leading industrial countries in relation to economic growth performance. However, the problems that we wish to investigate can only to a small degree be illuminated by statistical evidence, since they involve also social, institutional and organizational questions and qualitative rather than quantitative assessment. Moreover, this is a first and rather tentative and speculative attempt to examine a range of problems, which have not hitherto been the subject of systematic investigation. Consequently the method will be that of 'reasoned history', only occasionally supported by fragments of quantitative evidence.

This need not distress us too much. It was Schumpeter (1939) who, more than any other twentieth-century economist, recognized the fundamental importance of technology for competition between firms, and who in his work on long-term developments in the world economy commented:

> . . . it is absurd to think that we can derive the contour lines of our phenomena from our statistical material only. All we could ever prove from it is that no regular contour lines exist . . . We cannot stress this point sufficiently. General history (social, political and cultural), economic history and more particularly industrial history[2] are not only indispensable, but really the most important contributors to the understanding of our problem. All other materials and methods, statistical and theoretical, are only subservient to them and worse than useless without them.

Clemence and Doody (1950), in their summary of the Schumpeterian system, add further:

> If innovation and qualitative change are the fundamental elements in economic development, then no amount of quantitative analysis can reveal the really significant pattern. As soon as we open the door to qualitative phenomena we admit a degree of human judgment that must largely supplant more objective and mechanical devices.

Whilst not everyone may be entirely happy with this degree of demotion for quantitative techniques of inquiry, we may now proceed to discuss the following questions: what changes in the science-technology system of a country might help to explain its rise to technology leadership over a considerable period and its corresponding rise in world market leadership? Were such changes the result of deliberate national policies designed to improve competitive performance? Are there any pointers to the type of policies, which might prove more effective for the next wave of new technologies? In attempting what must inevitably be rather sketchy and flimsy preliminary answers to these very fundamental questions, we accept fully the point made by Chesnais (1981) in his critique of some earlier research: the social

[2]A good example of Schumpeter's point with respect to the semi-conductor industry is to be found in Dosi (1981b).

circumstances surrounding each new long cycle of technological and economic development differ from the preceding cycle.

Nevertheless we may distinguish certain features of the process of technical innovation which are inherent in the very nature of innovation[3] itself. What changes in successive historical periods in the mode of dealing with these basic characteristics, i.e. which social innovations permit and stimulate a particular society to introduce specific new technologies and to achieve technological and economic leadership?

4. Some basic characteristics of technical innovation

If it is accepted that success in technical innovation is a crucial element in competitiveness and if we wish to place it at the heart of our analysis, instead of relegating it to a peripheral or residual role, then it follows that some basic characteristics of innovation must be taken into account. These may be summarized as:

1. Coupling (of changing technology, production and markets)
2. Creating (new products, processes, systems and industries)
3. Clustering (of groups of related innovations)
4. Comprehending (new skills, new technologies, new markets)
5. Coping (with the technical and market uncertainty of innovation)

We shall consider each of these briefly in turn before going on to discuss the ways in which various countries modified and changed the institutional framework in which they dealt with these characteristic features of innovation in successive cycles of economic development.

4.1 Coupling

This aspect of innovation may be considered as definitional or as purely tautological. Nevertheless it is a feature of the process, which is often forgotten in practice (thus leading to failure in attempts at innovation both in market and in planned economies). Its profound implications for theory are often also overlooked. Following Schumpeter, innovation is usually defined as the commercial realization or introduction of a new product, process or system in the economy. This may be contrasted with *invention*, which is simply the bright idea for such a new product, process or system. Schumpeter pointed out that there is a world of difference between the two. Most inventions never become innovations since there is many a slip between cup and lip, and the process of developing an invention to the point of commercial introduction is often long and sometimes expensive and risky too. It also requires a special type of creative ability, which Schumpeter defined as entrepreneurship, reserving this term for the management of innovation rather than everyday management.

It follows from this definition of innovation that one of the most important roles of

[3]These characteristics, which we shall identify may be compared with Dosi's (1981b) list of 'stylised facts' about the economics of technical change (para. 26).

the entrepreneur or innovation manager is to match new technical and scientific possibilities with the needs of potential users of the innovation. At the very elementary level this may be quite straightforward, as, for example, in the inventions and innovations described by Adam Smith, where working men recognized the opportunities for improving their own machines and did the job themselves. On the other hand it can often be far more complicated, as, for example, in the introduction of an instrument landing system for aircraft or a new computerized radar system for air traffic control or a new drug. Such innovations require a complex matching process of new technical knowledge with information about, and experience of, many aspects of the potential market. It is the contention of this paper that whilst Adam Smith's incremental innovation is still extremely important and will remain so for the foreseeable future, the 'coupling' process between technology and the market (or simply users where markets are not involved) has tended to become increasingly difficult, because of the growing complexity of both. This means that social innovations in this coupling system have been a crucial factor in achieving and retaining technological leadership.

