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THE CONTRIBUTION OF NEW TECHNOLOGY TO ECONOMIC GROWTH: LESSONS FROM ECONOMIC HISTORY

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THE CONTRIBUTION OF NEW TECHNOLOGY TO ECONOMIC GROWTH: LESSONS FROM ECONOMIC HISTORY

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1. Introduction

Technological change is central to the study of economic history. Strong and sustained technological progress is the key characteristic of modern economic growth that distinguished the post-Industrial-Revolution world from earlier times and is the fundamental force which has raised living standards over the last 250 years. As Paul Romer said, "Our knowledge of economic history, of what production looked like 100 year ago, and of current events convinces us beyond any doubt that discovery, invention, and innovation are of overwhelming importance in economic growth" (1993, p. 562).

Accordingly, quantitative economic historians have devoted a great deal of effort to the analysis of technological change. This has resulted in a large body of evidence which in some ways complements that which can be drawn from the economics literature and which, to an extent, suggests that the conventional wisdom of economists needs to be modified. The difference in perspective stems from the range of experience which is provided by economic history and from a focus on explaining the evolution of economies over time. This paper highlights some findings which are well-known to those economic historians who study long-run economic growth but deserve a wider audience.

The exposition is organized by addressing two questions which relate, respectively, to what are sometimes called the 'proximate' and the 'ultimate' sources of economic growth. These questions are:

What have we learnt from historical growth accounting about the role of total factor productivity (TFP) growth?

When do countries exploit well the opportunities of new technology?

A review of some results from growth accounting and how to interpret them is highly appropriate since this represents the most important technique for quantifying the impact of new technology on productivity. A look at what Abramovitz and David (1996) called 'social capability' and 'technological congruence' allows an emphasis on some of the distinctive flavour of what economic history has to say about success and failure in growth performance, perhaps the most important topic in the discipline.

2. Lessons from Historical Growth Accounting

Growth accounting typically starts by supposing a Cobb-Douglas production function and then makes the distinction between moves along and shifts of this production function in accounting for changes in labour productivity. So

$$Y = AK^{\alpha}L^{1-\alpha}$$

where Y is output, K is capital, L is labour, and A is TFP while α and $(1-\alpha)$ are the elasticities of output with respect to capital and labour, respectively. Under conventional (neoclassical) assumptions, α and $(1-\alpha)$ are factor-share weights in income, profits and wages, respectively. The basic growth accounting formula is

$$\Delta \ln(Y/L) = \alpha \Delta \ln(K/L) + \Delta \ln A$$

This formula was first made famous by Solow (1957) and $\Delta \ln A$ is, of course, also known as Solow's Residual. While it was clear to Solow that the residual would capture any kind of shift in the production function, the concluding summary of his paper said that 7/8ths of the growth in American labour productivity between 1909 and 1949 was attributable to technical change (1957, p. 320).

This approach is quite flexible and can be adapted to embrace different specifications of the production function either in terms of changing the functional form (for example, translog) or incorporating additional factors of production (for example, human capital) or distinguishing between different types of physical capital (for example, ICT capital vs. non-ICT capital).

a) How Important is Crude TFP in Accounting for Labour Productivity Growth?

Crude TFP growth is the original Solow's Residual, namely, the estimate that is obtained from the basic growth accounting formula set out above which does not allow for any contribution to labour productivity growth other than that of physical capital. The first issue to consider is whether Solow's 7/8ths result generalizes to the wide experience of modern economic growth in what are now high-income countries, as Kuznets (1971), writing before historical growth accounting had produced any results, thought that it probably would.

Solow's finding that 7/8ths of US labor productivity growth during 1909-1949 was accounted for by TFP growth (where no separate allowance is made for educational quality of the labor force) is still pretty much what would be obtained applying his method to today's data. This does not, however, mean that this result has also been found by economic historians consistently for other periods and different countries, even though Kuznets (1971) suggested that it probably would be.

