TECHNOLOGICAL LEADERSHIP AND PRODUCTIVITY LEADERSHIP IN MANUFACTURING SINCE THE INDUSTRIAL REVOLUTION: IMPLICATIONS FOR THE CONVERGENCE DEBATE

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Abstract

The US has been the labour productivity leader in manufacturing since the early nineteenth century when Britain was the technological leader, and remains the productivity leader today when technological leadership has passed to Germany and Japan. US productivity leadership is based on the more widespread use of mass production methods, determined by resource and factor endowments and demand patterns. Countries with different conditions use craft production methods more extensively and have lower labour productivity. The two systems can coexist so long as the technologically lagging system imitates and adapts. Changes in the relative dynamism of the two systems explain changes in technological leadership, but without necessarily leading to changes in productivity leadership.

I. INTRODUCTION

Few would dissent from the view that in terms of technology, Britain was the leading manufacturing nation during the first half of the nineteenth century, that leadership had passed to the United States by the beginning of the twentieth century, and that since the 1970s US leadership has been challenged by Germany and Japan (Landes, 1969; Lazonick, 1990; Nelson and Wright, 1992). The data on comparative levels of labour productivity in manufacturing over the long run, however, do not at first sight accord well with these widely shared perceptions of technological leadership. The US had higher labour productivity even in the early nineteenth century when Britain was the technological leader, and continues to enjoy a substantial labour productivity lead over Germany and Japan to this day (Broadberry, 1992, 1993; Pilat and van Ark, 1992). The purpose of this paper is to reconcile these apparently conflicting pictures of technological and productivity leadership and to draw out the implications for the convergence debate.

The key distinction is between technological systems geared to mass production and craft production. In mass production, special purpose machinery and resources are substituted for skilled labour to produce identical products, while craft production methods make extensive use of skilled labour to produce customised output (Piore and Sabel, 1984; Tolliday and Zeitlin, 1991). The extent to which mass production methods are adopted in a country will depend on factor and resource endowments and demand patterns. In nineteenth century America, for example, cheap resources, scarce skilled labour and homogeneous demand patterns dictated a wider adoption of mass production methods than in Europe or Japan (Ames and Rosenberg, 1968). The greater labour intensity of craft production methods results in lower output per worker.

It is possible for both mass production and craft production methods to coexist in the face of different endowments and demand patterns. Rapid technological progress in one system need not lead to the demise of the other so long as there is an adequate response, imitating, or adapting the innovations to local circumstances (David, 1975). It is possible for the craft production system or the mass production system to be technologically more progressive. If the craft system is technologically more dynamic, as in the early nineteenth century, then it is possible to have technological leadership by a country such as Britain with lower labour productivity than America (Habakkuk, 1962). In the second half of the nineteenth century and the first half of the twentieth century, the American system became more progressive and American labour productivity leadership was matched by technological leadership (Hounshell, 1984; Strassman, 1959; Chandler, 1990). In the period since the 1970s, with the massive reduction in the cost of computation, craft production has again become technologically more progressive, and again we see technological leadership shift to countries with lower labour productivity than the US (Piore and Sabel, 1984; Lazonick, 1990).

We thus reject the notion of global convergence within manufacturing in favour of a process of local convergence (Durlauf and Johnson, 1992). For global convergence we require all economies to converge to a single productivity path, i.e. in the limit productivity levels are equalised between all countries. For local convergence, however, we can have a group of economies converging on a productivity path which remains below the path of another group. Thus, for example, we find local convergence within European manufacturing, but a persistent substantial productivity gap between Europe and North America. Although Baumol (1986) acknowledges the failure of third world countries to catch up with the OECD countries at the whole economy level, within the OECD group he finds a single 'convergence club', using data on GDP per hour worked. Our findings for manufacturing suggest that this global convergence amongst the OECD economies at the whole economy level cannot be due to the transfer of technology in manufacturing, as is often claimed (Gomulka, 1971; Cornwall, 1977; Nelson and Wright, 1992). Rather it must be the result of trends in non-manufacturing and structural change between major sectors (Broadberry, 1992b).

II. COMPARATIVE PERFORMANCE IN MANUFACTURING SINCE 1820

Table 1 presents estimates of comparative output per worker in manufacturing in four countries, accounting for between half and two-thirds of world trade in manufactures (see Table 3). The series are reported taking the UK as 100 in all years. The results are obtained by extrapolating with time series on output and employment from benchmark estimates of comparative productivity levels, indicated by an asterisk. Other benchmark estimates are reported in parentheses, to provide a check on the time series extrapolations. All benchmark estimates are made on a bilateral basis with the UK. Pre-1939 benchmark estimates are based on direct comparison of physical output per worker, following the methodology of Rostas (1948). Post-1939 benchmark estimates are based on comparisons of prices for individual products, following the methodology of Paige and Bombach (1959). The use of physical quantities or price ratios obtained from production censuses means that we avoid the bias of using the exchange rate to convert values in different currencies (Gilbert and Kravis, 1954).

Part (a) of Table 1 presents figures for the four countries over the period 1869-1989. In addition, part (b) presents estimates for the US/UK comparison covering the nineteenth century, based on an extrapolation of time series from the 1907 benchmark. The evidence from Table 1 suggests that US labour productivity has remained about twice the British level since the middle of the nineteenth century, although there have been substantial swings in comparative productivity for sustained periods, particularly covering major wars. Furthermore, British and German levels of labour productivity in manufacturing have been similar since the late nineteenth century, although Germany built up a substantial lead during the 1970s, only to be eroded by rapid labour productivity growth in British manufacturing during the 1980s. Japan has caught up with and overtaken Britain and Japan is now substantially ahead of Britain in terms of output per worker, although it should be noted that Japanese productivity levels are rather lower if an adjustment is made for hours worked. Any adjustment for hours has only a small effect on the results for the other countries, however. Since data on hours before 1945 are not very reliable, we have chosen to stick to productivity on a per worker basis to provide a consistent long run picture (Broadberry, 1992b,6-7).

Although our figures are consistent with a form of catching up (Abramovitz, 1986), since a period when one country widens its labour productivity lead is followed by a period when the gap narrows, they also suggest over the long run a persistent substantial labour productivity gap between the United States and the other major industrialised countries. We would see Britain and Germany as converging on the same European productivity path (Broadberry, 1992b). The position in Japan is unclear as Japan continues to catch up on the US. This diversity of experience in manufacturing is in contrast to the position for the whole economy. Using Maddison's (1991) figures for GDP per worker in Table 2, it is possible to see a process of global convergence, at least amongst the OECD economies.