4.2 Creating

As has already been indicated above, creativity is an essential element of entrepreneurship, since it involves the bringing together of what were previously disparate and scattered pieces of knowledge to create something new. Sometimes the term 'creativity' is reserved for those abilities of the scientist, which lead to new discoveries or of the artist, which lead to new works of art. These kinds of creativity are important for innovation too. But when we are considering national innovation systems (as opposed to global civilization and the world economy) then at least in the past they have not been so central to innovative success as those types of creativity which are characteristic of the engineer in the work of invention and design and of the entrepreneur. In these entrepreneurial/engineering types of creativity the *synthesis* and creative application of information from a variety of different sources (including the arts and sciences) are critical. Another contention of this paper is that the capacity for such creative synthesis has become increasingly related to more effective modes of coupling with the arts and sciences and their creative initiatives.

4.3 Clustering

It was Schumpeter (1939) again, who observed that innovations, like troubles, do not come singly but in battalions. They are 'more like a series of explosions than a gentle though incessant transformation'. They are not distributed at random, but tend to concentrate in certain sectors and those other sectors, which are intimately affected. This clustering is related to the diffusion process, which leads to further innovations as the band-wagon gets rolling. These observations of Schumpeter have been amply confirmed by much empirical research since his day. All statistics of the inputs and outputs of the R&D system illustrate the point. They show heavily skewed distributions of research, inventive and innovative activities. Moreover, the research-intensive industries and activities tend to be the same throughout the world, with certain exceptions related to military R&D and to the small size of many countries. This suggests that the common underlying factors are the progress of world science and technology and new market opportunities related to income growth. There are a number of mechanisms, which might explain the clustering in terms of world technology. A major new material would involve many applications innovations to take advantage of its new properties in various areas of application. A new piece of equipment, such as a computer, would lead both to component innovations and applications innovations, which are an obvious feature of the contemporary industrial scene. Most product innovations lead to further process and product innovations, as their scale of manufacture increases and as competitors strive to gain some cost of production or quality improvement advantage. The expression ‘natural trajectory’ has been coined to describe this process of the cumulative exploitation of new ideas, and Nelson and Winter (1977) have pointed out that:

> . . . there is no reason to believe (and many reasons to doubt) that the powerful general trajectories of one era are the powerful ones of the next. For example, it seems apparent that in the twentieth century two widely used natural trajectories opened up (and later variegated) that were not available earlier: the exploitation of the understanding of electricity and the resulting creation and improvement of electrical and later electronic components, and similar developments regarding chemical technologies. It is apparent that industries differ significantly in the extent to which they can exploit the prevailing general natural trajectories, and these differences influence the rise and fall of different industries and technologies.

Schumpeter suggested that ‘the rise and fall of different industries and technologies’ lay behind the ‘Kondratiev’ long cycles of economic development, lasting about half a century. He distinguished three such cycles—the first (1780s to 1840s) based primarily on the steam engine and a cluster of textile innovations; the second (1840s to 1890s) based on railways and steel; the third (1890s to 1940s) based on electricity, the internal combustion engine and chemicals. Had he lived, he might have identified a fourth (1940s to 1990s) based on electronics, synthetics, petrochemicals and nuclear power, and speculated about a fifth. The controversy about such ‘long waves’ has recently given rise to a considerable literature, as the change in the economic climate of the 1970s and 1980s has become a matter of increasing concern (Freeman, 1981). However, this controversy need not detain us here. The substantive point for this discussion is the one made by Nelson and Winter—as it implies that changes in world technological leadership may be associated with the emergence of ‘new technological systems’ and the associated changes in industrial structure. Further, it suggests that some countries might fall behind through a failure to adapt sufficiently quickly to the new ‘natural trajectories’. If the new technological systems have very widespread applications—as, for example, electricity or computers—then they could help to explain the tendency for countries to succeed (or fail) in many different sectors in the same periods. It is the contention of this paper that the capacity to exploit a 'natural trajectory' or a 'new technological system' rapidly and efficiently is strongly related to various types of infrastructural investment, especially education, as well as to the modes of interaction between industrial firms themselves and their own arrangements for education and training.

4.4 Comprehending

In whatever country and in whatever institutions the original scientific and technical ideas, which underlie a new technological system, may have originated, the ability to innovate successfully and continuously depends upon the number and quality of the people who have assimilated these ideas and the depth of their understanding. These in turn depend upon monitoring systems, information systems and education systems as well as upon the general 'openness' of a society and the movement of people and ideas.

4.5 Coping

Again this is in part a matter of definition. Innovation inevitably involves uncertainty with respect to technology and markets. By definition, it is not possible to make accurate predictions of the costs, duration and consequences of technical innovation. If it is possible, then what is being done is not innovation. It is possible to speculate, to make informed guesses, and to anticipate some of the problems and some of the consequences. The less radical the innovation, the easier this is, and in the case of simply imitating an innovation made elsewhere the uncertainty may be minimal. Nevertheless, the ability to cope with uncertainty and to live with it is an essential element in the successful management of innovation. This has many implications for technological leadership. It puts a premium on flexibility in ideas and in institutions. It puts a premium on 'management slack' of some kind or other in innovating organizations. It puts a premium on long-term patience with radical new ideas and inventions, and long-term strategies generally as opposed to the apparent near-certainties of short-term profit maximization.