Table 1 reports that on the basis of conventional growth accounting for the United States over the long run, the picture is one of dominance of crude TFP from the late nineteenth century till the end of the post-World War II boom in the late 1 960s. However, Table 1 also shows that before 1890 and after 1966 crude TFP contributes at best only 50 per cent of labor productivity growth.

In fact, at face value, given that TFP growth is below 0.5 per cent per year prior to 1890, the estimates in Table 1 invite the conclusion that technical change was insignificant in the American economy for much of the nineteenth century and only came to prominence with the rise of the science-based industries and R & D in the so-called second industrial revolution. This runs counter to standard historical discussions, however, and is certainly not the interpretation in Abramovitz and David (2001). If, as they suggest, the nineteenth-century US economy was characterized by a low elasticity of substitution between factors together with capital-using technical change, then TFP growth may have been considerably stronger than shown in Table 1 which assumes that $\sigma = 1$. Whereas the crude TFP growth estimates give a rate of 0.24 per cent per year for 1835 to 1890, if, instead, estimates are obtained using the assumption of an aggregate production function with the properties that Abramovitz and David believe that the evidence supports, this would generate a revised estimate for TFP growth of 0.9 per cent per year and thus restore it to a dominant role.[1]

[1] This calculation is based on the formula given by Rodrik (1997) that the correction to TFP growth = $0.5\alpha((1 - \sigma)/\sigma)(1 - \alpha)(\Delta K/K - \Delta L/L)(\Delta A_L/A_L - \Delta A_K/A_K)$ where the term in the last parenthesis captures the degree of

For the late-twentieth century slowdown, it is also likely that the impression given by Table 1 is misleading. Here the main issue relates to the measurement of output growth. Boskin et al. (1996) thought that, for a variety of reasons, inflation had been overestimated (and thus real GDP growth and TFP growth had been underestimated by a similar amount) in the national accounts and that the correction required was of the order of 0.6 per cent per year. Again, this would raise the contribution of crude TFP growth well above that of capital-deepening without quite reaching the 7/8ths mark.[2]

For other countries, the story is different. In Tables 2 and 3, the picture of modern economic growth in Europe through the 1970s is set out. The estimates reported in the former table show only two cases (Great Britain in 1801-31 and Portugal in 1910-34) where the TFP contribution to labour productivity growth is as much as 80 per cent. A distinctive aspect of Table 2 is that as modern economic growth spread across nineteenth-century Europe TFP growth was initially quite modest and any tendency for TFP growth to dominate capital-deepening is generally a post-1890 or post take-off phenomenon. Looking at the top of Table 3, crude TFP growth does dominate capital-deepening but even so the proportion accounted for is almost always less than 7/8ths.

As Krugman (1994) highlighted, and, as economic historians in the Gerschenkronian tradition might have predicted, rapid catch-up growth in the east Asian developmental states looks rather different from the earlier OECD experience.[3] In Korea, Singapore and Taiwan the contribution of capital deepening has been formidable and exceeded that of TFP growth in the period 1960 to 1990.[4] There is a strong contrast with the well-known cases of Italy, Japan and Spain in the Golden Age.[5]

In sum, it appears that the US growth record that Solow (1957) analyzed was far from typical of the experience of other industrialized economies in the two centuries since the Industrial revolution. Generally speaking, even without the refinements suggested by subsequent authors which tend to downsize the role of TFP, the contribution of TFP growth to labour productivity growth is well below 7/8ths. Had Solow's first growth-accounting estimate been made in the 1 950s for Spain, the results would have been far less sensational.

b) TFP Growth ≠ the Rate of Technical Change

While Solow (1957) put the growth economics into growth accounting and showed that the residual could be interpreted as a measure of the rate of technical change, in practice, this is

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factor-saving bias in technological progress measured as the difference between the rate of labour augmentation and the rate of capital augmentation. The formula is parameterized using values suggested in Abramovitz and David (2001), including $\sigma = 0.3$, and applying them to 1835-1890, the period which is singled out by these authors.