It should be noted that starting the story in 1950, as in much of the convergence literature, is misleading since although there has been a substantial narrowing of the gap between the United States and other countries since the Second World War in manufacturing as well as in the whole economy, this must be seen in the context of the widening of the gap across the war.

To the extent that these figures for manufacturing appear to be consistent with the whole economy evidence (Broadberry, 1992b), this suggests that convergence at the level of GDP per worker is not simply due to technology transfer in manufacturing. Indeed, we shall argue that in manufacturing the labour productivity gap has persisted because of different production methods in different countries with different circumstances.

Before turning to our model of persistent labour productivity differences, we note that a more conventional picture of comparative performance in manufacturing can be obtained from data on shares of world exports of manufactures, in Table 3. In particular, the rise of the US during the late nineteenth century at the expense of the UK, and the rise of Germany and Japan in the post-1945 period at the expense of the US and the UK can be seen. This suggests that labour productivity on its own is not a good indicator of competitive advantage. Indeed, the US/UK comparison for the late nineteenth century suggests that a country with substantially lower labour productivity can still dominate world trade if wages or other costs are sufficiently low.

III. CHOICE OF TECHNOLOGY AND TECHNICAL PROGRESS

The central problem suggested by the empirical findings reported in Section II is to explain the persistence of a large labour productivity lead in the United States, despite changes in technological leadership. Here we draw on the literature concerned with Anglo-American productivity differences in the nineteenth century.

Habakkuk(1962) suggested that higher labour productivity in the US could be explained by labour scarcity, which forced firms to use more capital. However, as Temin (1966; 1971) points out, in a standard two good, three factor neoclassical model it is not obvious that labour scarcity leads to greater capital intensity in manufacturing. Furthermore, as Field (1985) notes more recently, the evidence from historical data on the capital stock does not support the notion of greater capital intensity in the US during the nineteenth century.

The first issue of the link between factor endowments and capital intensity is resolved by complementarity between capital and material inputs in manufacturing, as suggested by a number of authors (Ames and Rosenberg, 1968; Rosenberg, 1976; David, 1975). The second issue of relative capital intensity between the US and UK is still subject to considerable empirical uncertainty. James and Skinner (1985) suggest that a distinction should be made between the skilled and unskilled manufacturing sectors, with greater US capital intensity only in the former. The distinction is based on the skill of the workers; only in the skilled manufacturing sector were there sufficient incentives for US firms to substitute capital and cheap natural resources for skilled labour. Furthermore, as Field (1985) is at pains to point out, it is important to distinguish between machinery and capital. Even if fixed capital per worker was greater in nineteenth century Britain, it is still possible that machinery per worker in manufacturing was greater in the US, due to the importance of structures (55-60% of the US capital stock), inventories (10-20%) and consumer durables (7-15%), (although Field himself believes that machine intensity was greater in British manufacturing on the basis of a number of crude assumptions used to break down the total capital stock figures into asset types by sector).

Thus it is helpful to see the choice of technology as one of substitution between fixed capital in the form of machinery and human capital in the form of skilled labour, as in Figure 1, which is adapted from David (1975). In Figure 1(a) there are two available technologies which differ in the proportions of machine capital (K_M) and human capital (K_H). Once the technique has been chosen, substitution possibilities are very limited, so that to all intents and purposes fixed coefficient technology can be assumed. The convex combination of these alternative techniques determines the available process frontier (APF), since firms could in principle use a combination of both processes. If we assume a further set of latent techniques, spanning the range of factor proportions, then joining up the points of minimum input combinations we obtain a continuous, differentiable isoquant of the fundamental production function (FPF).

In Figure 1(b) we add in relative factor prices. If, as in Britain, skilled labour is relatively cheap, the relevant factor price line is P_0 and firms produce at B. On the other hand, if skilled labour is relatively expensive as in America, the factor price line is P_1 and firms produce at A. Although British and American firms produce with different techniques, they have access to a common technology in the form of the fundamental production function.

David (1975) goes on to explain how the initial choice of technique led to differential rates of technical progress in Britain and America, although the possibility of imitation allows for catch-up growth. David's model of endogenous localised technical change, drawing on the work of Atkinson and Stiglitz (1969), is represented in Figure 2(a). American firms, having settled at point A, attempt to reduce inputs and thus move towards the origin around the process ray α. The 'elastic barriers' surrounding the process ray can be seen as representing non-convexities in micro- engineering designs. David (1975, 81) gives an example of a batch brewing process. If you try to reduce capital costs by drastically increasing the size of the vessel (costs rise in proportion to surface area and hence the square of the radius, while volume rises in proportion to the cube of the radius) this is likely to cause problems for the cooling system and raise unit cooling costs. Hence it is likely that small local changes will be introduced which do not drastically alter factor proportions, i.e. technical progress is locally neutral. Technical progress is path dependent and where you end up depends on where you start from. In figure 2(a), technical progress shifts the available process frontier from APF to APF' as technical progress occurs as a stochastic process between the elastic barriers around the α-ray.

Figure 2(b) illustrates competition between the two technologies. As technical progress occurs in America along the α-ray, the changes can be adapted to British conditions and imitation occurs along the β-ray. British firms, faced with relatively cheap skilled labour will continue to produce using the (evolving) British technology, while American firms, faced with relatively expensive skilled labour, will continue to produce using the (evolving) American technology.

Consider the situation in Figure 3, however. Technical progress in America has been so rapid from A to A' along the α-ray that the new available process frontier makes the American technology superior at all relative factor prices. At this point, competition should force the British firms to abandon the British technology. Note, however, that this will not simply lead to the British firms adopting the American technology. Rather, they will be forced to search for a new technique on a different part of the fundamental production function. If the search is successful, British firms will end up using a technique which is still more skilled labour intensive and less machine intensive than the American technique.

This characterisation of endogenous technical progress as localised learning along different paths dictated by the initial choice of technology is implicit in much of the historical literature on growth, with a contrast between the 'American system' of large scale, high throughput, machine intensive mass production of standardised products with strong managerial control and the 'British system' of low throughput, skilled labour intensive production of customised products with strong craft control (Elbaum and Lazonick, 1986; Lazonick, 1990; Chandler, 1990; Tolliday and Zeitlin, 1991; Piore and Sabel, 1984).