We now turn to consider some historical examples of major shifts in world technological and trade leadership in the light of the above discussion. We first consider the way in which Britain, the leading country of the first two waves of new technology (steam power, textiles and railways), was overtaken and surpassed by other countries, particularly Germany. We then consider another case—Japan—a relative latecomer to international technological competition. We also take a sidelong glance at the Soviet Union, even though this has not been a market economy since 1917.

5. Friedrich List, laissez-faire and mental capital

George Ray, who introduced the discussion on the changing locus of technological leadership in relation to Kondratiev long waves (Ray, 1980), has pointed out that British dominance of world production and world exports in the first half of the nineteenth century was so complete that she accounted for half or more of total output of most of the major industrial commodities of that time, including coal, iron, steel, metal products and cotton cloth. Although bought at a high price in working class suffering, the great success story of the industrial revolution, which made Britain the 'workshop of the world', was regarded at that time in rather the same way as the contemporary industrial and trade success of Japan. Britain was the home not only of the industrial revolution but also of classical political economy, which she recommended to her competitors and would-be imitators as a sure and universal prescription for success. However, although classical economics did indeed have a powerful worldwide influence, both as a social science paradigm and as a religion, not all of its propositions commanded the same allegiance as in Britain. Foreigners were more inclined to ascribe British success to her technology, her institutions and her investment in manufacturing than to any natural comparative advantages or special dispensation from above.

In particular, the most important and influential economic theorist in Germany, Friedrich List, discussed the British economy in terms highly reminiscent of much contemporary discussion on Japan. He was a powerful critic of Adam Smith on a number of key issues, which are relevant to our analysis:

> Commerce is also certainly productive (as the Laissez-Fare school maintains); but it is so in quite a different manner from agriculture and manufactures. These latter actually produce goods, commerce only brings about the exchange of goods . . . . From this it follows that commerce must be regulated, according to the interests and wants of agriculture and manufactures, not vice-versa. But the school has exactly reversed this last dictum by adopting as a favourite expression the saying of old Gourney, 'Laissez-faire, laissez-passez', an expression which sounds no less agreeable to cheats and thieves than to the merchant, and is on that account rather doubtful as a maxim. This perversity of surrendering the interests of manufactures and agriculture to the demands of commerce without reservation, is a natural consequence of that theory which everywhere merely takes into account present values, but nowhere the powers that produce them, and regards the whole world as but one indivisible republic of merchants. (List, 1845)

He accompanied this onslaught on the 'school' by another line of attack in which he anticipated by more than a century the 'human capital' theories of the neo-classical school. Adam Smith had condemned the idea of 'artificially' directing capital into new industries, but List replies:

> Adam Smith has merely taken the word capital in that sense in which it is necessarily taken by rentiers or merchants in their book-keeping and their balance sheets . . . He has forgotten that he himself includes (in his

> definition of capital) the mental and bodily abilities of the producers under this term. He wrongly maintains that the revenues of the nation are dependent only on the sum of its material capital. His own work on the contrary contains a thousand proofs that these revenues are chiefly conditional on the sum of its mental and bodily powers, and on the degree to which they are perfected, in social and political respects, and that although measures of protection require sacrifices of material goods for a time, these sacrifices are made good a hundred-fold in powers, in the ability to acquire values of exchange, and are consequently merely reproductive outlay by the nation. He has forgotten that the ability of the whole nation to increase the sum of its material capital consists mainly in the possibility of converting unused natural powers into material capital, into valuable and income-producing instruments He has not taken into account that by the policy of favouring native manufacture a mass of foreign capital, mental as well as material, is attracted into the country . . . He falsely maintains that these manufacturers have originated in the natural course of things and of their own accord; notwithstanding that in every nation the political power interferes to give to this so-called natural course an artificial direction for the nation's own special advantage.
>
> He has illustrated his argument, founded on an ambiguous expression and consequently fundamentally wrong, by a fundamentally wrong example, in seeking to prove that because it would be foolish to produce wine in Scotland by artificial methods, therefore it would be foolish to establish manufactures by artificial methods . . . He reduces the process of the formation of capital in the nation to the operation of a private rentier . . . The augmentation of the national material capital is dependent on the augmentation of the national mental capital and vice-versa.

These arguments of List have been quoted at considerable length for several reasons. First, to convey the flavour and the vehemence of List's onslaught. Second, because List is seldom read in the original in these days. Third, and most important, because in these passages are contained the seeds of most of the policies later adopted in Germany (and in other countries trying to overtake established technology and trade leaders). If we are really to understand international competitivity, then it is of no use to go back to Adam Smith and still less to Ricardo and the 'school' of neo-classical comparative advantage theory, and Michalet (1981) has rightly warned against this. We must go to the original source of the national competitivity school. No doubt, if Adam Smith had been writing two hundred years later, he would have been able to find many much better examples of the folly of 'artificial' investment in non-competitive industries than the hypothetical and improbable one of vine-growing in Scotland. No doubt either, as many have observed, that List exaggerated somewhat the extent to which Adam Smith might be criticized for the dogmatism of his followers (the 'school'). Nevertheless, the debate still has a contemporary ring and is echoed today around the whole world, and not only in the industrializing countries of the Third World with their infant and teenage industries.