2 The Boskin bias in inflation measurement does not appear to generalize to other periods, cf. Costa (2001).

3 In a very influential contribution, Alexander Gerschenkron (1962) proposed that the growth of 'backward' follower countries would differ from that their predecessors. In particular, there would be a much greater emphasis on capital accumulation and a key role for what would later be called the 'developmental state' in implementing this.

4 Rodrik (1997) argued that the east Asian growth accounting estimates were biased; applying a similar correction formula to that in footnote 3 might add around 0.8 per cent per year to TFP growth which would change the detail but not the substance of this point.

5 Portugal, however, is more similar to the east Asians.

generally not the case. Indeed, the estimated rate of TFP growth can be either an under- or an over-estimate of the contribution of technological change to labour productivity growth.

There are two important cases where it will be an under-estimate. First, as noted in the previous section, if technological change is labour-saving and the elasticity of substitution is less than, then the rate of TFP growth obtained by imposing standard assumptions of a Cobb-Douglas production function with neutral technological change is too low. Second, if technological change is embodied in new types of capital goods, as economic historians often suggest and is common in endogenous-growth economics, then the technological change contribution would subsume both TFP and part of what is normally counted as capital-deepening (Barro, 1999).

On the other hand, especially when TFP is growth is rapid, as in famous cases of catch-up growth, it is likely that there is a substantial component from reductions in inefficiency, both allocative and productive. For example, Maddison (1987), like Denison (1967), concluded that much of the Solow residual was typically attributable to some combination of labor quality, improved allocation of resources, changes in the utilization of factors of production, reductions in technology gaps and economies of scale leaving only a modest share 'unexplained' - and perhaps reflecting disembodied technical change (cf. Table 3).

Maddison's list of the components of rapid TFP growth in the European Golden Age is broadly in line with conventional economic histories but precise quantification is, of course, very difficult and there is no consensus on the details.[6] Maddison himself acknowledged that his exercise was rather speculative and papers in the empirical growth literature cast doubt on its reliability without, however, amounting to an alternative decomposition. For example, Broadberry (1998) proposes a different calculation for the effect of structural change which would increase its magnitude considerably, Badinger (2005) offers an econometric estimation of the productivity implications of economic integration which suggests foreign trade was more important than Maddison suggests. Nevertheless, these are issues about the detail not the principle.

It should be noted that the various components of TFP growth differ in relative importance over time while it is generally believed that the factor-saving bias of technological change has also varied, as indeed new growth economics suggests should be the case (Acemoglu, 1998). This means that differences in the rate of TFP growth between periods may not be a good guide to comparative rates of technological change. This point is accentuated when it is recognized that growth accounting estimates sometimes indicate negative TFP growth over lengthy periods, for example, as in much of Africa over the last decades of the 20th century (Bosworth and Collins, 2003). This seems much more plausibly interpreted as reflecting problems of inefficiency and capacity utilization rather then technological decline.

When growth accounting is used to compare levels of labour productivity across countries, it is now generally agreed that TFP gaps account a large part of the difference between rich and poor countries. Table 4 reports results from a recent study by Duval and de la Maisonneuve (2009) which show this and which confirm the basic findings in the much-cited paper by Hall

[6] It should be noted that the results of a data envelopment analysis also give strong support to the claim that TFP growth during the European Golden Age was boosted considerably by improvements over time in the efficiency of factor use (Jerzmanowski, 2007).

and Jones (1999) which also notes that the TFP gaps seem to be strongly correlated with low levels of institutional quality.

What explains low TFP levels in poor countries? This could represent inefficient use of factor inputs. But it could also result from 'inappropriate technology' in the sense that the technological advances in rich countries improve the production function at their factor endowments but not at those prevailing in poor countries contrary to the conventional neoclassical assumption that the production function improves proportionately at all factor intensities. So, the conventional decomposition of labour productivity differences into a component from TFP and a component from the capital to labour ratio, as in Figure 1a) is modified to allow for discontinuities in the production function as in Figure 1b). This allows TFP to be decomposed into a technology component and an inefficiency component.