Within this framework, then, long run productivity ratios are determined by resource and factor endowments and demand conditions. Any divergence from long run ratios should be followed by catch-up as imitation and switching of technologies occurs. However, there is no reason to believe that countries will converge on the same level of labour productivity unless their endowments and demand conditions are similar. Note also that there may be changes of technological leadership without any corresponding change in productivity leadership, in contrast to the model of Brezis et al (1991), which equates technological and productivity leadership.

IV. BRITAIN AND AMERICA IN THE NINETEENTH CENTURY

The example of Britain and America in the nineteenth century illustrates clearly the distinction between technological and productivity leadership. Although the data in Table 1 suggest a substantial US labour productivity lead even in the first half of the nineteenth century, most economic historians see Britain as the technological leader at this time (Landes, 1969; Nelson and Wright, 1992).

Britain's technological lead was most obvious in cotton textiles, where a series of innovations in spinning and weaving between the mid-eighteenth and the mid-nineteenth centuries propelled Britain into dominance of world markets. By the 1820s, the self-acting mule in spinning and the powerloom in weaving were the dominant technologies (Musson, 1978, 80-82). The elimination of the handloom weavers and the dominance of the factory system in the British cotton industry may at first sight suggest an important milestone on the road to mass production, with the substitution of machinery for skilled labour. However, as Lazonick (1979) points out, skilled workers remained important in the British cotton industry. The self-acting mule, which was intended to break the power of the mule spinners in fact further enhanced their position because it was more effective in the hands of skilled workers.

Technology transfer from Britain to the United States during the first half of the nineteenth century confirms

Britain's technological lead in the cotton industry (Jeremy, 1981). However, as Jeremy notes, running speeds were generally faster in the US and technology was modified to American conditions of skilled labour shortage. Hence, as Broadberry (1992a) shows, the figures of Montgomery (1840) suggest that labour productivity was higher in the US cotton industry than in Britain in the 1830s.

By the late nineteenth century, US cotton firms had developed a new technology based on the ring spindle and the automatic loom. However, as Sandberg (1974) notes, these innovations were less well suited to British conditions and hence were much less widely adopted in Britain, where the savings on skilled labour were much less than in America. However, as Saxonhouse and Wright (1987) note, the American cotton industry never translated its technological lead into a competitive advantage on world markets.

In other industries there is evidence that the British technological lead was already under threat from the US by the middle of the nineteenth century, although Temin (1971) argues that we need to be careful to distinguish between the 'more machinery' and the 'better machinery' versions of the Habakkuk (1962) thesis. The primary evidence for the British loss of technological leadership comes from the accounts of British travellers to the United States in the 1850s. The 1855 Report of the Committee on the Machinery of the United States and the 1853 Special Reports of George Wallis and Joseph Whitworth, Commissioners appointed by the British government to attend the New York Exhibition, reprinted in Rosenberg (1969), point to the development of an 'American system of manufactures'. However, the reports are unclear as to whether this implies that American manufacturers used more capital than their British counterparts in response to different relative factor prices (which implies labour productivity leadership) or better capital (which implies technological leadership).

By the late nineteenth century, however, there was no ambiguity. The US had become the technological as well as the productivity leader. In terms of the model in section III, US technical choice was driven initially to a more machine intensive technique by resource and factor endowments. American firms substituted cheap resources and resource-using machinery for skilled labour (Ames and Rosenberg, 1968). The argument depends on a complementarity between machinery and resources. British firms could not simply adopt the American machinery, which was very wasteful of resources, but had to compete on the basis of skilled labour. The wood lathe is the classic early example of a machine which was very wasteful of resources and could not be adopted in Britain where wood costs were much higher. Subsequently, technical progress was more rapid with the machine intensive technology as American manufacturers developed the ideal of interchangeable mass production (Hounshell, 1984). Demand factors played a role here, as American consumers were more willing than their British counterparts to accept standardised products (Ames and Rosenberg, 1968, 114-115; Frankel, 1957, 75-77).

Again, referring to the model of section III, the response of British firms to the American innovations of the late nineteenth century can be understood. Faced with different factor and resource endowments and different demand conditions, British firms could not simply copy the American methods, but rather , needed to adapt them or imitate in ways suitable to British conditions. Thus in terms of Figure 2(b), imitation in Britain occurred down the β-ray in response to technical progress down the α-ray in America. A number of quantitative studies document the rationality of the British response in cotton textiles (Sandberg, 1974), iron and steel (McCloskey, 1973), machine tools (Floud, 1974) and engineering (Harley, 1974).

Harley's (1974) paper is important in drawing attention to the human capital implications of the alternative strategies of mass production in America and craft production in Britain. Whereas mass production takes skill away from the shop floor by substituting special purpose machines for skilled labour, craft production is intensive in the use of skilled labour. However, this does not give a complete picture of the stocks of human capital in the two countries. As Chandler (1990) argues, the American mass production system required strong managerial control of the production process, requiring in turn a well trained managerial class. By contrast, the British craft production system delegated control over the production process to the shop floor, thus requiring no such managerial elite. The slow development of a professional managerial class in Britain is regarded by

Chandler (1990) as a major failing. In our view, however, it is simply an inevitable consequence of the strategy of craft production pursued rationally by British firms faced with conditions less suited to mass production.

V. THE UNITED STATES AND EUROPE IN THE TWENTIETH CENTURY

According to Hounshell (1984), it is only really by the beginning of the twentieth century that American manufacturers achieved genuinely interchangeable mass production. Chandler (1977; 1990) charts the rise to dominance of American manufacturing on the basis of this technology. For the first half of the twentieth century, Chandler judges European corporations by the extent to which they copied American forms of organisation (Chandler and Daems, 1980; Chandler, 1990). This perspective is carried forward to the end of the 1960s by Channon (1973) and Dyas and Thanheiser (1976). However, whilst it is clear that the success of the American corporate economy demanded a response from European firms, we would argue that this did not mean slavishly copying American methods since economic conditions in Europe were different.

The key differences between Europe and America are in the areas of resource and factor endowments and demand conditions. These differences have been highlighted in a number of quantitative studies of comparative productivity in manufacturing during the twentieth century. Rostas (1948), Melman (1956), Frankel (1957) and Franko (1963) all emphasise the role of resource endowments in determining the amount of machinery used and hence the level of labour productivity. Melman (1956) makes explicit the link between relative prices and factor proportions, calculating the relative cost of an hour of labour and a kilowatt hour of electricity. He finds this ratio to be substantially higher in the US, i.e. labour is much more expensive than electricity in the US, giving an incentive to use more electrically driven machinery. Between 1924 and 1950, the ratio between US and UK relative labour/electricity costs varied between 205.2 and 442.4 (Melman, 1956, 206) i.e. labour was two to four and a half times as expensive in the US. Similar calculations for Germany and France also suggest much more expensive labour in the US during the first half of the twentieth century (1956, 213). Repeating Melman's calculations for the 1980s, we find that electricity remains substantially cheaper in the US than in the UK. For 1988, the ratio between US and UK relative labour/electricity costs is 178.9 (International Energy Agency, 1992). Furthermore, the International Energy Agency data allow us to see that what is true of electricity is also true of other fuels. For 1988 the US/UK relative labour/fuel costs were 180.2 for natural gas, 177.7 for heavy fuel oil, 145.3 for light fuel oil and 261.2 for steam coal.