The fundamental points in List's spirited defence of national competitive strategies were the following:

1. The importance of 'mental capital' ('intellectual capital' might be a better rendering today than the English translation of that time. As with Adam Smith, we must allow also for the changes in terminology over the past 150–200 years. When Adam Smith talked about 'natural philosophers'; we would talk today about scientists). But there can be no doubt whatever what List was talking about in this passage:

   > The present state of the nations is the result of the accumulation of all discoveries, inventions, improvements, perfections and exertions of all generations which have lived before us; they form the mental capital of the present human race, and every separate nation is productive only in the proportion in which it has known how to appropriate these attainments of former generations, and to increase them by its own acquirements.

2. The recognition of the importance of the interaction between 'mental capital' and 'material capital' (or as we might put it today 'tangible' and 'intangible' investment).

List clearly recognized both the importance of new investment embodying the latest technology and the importance of learning by doing from the experience of production with this equipment.

3. The importance of importing foreign (especially English) technology and of attracting foreign investment and the migration of skilled people as a means of acquiring the most recent technology.
4. The importance of skills in the labour force. One of the most telling criticisms of Adam Smith is for his failure to develop this aspect of his theory. He quotes Smith's famous passage—'Labour forms the fund from which every nation derives its wealth, and the increase of wealth depends first on the productive power of labour, namely on the degree of Skill, dexterity and judgment with which the labour of the nation is generally applied'—but argues that Smith did not follow up this clear insight into the importance of 'productive powers', skill, knowledge and education, but concentrated only on the division of labour aspect of the problem. He ridicules the 'school' for regarding teachers and doctors as 'non-productive': 'We now see to what extraordinary mistakes and contradictions the popular school has fallen in making material wealth or value of exchange the sole object of its investigations, and by regarding merely bodily labour as the sole productive power . . . A Newton, a Watt, or a Kepler is not so productive as a donkey, a horse or a draught-ox (a class of labourers who have been recently introduced by McCulloch into the series of the productive members of human society).'
5. The importance of the manufacturing sector for economic progress and the

necessity for investment in manufacturing as a means of stimulating the development of the entire economy and especially agriculture.

6. The importance of taking a very long-term historical view in developing and applying economic policies. He clearly regarded the development of the appropriate institutions and 'mental capital' to enable manufacturing to flourish as a matter of many decades. He ridiculed J. B. Say for his acceptance of the infant industry argument exception to free trade only in those cases where a branch of industry would become remunerative after a few years.
7. The importance of manufacturing industry for national defence and the importance of national defence for national morale, political power and indirectly for economic progress. The nationalistic, not to say chauvinistic, tone of many passages in List's 'National System' and his frank advocacy of colonialism are the least palatable aspects of his entire theory. But it is important to remember again the historical context in which he wrote. Nor should our distaste for his nationalism blind us to the real importance of the issues, which he raised. The military sector is really important in the national economy and especially in the twentieth century its relationship to the accumulation of 'mental capital' is a crucial (although complex) issue. Moreover, it is essential to recognize that the exemption of this sector from the otherwise inexorable rules of laissez-faire provided an escape clause of enormous proportions. In this respect its importance was analogous to the relaxation of the Mediaeval strictures on the rate of interest and usury more generally through the Protestant Reformation.

After Calvin's revision of the traditional doctrine and the general acceptance of the loophole which this provided, God-fearing Christians could sleep peacefully at night whilst allowing the market rather than the scriptures to determine the rate of interest. Similarly, ardent believers in the theory (and the virtues) of free market forces and the undesirability (and the evils) of government intervention did not suffer the pangs of conscience or the agonies of doubt in authorizing or endorsing massive government expenditure on defence R&D or other forms of government intervention which would have horrified them in any other context. It is difficult, however, not to agree with List in his critique of Adam Smith about the significance of this particular one of the three 'special cases' which Smith accepted as providing some justification for protection:

> By the second exception, Adam Smith really justifies not merely the necessity of protecting such manufactures as supply the immediate requirements of war, such as, for instance, manufactories of arms and powder, but the whole system of protection as we understand it; for by the establishment in the nation of a manufacturing power of its own, protection to native industry tends to the augmentation of the nation's population, of its material wealth, of its machine power, of its independence, and of all mental powers, and therefore of its means of national

> defence, in an infinitely higher degree than it could do by merely manufacturing arms and powder.

As we shall see, this argument about the interdependence of the arms industry and the rest of the national economy is a two-edged one, but it is difficult to deny List's basic contention that the productive power of the economy as a whole is highly relevant to long-term defence capability.

8. Finally, List stressed very strongly the importance of an active interventionist economic policy in order to promote long-term development, and as we have seen, rejected the philosophy of the 'night-watchman state' decisively.

6. The case of Germany

We have quoted rather extensively from the original text of Friedrich List not only for the reasons which have already been advanced, but also because of the importance of Keynes's (1936) dictum:

> The ideas of economists and political philosophers, both when they are right and when they are wrong, are more powerful than is commonly supposed. Indeed, the world is ruled by little else. Practical men, who believe themselves to be quite exempt from any intellectual influences, are usually the slaves of some defunct economist. Madmen in authority, who hear voices in the air, are distilling their frenzy from some academic scribbler of a few years back.