Jerzmanowki (2007) implemented an analysis of this kind and some of his results are summarized in Table 5. These give some support to both hypotheses, though very low levels of TFP do seem to be primarily due to low efficiency, and suggest that negative TFP growth in Africa should be interpreted as due to reductions in efficiency rather than technological decline.[7] Catch-up growth in East Asia and in Europe has resulted both from bridging the technology gap and from improvements in efficiency, albeit in quite different proportions in various countries. More generally, though the point that emerges is that TFP growth in excess of 1.5 per cent per year is generally to be interpreted as resulting from considerable improvements in efficiency as well as technology. Transferring labour out of agriculture is typically part of this but so is improving the management of firms.[8]

c) What Have General Purpose Technologies (GPTs) Meant for Productivity Growth?

The Solow Productivity Paradox was announced in 1987 with the comment that "You can see the computer age everywhere except in the productivity statistics". Subsequently, a great deal of effort was devoted to explaining this (Triplett, 1999) and it was an important trigger for the literature on GPTs which developed models that had negligible or even negative impacts on productivity performance in their first phase but substantial positive effects later. Indeed, a GPT can be defined as "a technology that initially has much scope for improvement and eventually comes to be widely used, to have many uses and to have many Hicksian and technological complementarities" (Lipsey et al., 1998, p. 43).

Table 6 compares the impact of two GPTs, namely, steam and ICT, in the leading economies of the time. These were indeed technologies where the potential was not well-understood in the early days. Thus, the pioneers of steam power did not realize its implications for transport over both land and sea and the early developers of microchips did not foresee the mobile phone and the internet. While the improvement in microchip technology was forecast early on (Moore's Law), the advantages of high-pressure over low-pressure steam only became clear many years after James Watt's (1769) patent. Technological progress led to a dramatic fall of about 50 per cent per year in the cost of computing between 1950 and 2005

[7] Caselli and Coleman (2006) conduct a similar analysis but use a different specification for the production function and a different econometric methodology. Nevertheless, their results lead to similar conclusions.
[8] Inefficient use of inputs is still characteristic of both Chinese and Indian manufacturing; if capital and labour were used as efficiently as in the United States, Hsieh and Klenow (2009) estimate that manufacturing TFP would rise by 25-40 per cent in India and 50-60% in China.

(Nordhaus, 2007). By contrast, the cost of steam power fell by only about 7/8ths in total between 1760 and 1910 (Crafts, 2004).

Two points stand out from Table 6. First, it was a very long time after James Watt's invention that steam had any significant effect on labour productivity growth. The long lag reflected the time it took to improve the technology so that it consumed less coal and became cost effective - only about 165,000 horsepower were in use as late as 1830 (Kanefsky, 1979). Second, the impact of ICT on the rate of productivity growth throughout 1973-2006 exceeded that of steam in any period and was already close to twice the maximum impact of steam in the late 1 980s. Indeed, these estimates suggest that the cumulative impact of ICT on labour productivity by 2006 was about the same as that of steam over the whole 150-year period, 1760-1910.

The arithmetic of growth accounting immediately reveals why the initial impact of a GPT is relatively modest. Despite rapid growth in the use and productivity of the new technology, it has only a small weight in the economy as a whole. To an economic historian, the true paradox is that Solow's ICT paradox was regarded as such, given that by earlier standards the contribution of ICT in the late 1 980s was already stunning. A plausible inference seems to be that society is getting better at exploiting the opportunities presented by new GPTs which may reflect a number of factors including more investment in human capital, superior scientific knowledge, improved capital markets and greater support for R & D by public policy.