Frankel (1957) also drew attention to the US advantage in resources besides energy. Franko (1976) and Davidson (1976) provide a generalisation of Melman's energy calculations by assuming perfect world markets in other resources and purchasing power parity at a benchmark point in time (1963), so that relative labour/material costs at that time are given simply by relative labour costs. Indices of labour and material costs are then used to extrapolate to other years. Materials used include oil, coal, lumber, cement, steel, aluminium, glass, rubber and water. The details of the calculation are open to criticism but the central message is clear; even if materials cost the same in all countries, higher wages in the US provide incentives for less labour intensive and more resource intensive production methods. Thus previous accumulation strategies continue to affect the choice of technique into the future through their implications for human capital i.e. the growth process is path dependent (David, 1985; Arthur, 1989).

The evidence presented above suggests that Nelson and Wright's (1992) recent dichotomy between the pre- and post-World War II periods, with resources seen as an important factor in America's productivity lead before the war, but not after, goes too far. In particular, we still find US industry benefiting from relatively cheap energy costs, which favours a more machine intensive technology and higher labour productivity.

Another factor explaining the adoption of machine intensive production methods in the US is the nature of demand. Rostas (1948), Frankel (1957) and more recently Chandler (1990) stress the importance of a large homogeneous American home market in permitting economies of scale through the adoption of mass production methods. It should be noted that this is not simply a matter of the size of the home market. For although population in the US has been substantially greater than in all individual European countries in the twentieth century, this was not the case for much of the nineteenth century (Maddison, 1991, 226-239). Chandler (1990) emphasises the importance of investment in marketing in conjunction with the investments in production and management to attain economies of scale and scope. However, Frankel (1957, 73-80) while acknowledging the benefits of standardised demand, accepts the possibility that greater inequality in the distribution of income and wealth and greater class distinctions in Britain may have made standardisation more difficult to attain. Furthermore, concentration on Empire markets, particularly in the face of rising protection in the US and Continental Europe, reinforced this lack of standardisation.

Our analysis so far suggests that endowments and demand conditions dictate a more machine intensive technology in the US, leading to higher labour productivity than in Europe. It might be expected, then, that an approach relating comparative labour productivity to comparative fixed capital per worker via a conventional production function would be successful in explaining international differences in productivity. However, as can be seen from Tables 4 and 5 for the US/UK and Germany/UK comparisons respectively, gaps in total factor productivity (TFP) are almost as large as in labour productivity.

The conventional 'levels accounting' approach based on the Solow (1957) 'growth accounting' model fails for a number of reasons. The first problem concerns the measurement of the capital stock from data on investment. The perpetual inventory method calculates the capital stock by cumulating investments and allowing for retirements. However, since there are large differences in the asset lives assumed in different countries, with slender evidence to justify them, peculiar results emerge. For example, the UK is shown by the official capital stock estimates to have higher capital per worker than Germany, despite investing less (O'Mahony, 1992b). To counter this, it is possible to provide alternative estimates using standardised asset lives. We present standardised capital stock estimates in Tables 4 and 5 for the post-World War II period. However, for the pre-World War II period, this procedure runs into difficulties because the historical capital stock estimates of Feinstein (1972), Kendrick (1961) and Hoffmann (1965) for the UK, US and Germany respectively are derived at least in part from stock data. Indeed, Giffen's (1889) study based on stock data did suggest that capital per worker was greater in the UK than in the US, as indicated by the official figures for 1869 and 1879 in Table 4. This clearly presents a problem for the conventional levels accounting approach because higher labour productivity in the US cannot be explained by higher capital intensity in the UK.

The second problem, then, concerns the relationship between capital and machinery. For economists invariably mean machinery when they write about capital as a determinant of labour productivity. Yet, as Field (1985) notes, machinery has historically been a relatively small proportion of the capital stock, which has been dominated by structures. As noted in section III, it is possible that during the nineteenth century US manufacturing was more machine intensive despite UK manufacturing being more capital intensive.

For the first half of the twentieth century, indeed, there is evidence of a strong link between machine intensity and labour productivity for manufacturing as a whole. For the pre-World War II period, the evidence from Table 6 suggests that US horsepower per worker was about twice the British level, while in Germany and France, horsepower per worker was of the same order of magnitude as in Britain. These ratios are roughly the same as the labour productivity ratios.

The strong link between machinery and labour productivity suggested by the above data for the pre-World War II period is given further support for the postwar period by De Long and Summers (1991), who note a strong relationship between productivity growth and equipment investment, thus avoiding the calculation of capital stocks with doubtful asset life assumptions. These results are confirmed by De Long (1992) for the period 1870-1980.

The figures in Table 6 suggest the possibility of a unit coefficient on capital, as suggested by Romer (1986) in his early work on endogenous growth. However, the evidence of Rostas (1948) suggests the need for caution here. In the cross sectional sample assembled by Rostas for the US and the UK in the mid-1930s, the relationship is not so simple. Out of a sample of 28 industries, he found only six cases where there was a proportional relationship between comparative horsepower per worker and comparative output per worker. In fourteen industries, the US employed disproportionately more horsepower per worker to achieve a higher output per worker, while in eight industries the US productivity advantage was greater than the horsepower per worker advantage.

Whilst there must inevitably be qualifications about the use of horsepower per worker as a measure of machine intensity, the relationship between horsepower per worker and output per worker identified by writers such as Rostas (1948) and Melman (1956) is suggestive of a higher coefficient on capital than that commonly used in conventional TFP studies. This brings us to the third problem with the levels accounting approach, which assigns too low a coefficient to capital. This means that huge differences in capital per worker are needed to explain even relatively small differences in labour productivity. Using a unit coefficient on comparative capital per worker in Table 4, however, would go a long way towards explaining comparative output per worker, especially using standardised asset life assumptions for the postwar period.