It was because he believed that the entrenched authority of a 'school' was such a powerful influence on national economic policies that Keynes in his day launched an attack on the classical school no less vigorous (and some might say no less exaggerated) than that of List. And, at least for a generation, if not longer, both were successful in establishing a new orthodoxy. The 'defunct economists' who influenced most of those rising to authority in Germany in the latter half of the nineteenth century were not the classical school, as in Britain, but the school of Friedrich List. This was of decisive importance for the evolution of German politics, first of all in the various states grouped in the Zollverein (itself a triumph of List's vision) and later in Imperial Germany.

The importance of protecting manufacturing industry by 'regulating commerce' was fully accepted, but it would be a great mistake to see German policy purely in the light of this traditional 'free trade versus protection' argument. One of the legacies of British dominance in academic economics over two centuries has been the very narrow context in which many of these issues were perceived and debated. It is the central argument of this paper that the other aspects of List's heritage were actually more important than his protectionist doctrines in shaping the climate of opinion and the policies that were adopted in Germany and less directly in other nations, particularly Japan, as they strove to overtake the technological leaders.

As we have seen, the central feature of List's doctrine was his belief that economic progress depended on building up the 'mental capital' and productive powers of the nation. This depended in turn on the capacity to assimilate and use all the discoveries, inventions and improvements which had been made in any part of the world and to improve upon them. In practice, this meant that English technology was acquired through three main channels: first, the movement of British inventors, entrepreneurs and mechanics to the rest of Europe—this was particularly important in the early period of the Industrial Revolution; second, through German inventors, and entrepreneurs working in England—this was important for both the metal and the chemical industries in the mid-nineteenth century (Freeman, 1974; Freeman *et al.*, 1982); third, through the development of an education and training system capable of putting the whole process of acquiring and disseminating world technology on a regular and systematic basis.

The last channel was ultimately the most important and its benefits became increasingly apparent to contemporary observers and to historians as the century wore on, and indeed up to the present time (Albu, 1980; Prais, 1981). However, the importance of the other two channels in the early period should not be underrated. Most studies on the transfer of technology are in agreement that the movement of ideas 'on the hoof' is one of the most efficient channels. In the case of the United States, it was of quite exceptional importance for craftsmen and technicians of all kinds, and in the twentieth century especially for scientists and technologists. So much was this so that it may have led the US to neglect the systematic development of industrial technical training and even of science education in schools despite the general expansion of the education system on a scale far surpassing that of any European country.

The advantages which German industry and the German economy acquired through the development of what is by general consent a first-rate system of educating and training craftsmen, technicians and technologists would be difficult to overestimate. This was recognized clearly by the Japanese, who, when they systematically investigated the various national systems of education, chose the German system as the one most worth emulating. It was also recognized, though very belatedly, by the British as they began to realize that the ever increasing effectiveness of German trade competition in the period leading up to the first world war was related to superior technology and quality of products, based on the achievements of the Technische Hochschulen and the other institutions involved in the advance of knowledge and its dissemination.

This belated British recognition, although it was important in various attempts at educational reform in the nineteenth and twentieth centuries (such as the establishment of Imperial College), was never sufficiently widespread as to overturn the dominant influence of the classical school on industrial and economic policy. So much was this so that the majority of British engineers down to the middle of the twentieth century had no professional academic qualifications, but only a part-time qualification based on evening class study. British industry paid the penalty for national complacency related to the early predominance of Britain in the first two Kondratiev waves. In that period, the method of training engineers 'on the job' on a part-time amateur basis was probably rather effective, but it was not capable of coping with the increasingly sophisticated technologies of the third and fourth Kondratiev cycles. The German system, on the other hand, based on the thorough and deliberate professional development of new technology and its application proved far more effective. It was also of the greatest importance for the general 'management culture' in German industry. Since there were rather few professional academically trained engineers in British industry (and for other socio-cultural reasons), the dominant management tradition was amateurish and inclined to give weight to accountancy considerations on a short-term basis. The German management tradition was much more heavily influenced by professional engineers, who had both high status and high rewards. The type of long-term strategic thinking necessary for long-term success with new technologies was therefore far more characteristic of German than of British industry, as well as an insistence on high quality on the technical side.

The importance of this long-term way of thinking was by no means confined to industry. It was also extremely important in government (for example in the finance of research and education, as well as in measures to promote strategic industries and in financial institutions). In commenting on the development of the German banking system and its approach to the provision of industrial capital, the historian David Landes (1970) comments:

> Britain's relative lack of skills and knowledge (who could have imagined this eventuality in the first half of the nineteenth century?) was accompanied by, and contributed to, an equally astonishing inadequacy of venture capital. This statement may well strike the reader as inconsistent with our earlier discussion of Britain's plethora of wealth. But savings are not necessarily investment, and there are all kinds of investment—foreign and domestic, speculative and safe, rational and irrational. The British had the capital. But those who channelled and dispensed it were not alert to the opportunities offered by modern technology; and those who used it did not want or know enough to seek it out.

An essential element in List's approach to economic growth was his insistence on the importance of a capacity to improve technology. In the early part of the nineteenth century this was closely related to direct experience of production and this remains an extremely important source of technical change. However, with the newest technologies, the institutionalization of professional research and development became of steadily increasing importance. As Whitehead pointed out, perhaps the most important invention of the nineteenth century was the discovery of the method of invention itself—the professional research laboratory. It was an invention that was made in Germany. The German universities were the first to institutionalize a system of science laboratories and postgraduate training through laboratory research, which later became characteristic of science education generally.