d) User Benefits of New Technologies

One of the most famous episodes in cliometrics concerned the contribution of the railroads to nineteenth century American economic growth. The best-known study was by Fogel (1964) who pioneered the technique of social savings as a methodology. This is based on estimating the cost-savings of the new technology compared with the next best alternative. A contribution from railroad capital deepening is not included as it is assumed that this earned a normal profit equal to its opportunity cost so, in the absence of railroads, another investment would deliver an equal return.[9] The saving in resource costs was also taken to be equal to the gain in real national income (Fogel, 1979, p. 3). This is valid if the rest of the economy is perfectly competitive with constant returns to scale (Jara-Diaz, 1986). Imperfect competition or benefits from internal of external economies of scale in the transport-using sector will mean that the economic benefits exceed the transport benefits. The new economic geography suggests we should take these seriously and this is an important agenda for future research; in growth accounting terms this would amount to looking for TFP spillovers.

For railways the amount of social savings (SS) was calculated as

$$SS = (P_{T0} - P_{T1})\, T_1$$

where P_{T0} is the price of the alternative transport mode, water, P_{T1} is the price of rail transport and T_1 is the quantity transported by rail. Fogel deliberately intended this to be an upper- bound measure, constructed as if demand for transport was perfectly price inelastic, to compensate for omitted gains in the transport-using sector.

[9] If railroads earned supernormal profits, then it would be appropriate to add just the producer surplus component of profits to find a true estimate of the real income gain, McClelland (1972).

The natural interpretation of the gain in real income obtained from reducing resource costs in transportation is as an increase in TFP. Harberger (1998) reminded us that TFP growth can be interpreted as real cost reduction and the price dual measure of TFP confirms that the rate of fall over time in the real cost of railroad transport under competitive conditions is also equal to TFP growth. Since railroads will only be introduced at the point where they can offer transport at the same cost as water transportation, if expressed as a contribution to the annual growth rate, the social savings measure should equate to the own TFP growth contribution. Indeed, this equivalence is exactly how Foreman-Peck (1991) extended the social saving estimate for British railways made by Hawke (1970) for 1865 to 1890.

The price dual measure of TFP growth equivalent to (3) is

$$\Delta A/A = s_K \Delta r/r + s_L \Delta w/w - \Delta p/p$$

where r is the profit rate, w is the wage rate and p is output price. Thus when input prices are constant, TFP growth equals the rate of nominal price decline.

Using this result, the rail social saving in year t compared with the year of introduction, $t-1$, expressed as a fraction of rail revenue is

$$(p_{t-1} - p_t)q_t/p_t q_t = p_{t-1}/p_t - 1 = A/A_{t-1} - 1$$

or expressed as a fraction of GDP is

$$(A/A_{t-1} - 1)*(p_t q_t/GDP_t)$$

Rail social savings as a proportion of GDP are revealed to be the percentage change in TFP in the rail industry multiplied by the ratio of rail output to GDP. The social saving approach is then equivalent to taking only the TFP and not the embodied capital contribution of an innovation.

A major advantage of the social-saving methodology is that it focuses attention on the distribution of the benefits from a new technology together with how well these benefits are measured. In the case of railways, in both Spain and the UK, the evidence is that users got the lion's share of the benefits in terms of cheaper and faster transport and that there were few supernormal profits, as Table 7 reports. This would not be a surprise to Nordhaus (2004) who estimated that 98 per cent of the social gains from new technology went to the users and only 2 per cent to supernormal profits in the United States in the second half of the 20th century.

This discussion has been conducted entirely in terms of a closed economy. However, in an open economy, the users and producers of new technologies may be in different countries. Since the products of the new technology will experience falling prices, the impact of its production on real GDP will be greater that on real national income. History tells us that this consideration can be serious. The best example is probably cotton textiles during the British industrial revolution. Harley (1999) concluded that the welfare gain from the growth of cotton textiles during the industrial revolution was a little over 11 per cent of 1841 income whereas valuing output of the sector without making a terms of trade correction would have shown a gain of 25 per cent. The social saving methodology by valuing gains from domestic use of new technology is a better guide to welfare benefits than the usual growth accounting estimate.