Our interpretation of the competition between mass production methods in the US and craft production methods in Europe has important implications for the role of human capital in explaining labour productivity differences. If attention is confined to human capital embodied in skilled workers, as in the work of the NIESR (1991), then difficulties of interpretation are immediately apparent. There seems little doubt that Britain has historically had a large stock of skilled workers, while the US adopted a strategy of substituting machinery for skilled labour to a much greater extent. Thus for the period 1870-1914, a number of authors point to the success of British firms using skilled labour to compete with American mass production methods (Pollard and Robertson, 1979; Harley, 1974). More (1980, 172) presents some figures on the proportion of skilled workers in the labour force in 1906/07, suggesting a larger proportion in Britain than in the US. This is precisely what we would expect if British and American firms were pursuing rational strategies given their different resource and factor endowments and demand conditions. However, it means that calculations such as those by O'Mahony (1992a), who constructs a measure of the human capital stock in Britain and Germany for the 1980s weighting different skill levels by their relative wage rates, cannot simply be replicated for the US/UK comparison or for long run historical comparisons. For although the comparative stock of skilled workers is relevant to the comparative productivity performance of two countries using the same craft production techniques, it is not relevant when one of the countries is using different mass production techniques that do not require skilled workers to the same extent.

If the quantity of skilled workers in Britain should not be seen as a long standing historical problem, the same cannot be said of the quality, however. Commentators have stressed the shortcomings of the British education and training systems since the late nineteenth century (Wrigley, 1986; Sanderson, 1988). Again, though, it should be noted that the contrast is with Germany rather than the US. Indeed, Lazonick (1990) is just as critical of the American education and training system as of the British.

We have already noted in the previous section the implications of technological dualism for the stock of human capital embodied in management. Chandler (1980; 1990) sees the British economy as failing in the period 1870-1950 primarily because of inadequate investment in management. The persistence of 'personal capitalism' in Britain is contrasted with the successful development of 'competitive managerial capitalism' in the US. Yet to the extent that endowments and demand dictated a strategy of production based on craft control, British firms can hardly be criticised for failing to develop managerial capabilities geared to mass production methods suited to American conditions.

Allied to the rise of managerial capabilities in corporate America is the growth of research and development facilities. Romer's (1990a; 1990b) recent work has stressed the importance of R&D in creating knowledge capital, which can be used in the production process. Here international comparisons do suggest that Britain lagged behind the United States, but not behind continental Europe, in the first half of the twentieth century. Drawing on the figures of Sanderson

(1972) and Freeman (1962), Mowery (1986) suggests that the level of research intensity in Britain was about one third of the US level from the 1930s to the mid-1950s. Drawing on OECD figures from the 1960s to the present, however, Pavitt and Patel (1988) show that the American lead in industrial R&D as a proportion of industrial output has been eliminated. These findings, together with Maddison's (1991) figures on GDP per hour worked, lead Nelson and Wright (1992) to see the postwar period as characterised by global convergence. Yet, as we have seen, so long as endowments and demand conditions differ between Europe and America, we should only expect to see local convergence, with the productivity gap between Europe and the US continuing to exist.

The foregoing brief description of human capital trends suggests that we need to be careful to keep in mind overall accumulation strategy. Since at least the mid-nineteenth century, American firms have developed a strategy based on the substitution of machinery for skilled shopfloor labour, but relying on managerial and (from the twentieth century) research capabilities. In Europe, skilled labour intensive methods of production, allied with craft control, persisted and remain more important than in the US (Elbaum, 1989; Tolliday and Zeitlin, 1991). Different endowments and demand conditions suggest that these differences were basically economically rational.

However, since circumstances can and do change, we need to consider the difficulties associated with changing accumulation strategies. Returning to the situation depicted in Figure 3, it may be that technical progress makes the old skilled-labour-intensive techniques no longer economically viable. The question, then, is whether firms can make the switch to more machine-intensive methods requiring greater managerial control, when the relevant managerial capabilities have not been previously developed. Shorn of its anti-competitive markets and anti-neoclassical economics rhetoric, this is essentially the issue confronted in Elbaum and Lazonick's (1986) book on Britain's relative economic decline. In these circumstances, bargaining power in labour and product markets has an important bearing on comparative productivity performance.

Lewchuk (1986; 1987) presents a game theoretic interpretation of the choice of technology and effort levels in the British motor industry, with distrust between management and labour leading to sub-optimal outcomes in both the interwar and post war periods. In shipbuilding, Lorenz (1991) argues that when it became clear that the British could no longer compete on the basis of the old craft production techniques and needed to switch to mass production techniques in the late 1950s and early 1960s, management and labour were unable to cooperate because of a lack of trust which had been built up in preceding decades. Thus the British shipbuilding industry was unable to make a successful transition from craft production to mass production methods and was all but wiped out by the 1970s.

In these circumstances, we should expect comparative productivity ratios to vary by industry and these patterns of comparative productivity to change over time. The figures by manufacturing branch in Tables 7 and 8 can be interpreted in this light. In textiles, for example, British craft production methods with skilled labour continued to compete effectively with American methods before the Second World War, while from 1950, Britain's productivity position in textiles converged towards the position for aggregate manufacturing.

The other sector where British productivity performance was relatively good before the Second World War was food, drink and tobacco (Broadberry and Crafts, 1990). This is an interesting case in that in these process industries, Britain was quick to develop large scale production catering for standardised demand along American lines (Jefferys, 1954; Mathias, 1967; Vaizey, 1960; Alford, 1973). This shows up clearly in the comparative productivity figures for the first half of the twentieth century in both the US/UK and Germany/UK comparisons.

Turning to the heavier industries, the comparative productivity picture in engineering appears to have been dominated by sectors such as motor vehicles, where a large American productivity lead developed on the basis of mass production methods in the first half of the nineteenth century, but with British firms continuing to compete on the basis of skilled labour. The adaptation of American multinationals in motor vehicles to European conditions confirms the rationality of different strategies of technical choice on both sides of the Atlantic (Foreman-Peck, 1982; Bowden, 1991). The eventual switch by British firms to a more American style of production from the late 1960s has seen a convergence of relative productivity in engineering towards the figure for aggregate manufacturing. However, even within engineering the picture has not been uniform; in shipbuilding mass production techniques did not become dominant until the 1950s with the perfection of welding and prefabrication techniques and Britain continued to compete effectively on the basis of skilled labour until this time (Lorenz and Wilkinson, 1986). Also, it should be noted that the convergence of the productivity gap in engineering towards the figure for aggregate manufacturing does not imply the complete elimination of the gap between Britain and America, which we would expect to persist so long as endowments and demand conditions differ. British techniques have had to change but they are still not the same as American techniques.