This was especially important for the nascent German chemical industry and it was this industry, which was also the home of a major social innovation—the 'captive' in-house industrial R&D laboratory in the 1870s. The link between these R&D laboratories, especially in Bayer, Hoechst and BASF, and the subsequent astonishing success of the German dye-stuffs industry (and later other branches of chemical production and exports) is a story which has often been told (Freeman, 1974; Freeman *et al.*, 1982) and which will not be repeated here. Suffice it to say that the newer chemical technologies of the third and fourth Kondratiev long waves were based on cumulative scientific advances in the understanding of molecular structure, and the ability 'artificially' to synthesize and manipulate new materials. Such an understanding could not grow from the simple observation and experience of established production processes, as with some mechanical technologies. It required some basic scientific research. The same was true for electrical engineering.

The social invention of the industrial R&D laboratory was thus of central importance for the new technologies emerging in the late nineteenth centuries. It was their leadership in these newer technologies and their innumerable applications throughout the economic system that gave German and United States industry the edge in the long process of catching up with and overtaking Britain. The new technological paradigms and trajectories also gave some advantages to those enterprises which could organize their R&D on a sufficiently large scale to exploit 'clusters' of innovations—as for example in synthetic dye-stuffs drawing on accumulated knowledge and experience to introduce a whole range of products and—in the case of the electrical industry—systems innovations. This applied also to major process innovations, such as the Haber–Bosch process, which combined two or more technologies. The development of professional R&D was thus closely related to the process of industrial concentration, and the scale economies in many types of innovation, which so impressed Schumpeter. Many, but not all; the relationship between technical innovation and size of firm is a complex one. Especially in the early days of a new technology, flexibility, speed of decision-making and imaginative flair in entrepreneurship favour the small innovative enterprise.

As a technology matures, comparative advantages in production and marketing (especially export marketing) and in large-scale process innovation and applications research shifts overwhelmingly to the larger enterprises. It was characteristic of the two new leaders in world technology, that they combined the advantages of large- and small-scale industrial organization in various sectors of their industrial system. British industry lagged well behind in the development and application of the newer technologies and in the growth of industrial R&D. This lag was reflected in the growth of American and German investment in Britain in the newer industries, especially electrical, as well as in Britain's steadily declining share of exports and her chronic imbalance of visible trade.

It has only been possible to sketch, in the briefest and crudest outline, some aspects of the displacement of Britain as the world technology and trade leader. But from what has been said, it is clear that in their international competitive struggle, Germany and the United States relied not simply on tariffs, important though these were, but on technology, and that in gaining that technological lead, the development of the education system was of central importance for almost all industries, whilst the role of professional R&D became of growing importance for many. In sum, the German economy proved capable of assimilating (comprehending) the best available technology of the day, of improving upon it (creating), of organizing the linkages between science, technology and markets (coupling) necessary for the efficient exploitation of new technological trajectories (clustering), and of coping with the long-term strategies of tangible and intangible investment which all of this implied. As we shall now see, Japan in the twentieth century carried all these strategies to the *n*th degree in pursuing her own competitive advantage.

7. The case of Japan

When historians describe the intense Japanese efforts to overtake Western Europe and the United States, they usually start with the Meiji Restoration of 1868, which marked the commencement of a sustained and determined modernization policy. Here it is possible only to summarize very briefly some features of Japanese policy since the end of the Second World War, but it is freely acknowledged that the historical roots of the extraordinary Japanese success go much deeper. Indeed, it is a central part of the entire thesis that policies lasting half a century or more underlie the major shifts in competitiveness. The long-term nature of Japanese education policy has already been mentioned and already in the nineteenth century many policies had been adopted to stimulate the growth of manufacturing industry and to import the best available technologies from wherever in the world they might be available.

The central point of interest from the standpoint of this analysis is that in the immediate post-war period, after an intense debate, Japan specifically rejected a long-term development strategy based on traditional theory of comparative advantage, which was apparently at that time being advocated by economists in the Bank of Japan and elsewhere who subscribed to the free trade doctrines of the classical school. They had advocated a ‘natural’ path of industrial development, based on Japan’s relatively low labour costs and comparative advantage in labour intensive industries such as textiles. One of the central points at issue was whether Japan could hope to compete in the automobile industry and whether special steps should be taken to encourage its growth, but the debate affected industrial and trade policy in its entirety. In the early days, according to G. C. Allen (1981) (one of the few European economists who has consistently attempted to study and learn from Japanese experience), the views of the Bank of Japan had some influence. They blocked loans in 1951 for a large new up-to-date steel works and:

> Sony was obliged to postpone its imports of transistor technology because the officials in charge of foreign exchange licensing were doubtful both about the technology and about Sony's ability to make use of it. But on the whole the bureaucrats and their advisors at the Ministry of International Trade and Industry (MITI) prevailed. They repudiated the view that Japan should be content with a future as an underdeveloped country with low productivity and income per head.