Finally, it should be recognized that technological change may provide 'new goods' which have previously unavailable characteristics and are imperfect substitutes for the old. This type of benefit, which reflects consumers' willingness to pay for the new attribute, is ignored in conventional growth accounting, although it may be large as Hausman (1997) showed when comparing mobile with landline telephones. For railways, the new characteristic was speed of passenger travel. Indeed, time savings account for about half the social savings in the UK in 1912 reported in Table 7. Implications for time use deserve to be taken seriously in the context of other technologies, most obviously ICT, as is suggested in an innovative paper by Goolsbee and Klenow (2006). They estimated that taking into account the opportunity cost of time saved, the consumer gains from the internet in the United States in 2005 were $2500 per person rather than the $50 that resulted from a conventional consumer-surplus calculation.

3. Taking Advantage of the Opportunities of New Technology

Economic historians are fascinated by success and failure in long-run growth. They have always been inclined to believe that institutions and policies, i.e., incentive structures, matter in this context even when mainstream economics claimed that they could only have levels rather than growth-rate effects. With the advent of endogenous growth theory and explicit analysis of the determinants of innovation, there is now much more common ground between economics and economic history, although significant differences of emphasis remain. Some of these stem from the explicitly internationally comparative nature of much work in economic history some from the perspective that results from looking at the process of adjusting to change as technology evolves and diffuses.

a) Appropriate Technology

As noted earlier, there has been considerable interest among economists recently in the hypothesis that technologies developed for the factor endowments and cost conditions of advanced countries may not improve the production function for poor countries (cf. Figure 1b). This idea looms larger in work by economic historians on the development and adoption of new technology, notably, with regard both to the divergence between American and British technology during the 19th and early 20th centuries and also the reasons why the Industrial Revolution happened first in Britain.

Habakkuk (1962) famously claimed that land abundance and labour scarcity in the United States promoted rapid, labour-saving technological change. New economic historians spent quite a long time trying to pin down these arguments. Eventually, it was found that the US was able to exploit complementarities between capital and natural resources to economize on the use of skilled labour in an important subset of American manufacturing (James and Skinner, 1985) and that scale economies and biased technological change biased in favour of capital and materials-using were pervasive in manufacturing (Cain and Paterson, 1986).

Following the lead of David (1975), Broadberry (1994) used Figures 2a) and 2b) to locate this as a situation of localized technological progress in the two economies, down the á and â rays rather than a universal inwards shift of a smooth isoquant. Although eventually the technology might develop far enough to dominate at both sets of relative factor prices, it might remain inappropriate for the country starting from point B for a long time. Acemoglu (2009) provides a model in the endogenous innovation tradition that predicts an outcome like Figure 2b) of faster technological change under conditions of labour scarcity if, as may well be the case for the 19th century, technology is biased in the direction of being strongly labour saving.

Looking at late-Victorian Britain, the flip-side of this story is that innovations that were made in the United States were frequently inappropriate on the other side of the Atlantic because they were not cost-effective at British relative factor prices and/or market size; had they been profit-maximizing, competition in product markets would have ensured rapid adoption. (Magee, 2004). Thus, allegations that 'entrepreneurial failure' was to blame for the neglect of American technology made by writers such as Landes (1969) were misplaced and British business was exonerated. The implication is that lower TFP in British industry was unavoidable. Unlike the inappropriate-technology literature in economics, however, this is about the development of North-North rather than North-South technology.

Allen (2009) takes a global perspective on the first industrial revolution and argues that it happened in Britain because of the unique relative factor-price configuration there, in particular, the combination of very expensive labour and very cheap energy. He points to the success of famous innovations, for example, in textiles and metals, in changing factor proportions by using coal and saving labour - maybe this is best seen as induced factor substitution making available a new point on the APF in Figure 2a).