Comparative productivity trends in chemicals and basic metals are similar to trends in engineering with a recent improvement in British performance removing a long standing above-average productivity gap in these sectors.

VI. THE RISE OF JAPAN

Since the 1970s American manufacturing has faced a challenge to its technological leadership. As well as the threat from a resurgent Germany, US manufacturing has been challenged by the rise of Japan (Baily and Chakrabarty, 1988; Dertouzos et al, 1989). Manufacturing in both Germany and Japan is based on craft production methods, intensive in the use of skilled labour with general purpose machinery.

The key change which has made craft production more dynamic than mass production since the 1970s is the decline in the cost of computation (Milgrom and Roberts, 1990). Given the dramatic reduction in the cost of information processing, production can be geared cheaply to individual demands by skilled workers using computer aided design, numerically controlled machine tools and robots. This modern form of craft production is often labelled 'flexible manufacturing' (Edquist and Jacobsson, 1988; Milgrom and Roberts, 1990).

In terms of Figure 2(b), the β-technology has become more dynamic in Germany and Japan, requiring a response from American firms using the α-technology. It should be stressed, however, that this switch of technological leadership does not necessarily imply a switch of productivity leadership. Just as in the early nineteenth century Britain had technological leadership despite US labour productivity leadership, so in the late twentieth century the US continues to enjoy productivity leadership despite the loss of technological leadership to Germany and Japan.

Just as in the nineteenth century the American system of manufactures was characterised by a complementarity between resources and machinery (Ames and Rosenberg, 1968), so in the late twentieth century the Japanese system of 'flexible manufacturing' appears to be characterised by complementarities. In the context of the response by British industry to the rise of Japan, Oliver and Wilkinson (1988) note that successful 'Japanisation' requires the adoption of a number of practices together. A more formal treatment of the complementarities is given in Milgrom and Roberts (1990). Whereas in the nineteenth century the complementarities were simply between inputs in production, the new technology is characterised by complementarities between groups of activities such as design, production and marketing. For example, some computer aided design programmes prepare actual coded instructions for programmable production equipment, while flexible production allows firms to economise on inventories, adopting a policy of just-in-time delivery.

Our approach emphasises the flexibility of the Japanese system, which puts it in the tradition of craft production and suggests that Japanese technological leadership will not be matched by labour productivity leadership. Although this appears to be consistent with the findings on comparative labour productivity in manufacturing as a whole, the picture is less clear at the level of individual manufacturing industries. Indeed, Pilat and van Ark (1992) find Japanese labour productivity slightly ahead of US levels in machinery and transport equipment and also in rubber and plastic products. In these sectors the Japanese have been successful in combining the scale economies of mass production with the flexibility of customised production. To what extent this success in motor vehicles and consumer electronics can be replicated in other sectors remains to be seen. A number of considerations suggest a continued productivity lag in Japan relative to the US. First, the Japanese success in building up volume in these sectors has been accompanied by widespread allegations of protection, subsidies and other unfair trade practices (Baily and Chakrabarti, 1988; Dertouzos et al, 1989). Outside these favoured sectors, Japanese productivity performance has often been very poor, particularly in lighter industries such as textiles and food, drink and tobacco (Pilat and van Ark, 1992; Kagomiya, 1993). Second, it should be noted that Germany, the other major exponent of flexible manufacturing, has not attained productivity levels close to US levels, even in its most successful industries (Pilat and van Ark, 1992). Third, in terms of resource base, Japan is disadvantaged even relative to Britain and Germany. However, against this, population and home market size are substantially larger in Japan, suggesting more favourable demand conditions than in Europe.

VII. THE CONVERGENCE DEBATE

Finally, we spell out the implications of our analysis for the recent debate on convergence (Baumol, 1986; De Long, 1988; Baumol and Wolff, 1988). Underlying this debate seems to be the notion that in a fully integrated world, productivity levels would be the same in all countries since they would all be producing with the same techniques. In this world, one country may steal a lead for a while through innovation, but would inevitably be caught up as the new technology was transferred to the rest of the world. Qualifications to this conventional convergence hypothesis usually concern some threshold level of 'social capability', below which a country cannot benefit from technical progress in the advanced countries and thus falls behind (Abramovitz, 1986).

By contrast, our interpretation suggests that countries with different endowments and demand conditions will produce with different techniques and hence with different levels of labour productivity. In particular, we draw a distinction between the prevalence of mass production in the US and craft production in Europe and Japan. Indeed, we would accept that for some purposes it may be helpful to make a finer distinction between British, German and Japanese production strategies (Lane, 1989).

We thus reject the notion of global convergence in manufacturing in the sense of all economies converging in the limit to the same level of productivity (Durlauf and Johnson, 1991). However, our findings are consistent with local convergence in manufacturing, since economies with similar endowments and demand conditions will tend to converge on the same level of labour productivity. There is evidence of local convergence within Europe but a persistent gap between Europe and the US.

Our findings are consistent with what Barro and Sala i Martin (1990) call β-convergence and σ-convergence in manufacturing. β-convergence is simply the tendency for catching-up. When a country widens its labour productivity lead, this is followed by a period when the gap narrows, but without necessarily implying that the gap will be eliminated altogether. The widening and then narrowing of the US labour productivity lead across the two World Wars is clearly consistent with this definition of convergence. σ-convergence is simply a narrowing dispersion, which again is quite possible to have as countries converge locally but without the elimination of the gap between the different 'convergence clubs'.

Note that our rejection of global convergence in manufacturing does not conflict with Baumol's (1986) finding of a single 'convergence club' among the OECD economies at the level of the whole economy. Indeed, Broadberry (1992b) shows that the manufacturing and whole economy evidence can be reconciled so long as it is recognised that levels and trends of labour productivity differ between sectors.

VIII. CONCLUDING COMMENTS

In this paper we draw a distinction between technological leadership and productivity leadership, noting that changes in the former do not necessarily imply changes in the latter. Given different resource and factor endowments and different demand conditions, American manufacturers for at least the last century and a half have relied on a machine intensive, resource intensive mass production system, while European manufacturers have relied on a skilled labour intensive craft production system. For the second half of the nineteenth century the mass production system was more dynamic, with technological leadership passing from Britain to the United States, the productivity leader. Imitation and adaptation in Europe allowed the craft production system to survive, however. Since the 1970s, the reduction in the price of computation has allowed craft production methods to become more dynamic and technological leadership has passed to Germany and Japan, employing 'flexible manufacturing' methods. However, the US remains the productivity leader. Although our findings are not consistent with global convergence, they are consistent with a form of local convergence in manufacturing, with the US continuing to enjoy a labour productivity lead despite its loss of technological leadership.