Again, according to Allen (and many other observers):

> Some of these advisers were engineers who had been drawn by the war into the management of public affairs. They were the last people to allow themselves to be guided by the half-light of economic theory. Their instinct was to find a solution for Japan's post-war difficulties on the supply side, in enhanced technical efficiency and innovations in production. They thought in dynamic terms. Their policies were designed to furnish the drive and to raise the finance for an economy that might be created rather than simply to make the best use of the resources it then possessed.

Whether or not they had ever heard of List, and whether or not they were economists or engineers, those who were responsible in government or in industry (and again all observers agree that industry and government worked very closely together) had clearly accepted the central tenets of List's doctrine.[4] Like their German predecessors, they went far beyond tariff protection to a much wider range of infrastructural and interventionist policies.

In the early days of Japanese industrialization it was quite common for foreigners to treat her successes simply as 'imitation' and her very heavy imports of technology and huge deficit in the so-called 'technological balance of payments' were frequently cited as evidence for this proposition. But as time went by it became increasingly evident that Japanese assimilation of foreign technology went far beyond carbon-copy replication and was based on the creative systematic improvement of these technologies, and increasingly on original innovation. One clear piece of evidence for this is that for the technology agreements signed in recent years, Japan has a clear positive technological balance of payments. But even more decisive is the evidence of Japanese technological leadership in industry after industry and the opening up of a 'technology gap' between Japan and her competitors in productivity and in export performance in these industries.

A good example is that of the colour television industry, which has been studied by Sciberras (1981) and by Peck and Wilson (1982). They have shown that the extraordinary Japanese success in dominating world export markets (and world-wide

[4]In the financial system, too, whatever the views of the Government or the Bank of Japan may have been in the late 1940s, over the next 30 years a very different philosophy clearly prevailed.

overseas investment as trade barriers were thrown up) was due primarily to innovative leadership in design and in process technology in the 1970s. Sciberras concluded that:

> Japanese firms have been the most successful innovators. By applying advanced automation in assembly, testing and handling to large production volumes, the Japanese have achieved drastically superior performance in terms both of productivity and of quality.

He estimated that Japanese labour productivity was two or three times as high as European or American levels, and attributed this gap mainly to the integrated approach to automation technology and to the associated intensive industrial training and education programmes at all levels which enabled the Japanese labour force to handle and resolve problems of operating advanced technology, but which caused much greater difficulties elsewhere because of lower levels of responsibility, skill and initiative. Peck and Wilson pointed out that the Japanese manufacturers were actually the first to introduce integrated circuit technology into the colour television industry, with all the associated economies in assembly labour. Their success in this was apparently due to a joint research effort sponsored by MITI and involving five television manufacturers, seven semi-conductor manufacturers, four universities and two research institutes. This is an interesting illustration of the extraordinary capacity of the Japanese social system to bring about very close coupling of diverse partners to achieve a specific technological objective, even when their competitive interests might appear superficially to diverge.

Drawing upon these and many other examples, we might attempt to synthesize and summarize some of the ways in which Japan succeeded in pushing still further the competitive policies which had already proved so successful for Germany, the United States and several smaller European countries, such as Sweden.

First of all, we should note that, like the United States, Japan admits to secondary and higher education a higher proportion of young people than any European country (with the possible exception of the USSR). The system is more strongly oriented towards science and technology than most others, and is complemented by an extremely well developed industrial training and education system, which according to many accounts involves almost the whole of the workforce in the larger firms. It seems that this company-level education and training system makes a very big contribution to the remarkable ability of Japanese industry to assimilate new technologies rapidly and efficiently and, more importantly, to improve upon them. Both Germany and the United States showed a capacity to introduce production system innovations (the assembly line, interchangeable standardized parts, flow processes, etc.). But Japan has shown an even more remarkable ability to re-think and redesign production technologies in old as well as new industries.

The examples of ship-building and steel are often cited in this connection and that of colour television has already been mentioned, but the contemporary use of robotics, which is more advanced in Japan than anywhere else, suggests that even more dramatic changes may be ahead. The Japanese system sets great store on the involvement of employees in such system changes, affecting as they do the entire workforce. The 'quality circles' are a social innovation designed to maximize the specific contribution from the lower levels of the workforce and to assign to the lower management levels a responsibility for technical change. We should also note that the Japanese policy of mainly rejecting foreign direct investment as a means of technology transfer automatically places on the enterprise the full responsibility for assimilating imported technology, and is far more likely to lead to total system improvements than the 'turn-key plant' mode of import or the foreign subsidiary mode.

As in Germany and the United States, the greater part of R&D is carried out at the level of the industrial enterprise in Japan, but Japanese management appears to have taken this coupling mechanism a stage further by relating decisions on strategic priorities for R&D both in government and in industry on the one hand to a careful identification of the major growth areas in world markets, and on the other hand to a concerted effort to introduce the most up-to-date process technology and quality improvements. The long-term strategic approach to investment in physical plant is no less characteristic, and Allen particularly emphasizes that government policies and incentives were deliberately designed to encourage this long-term approach to investment.

Finally, as Allen (1981) points out:

> In the United States and Britain defence has absorbed not only a large proportion of total expenditure on R&D, but also the skill and energy of many brilliant scientists and technologists. Japan on the other hand, has been able to direct nearly all her resources, human as well as financial, to civil industry and foreign trade.

This point brings out the complexity of the defence technology relationship, which List discussed. In social systems with a heavy ideological bias against government involvement it permitted a means of promoting some of the most advanced technologies, which otherwise might not have been available. The scale of such involvement since the Second World War has however been so great in some countries that the opportunity costs identified by Allen have been extremely high. He mentions specifically the United States and UK, but probably the highest price for this diversion of scarce resources has been paid in the Soviet Union. The comparison here is particularly instructive because like Japan, the USSR was a large country, which industrialized successfully in the twentieth century but, unlike Japan, failed to close the 'technology gap' with the leaders, except in the military area (Amann and Cooper, 1982). Perhaps in retrospect, List was right here too and that the overall long-term consequences of industrial growth and technical change are the most important source of long-term defence capability. In any case most analysts, including much Soviet comment, are agreed that quite apart from the issue of the scale of the military sector, there are other long-term structural defects in the Soviet science-technology system, which have prevented effective 'coupling' with productive enterprises.

We may conclude this all-too-brief summary therefore by reiterating the conclusion that the success (or otherwise) of the leading countries in international technology and trade competition is heavily related to the long-term policies which they have pursued over many decades, rather than to any short-term manipulation of currency exchange rates, or exploitation of relative factor-cost advantages.

8. Conclusions

The implications which flow from this conclusion are many and varied, and it would be quite impossible in a short paper to do more than point to a few of the most important (i) at the international level and (ii) at the national level.

At the international level the analysis points to the conclusion that future reforms in the international trading and financial arrangements must start from the expectation that persistent disequilibria in international trade are likely to be the norm rather than the exception. The tendency for the strong (technical leader) countries to run a surplus is likely to persist over long periods and to re-assert itself repeatedly despite currency adjustments and other measures designed to restore equilibrium. Likewise, the tendency for the weak countries to run into vicious spiral problems is likely to be persistent. This means that there are serious dangers of deflationary pressures in the system arising from competitive national attempts to restore short-term equilibrium, unless (i) international financial arrangements and credit arrangements clearly recognize the very long-term structural (and developmental) nature of the underlying tendencies. The proposals which Keynes originally advanced at Bretton Woods are still relevant in this connection; (ii) surplus countries with the help of the international community, should have the imagination (and sense of history) to recognize that their own long-term interests depend not only on seeking exclusive national competitive advantages, but on the international transfer of technology as well as capital. List has been proved right in his belief that free trade could be an acceptable and desirable framework for countries once they had 'caught up', but unduly restrictive in his view for those who are still in the midst of catching up.

At the national level, the analysis points to the conclusion that long-term infrastructural investment in 'mental capital' and its improvement is crucial for successful economic development, and for competitive trade performance. Whilst this necessity may be mitigated to some extent by fortunate natural resource endowment (OPEC and up to a point such countries as Australia, Canada and even USA), it is an important issue for all. This has been a commonplace of development economics for a long time and it has also been a basic element in the work of the OECD since the 1950s. The DSTI in particular always gave prominence to work on education, training, research, development and technical innovation. But although this conclusion is itself far from novel, what has perhaps not been sufficiently recognized is the extent to which policies for science and technology are intertwined with policies for trade and industry. The 'coupling mechanisms' between the education system, scientific institutions, R&D

facilities, production and markets have been an important aspect of the institutional changes introduced in the successful 'overtaking' countries. These qualitative and institutional aspects of the problem have perhaps been underrated by comparison with the quantitative issues of scale of investment, annual expenditures, etc. Such quantitative analysis is essential and comparative studies of this type can certainly be instructive. But as at the enterprise level, the study of effective national competitive strategies must fully take into account those organizational and social factors, which make the difference between success and failure.

The recognition of the importance of this point does not emerge only from the success story of countries such as Japan. It emerges also from studies in smaller countries, such as The Netherlands. One of the most successful sectors of the Dutch economy has been agriculture, in terms of both productivity and trade performance. A recent study by a group of researchers at the TNO (Bilderbeek *et al.*, 1982) has concluded that its performance has been strongly affected by the close coupling mechanisms set up and systematically promoted between the research system, the specialized education system, the information dissemination system, the producers and the market. Taking such social-organizational factors as those identified by the Michigan group of Havelock (1973) and his co-workers on innovation, the TNO study found them all to be highly relevant to the experience of the Dutch agricultural system—openness, proximity (social and geographical), synergy, capacity to absorb external information and so on. The research at Aalborg on the inter-dependencies between various groups of firms in promoting technical progress in key sectors of the Danish economy is also highly relevant here (Andersen *et al.*, 1981). The work of Williamson (1975) and Phillips (1980) also suggests the limitations of formal competition theory in understanding the interactions of the science–technology system with production. They identify those characteristics of research and development activities which mean that specialist firms simply attempting to develop and sell information on a commercial market basis are not usually effective for successful innovation and only in-house R&D and other types of 'vertical integration' are typical. The innovation process is one which requires often rather extensive networks of information flows and rather free informal contacts over a fairly long period and often of a rather unpredictable kind. National competitive strategies, if they are to be relevant to the real problems, must take into account these types of empirical results, rather than rest on the laurels of the 'school' in economics.

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