TABLE 1: Manufacturing Output Per Person Employed (UK=100)

(a) 1869-1989

	US/UK		Germany/UK		Japan/UK	
1869	203.8					
1875			100.0			
1879	187.8					
1889	195.4		94.7			
1899	194.8		99.0			
1907	190.0	(201.9)	106.4		20.7	
1913	212.9		119.0		24.4	
1920	222.8				27.0	
1925	234.2		95.2		25.1	
1929	249.9		104.7		32.2	
1935	207.8		*102.0	(102.0)	38.8	(35.4)
1937	*208.3	(208.3)	99.9		39.4	
1950	262.6	(273.4)	96.0	(99.5)	19.9	
1958	250.0		111.1		35.5	
1968	242.6	(272.7)	120.0	(130.4)	72.5	
1975	207.5	(224.7)	132.9		102.9	
1980	192.8		140.2		133.8	
1985	182.3		121.5		140.0	
1987	188.8	(186.6)	107.8	(112.7)	137.4	
1989	177.0		105.1		*143.1	(143.1)

(b) 1819-1907

	US/UK	
1819/21	148.8	
1839/41	179.4	
1849/51	207.6	(200.3)
1859/61	238.5	
1907	*201.9	(201.9)

Note: * Benchmark year from which the time series are extrapolated. The figures in brackets are actual benchmark comparisons.

Source: (a) Broadberry (1993); Appendix I of this paper.
(b) Broadberry (1992).

TABLE 2 : GDP Per Person Employed (UK=100)

	US/UK	Germany/UK	Japan/UK
1870	95.1	48.8	17.8
1890	98.1	53.3	20.0
1913	127.9	64.1	23.5
1929	154.0	64.3	33.6
1938	143.0	74.9	38.9
1950	167.4	63.3	28.8
1960	167.5	90.2	43.8
1973	151.6	104.7	84.7
1987	128.9	105.6	98.7

Source: Maddison (1991).

TABLE 3 : Shares of World[a] Exports of Manufactures (% based on values in US $ at current prices)

	UK	US	Germany[b]	Japan
1881-85[c]	43.0	6.0	16.0	0.0
1899	34.5	12.1	16.6	1.6
1913	31.8	13.7	19.9	2.5
1929	23.8	21.7	15.5	4.1
1937	22.3	20.5	16.5	7.4
1950	24.6	26.6	7.0	3.4
1964	14.0	20.1	19.5	8.3
1973	9.1	15.1	22.3	13.1
1979	8.7	14.6	18.7	12.3
1987	7.3	12.6	19.3	16.3

Notes: a. World total is confined to the developed world, excluding small developing countries and centrally planned economies.

b. For Germany, pre-World War II estimates are 71% of contemporary Germany.

c. The estimates for 1881-85, based on the work of Hilgerdt (1945) are only imperfectly comparable with the estimates for later years, based on the work of Maizels (1965).

Source: Matthews et al (1982, 435); United Nations, International Trade Statistics Yearbook, Geneva.

TABLE 4: Comparative US/UK Levels of Output Per Worker and Capital Per Worker (UK=100)

(a) Official Capital Stock Data

	Y/L	K/L	TFP
1869	203.8	93.7	204.9
1879	187.8	91.8	189.7
1889	195.5	159.0	174.0
1899	194.8	188.2	166.8
1909	208.5	183.0	179.7
1919	206.9	178.1	179.5
1929	249.9	173.1	218.2
1937	208.3	151.2	187.7
1950	262.6	155.2	235.1
1958	250.0	165.1	220.7
1968	242.7	133.1	225.1
1975	207.5	142.1	189.2
1980	192.9	120.7	183.0
1984	183.3	110.5	177.5
1987	188.8	109.9	183.1

(b) Standardised Capital Stock Data

	Y/L	K/L	TFP
1950	262.6	251.3	199.1
1958	250.0	264.1	187.4
1968	242.7	202.7	193.3
1975	207.5	206.6	166.6
1980	192.9	174.4	159.0
1984	183.3	166.7	152.7
1987	188.8	172.8	156.1

Source: Broadberry (1993).

TABLE 5: Comparative Germany/UK Levels of Output Per Worker and Capital Per Worker (UK=100)

(a) Official Capital Stock Data

	Y/L	K/L	TFP
1875	100.0	60.4	116.4
1889	94.7	71.2	104.9
1899	99.0	97.6	99.8
1909	117.7	98.0	118.5
1913	119.0	105.3	117.2
1925	95.2	61.0	110.5
1929	104.7	67.1	118.0
1937	99.9	73.2	109.8
1950	96.0	77.8	103.6
1958	111.1	71.5	122.8
1968	120.0	95.3	121.8
1975	132.9	107.2	130.2
1980	140.2	92.7	143.5
1984	122.7	81.2	130.7
1987	107.8	76.4	116.9

Source: Broadberry (1993).

TABLE 6: Comparative Output Per Worker and Horsepower Per Worker (UK=100)

Country	Year	Output Per Worker	Horsepower Per Worker
US/UK	1909/07	208.5	212.8
	1929/30		195.6
	1939/30		255.8
	1937	208.3	
Germany/UK	1933/30		107.6
	1935	102.0	
France/UK	1906/07	65.0	77.1

Source: US/UK: UK, Census of Production, 1907; US, Census of Manufactures, 1909; Rostas (1948).
Germany/UK: Melman (1956); Broadberry and Fremdling (1990).
France/UK: Dormois (1991).

TABLE 7: US/UK Manufacturing Output Per Employee (UK=100)

	1909/07	1937/35	1950	1967/68	1975	1987
Chemicals	156.4	226.9	356.4	281	226.8	152.4
Metals	288.0	192.0	274.4	261	251.1	166.2
Engineering	202.3	289.1	337.3	294	190.6	185.8
Textiles	150.7	145.4	197.9	225	222.8	174.0
FDT	137.2	203.5	215.3	246	208.4	232.9
Other	227.2	210.8	284.7	276	274.8	207.5
Total	208.5	217.9	273.4	276	224.7	186.6

Source: Broadberry (1993).

TABLE 8: Germany/UK Manufacturing Output Per Employee (UK=100)

	1935	1967/68	1987
Chemicals	122.9	124.0	88.5
Metals	116.0	136.7	96.1
Engineering	119.7	116.8	111.6
Textiles	97.2	107.9	109.0
FDT	41.3	94.2	114.1
Other	101.8	140.6	131.6
Total	102.0	118.9	112.7

Source: Broadberry (1993).

APPENDIX 1: Data for Japanese Manufacturing (1929=100)

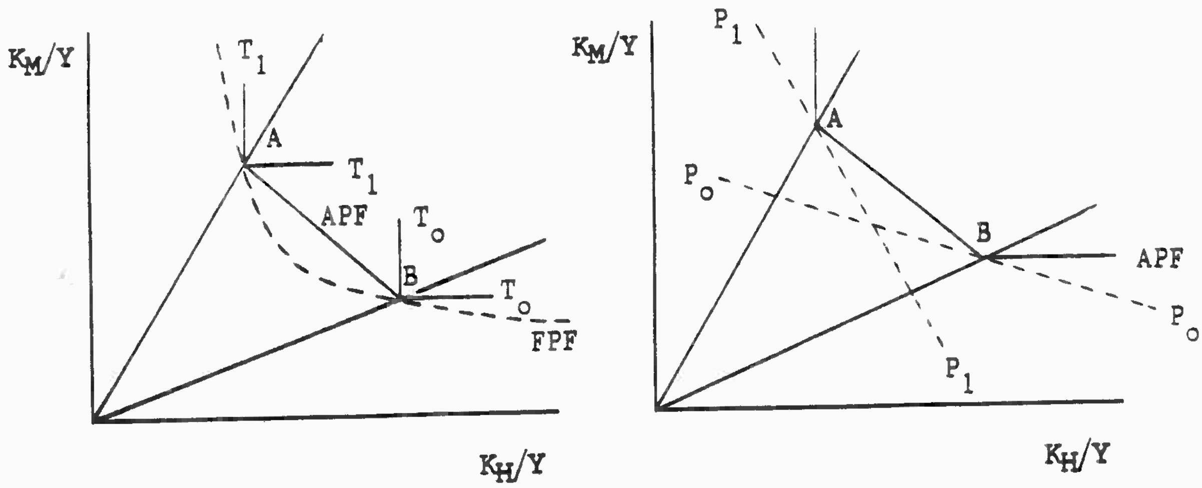
	Output	Employment
1907	28.8	59.4
1913	39.9	67.1
1920	61.5	99.0
1925	76.1	103.5
1929	100.0	100.0
1937	187.1	124.9
1950	110.2	134.0
1958	362.9	193.5
1968	1677.2	280.6
1975	2848.8	289.4
1980	4103.1	293.7
1985	5848.9	312.3
1987	6302.7	306.2
1989	7434.9	318.8

Sources for Output Data:
1907-1970: Ohkawa and Shinohara (1979), Tables A21-A22.
1970-1989: Real GDP in Manufacturing from Statistics Bureau, Management and Coordination Agency, Japan Statistical Yearbook, Tokyo.

Sources for Employment Data:
1907-1970: Ohkawa and Shinohara (1979), Table A54.
1970-1989: Employed persons on Labour Force Survey basis from Japan Statistical Yearbook.

Sources for Benchmarks:
1935: Output and employment in manufacturing on national accounts basis from Ohkawa and Shinohara (1979) and Feinstein (1972). Price data from Japan Statistical Association (1986), Historical Statistics of Japan, Vol. 2, Tokyo, and UK, Census of Production, 1935.
1989: Kagomiya (1993).

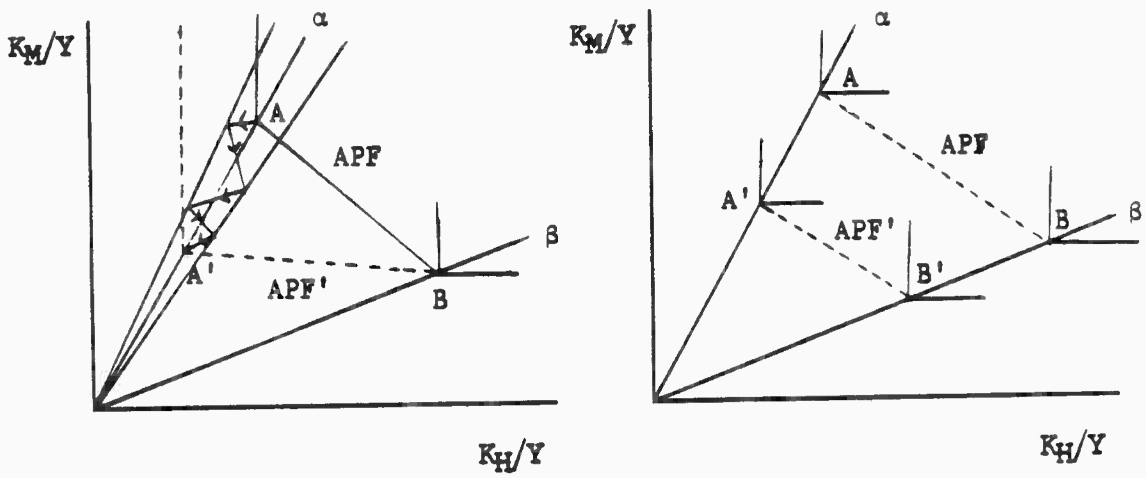
Fig. 1 : Choice of Technology



(a) **The Available Process Frontier and the Fundamental Production Function**

(b) **The Role of Factor Prices**

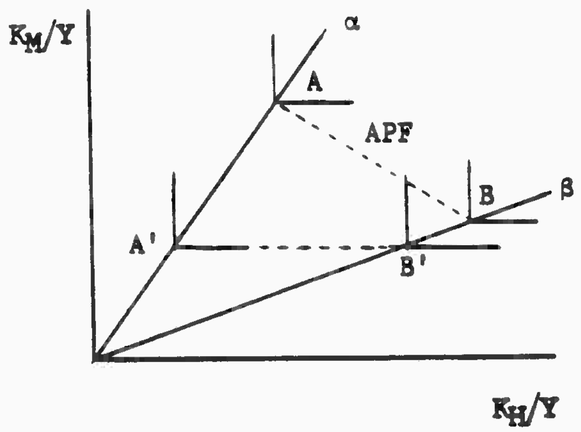
Fig. 2 : Technical Progress



(a) **Localised Technical Change**

(b) **Competition Between Technologies**

Fig. 3 : β-Technology Redundant



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