Allen stresses that the new technologies of the industrial revolution were very expensive to develop and, since they were not profitable to adopt in other countries, the only place where it was rational to do the R & D was Britain.[10] Eventually, as the industrial-revolution technologies advanced, they became profitable to adopt in other countries with different factor prices and Britain's advantage proved transient. Again, an endogenous-innovation approach can help make this argument work in theory as well as in practice. The model of directed technical change in Acemoglu (1998), in which profits to innovation are proportional to market size because of fixed costs of developing new technology, would be a possibility.

b) Social Capability and Schumpeterian Growth

For almost all countries including those which do substantial amounts of R & D such as France, Germany and UK, the main source of technological advance is technology transfer from abroad (Eaton and Kornum, 1999). This places a premium on the ability effectively to assimilate imported technology both in terms of speed of its diffusion and realization of its productivity potential. In a very influential paper, Abramovitz (1986) emphasized that catch-up by follower countries was by no means automatic but depended on 'social capability', i.e., having incentive structures based on institutions and policies that were conducive to the necessary investment and innovation.

[10] For example, Allen (2009) estimates that the rate of return on investing in a spinning jenny in the 1 770s was 38 per cent in Britain, 2.5 per cent in France and -5.2 per cent in India.

The claim that institutions matter is, of course, characteristic of economic historians' work on economic growth and development, most famously identified with North (1990). Here, since the mid-1990s, there has been a convergence between work on catch-up growth by economists and economic historians. Following the pioneering paper by Knack and Keefer (1995), it quickly became routine to include a measure of the quality of formal institutions in growth regressions and to find that it is economically and statistically important (Bleaney and Nishiyama, 2002). Similarly, since Hall and Jones (1999), it has become widely accepted that low TFP levels in poor countries is to a considerable extent due to inefficiency which persists in the context of bad institutions.

There clearly are, however, important differences as well as similarities between these two literatures. In particular, there are features of the economic-history work that have not yet been fully reflected in that of the economists. First, it is important to note the influential argument of Gerschenkron (1962) at an early stage of development the institutions (and policies) which are appropriate might differ from those desirable at more advanced stages of development. This entailed a more proactive role for the state, wider boundaries for the firm and greater reliance on relationship banking given the importance of co-ordination problems, inadequacy of the formal legal system, and a premium on dealing with capital market failures. It is also relevant to note that reform to achieve a more orthodox stance once take-off has been achieved will probably be desirable but possibly difficult as proved to be the case in East Asia (Crafts, 1999).

Second, the new institutional economic history stresses both the persistence of institutions and also the absence of any general tendency for good institutions to replace bad ones; a lot of weight is put on path dependence in institutional change (North, 2005). Once in place, institutional arrangements can develop network externalities and the support of the interest groups that they spawn. Informal as well as formal institutions matter but they are not readily amenable to 'top-down' reform. Thus, 'bad' or outmoded institutions, which arose through choices made long ago in different circumstances, may survive.

This suggests that many economists are over-optimistic about the prospects for catch-up and convergence in poor countries. If institutions matter and need continual reform to achieve full catch-up, it is very possible that countries either get stuck in a low-level equilibrium (much of Sub-Saharan Africa) or find catch-up easy to start but difficult to complete (for example, Japan). Thus, the neoclassical prediction of future convergence of incomes appears to be very optimistic even though enthusiasts argue that, now that it is understood which institutions and policies are conducive to growth, in a globalized world rapid catch-up growth financed by capital inflows should be much easier to achieve (Lucas, 2000). Similarly, the projections of future catch-up by the so-called BRICs economies that have been popularized by Goldman Sachs (Wilson and Purushothaman, 2003) have a mechanistic flavour which abstracts from the political economy of development.

It is useful to link the discussion of social capability to modern growth theory. The obvious way to do this is to consider the endogenous-innovation model proposed by Aghion and Howitt (2006) in which technological progress occurs through quality-improving innovations that render old products obsolete and which they describe as 'Schumpeterian' because it entails creative destruction. This model can be simply captured by the following equations:

$$y = A^{1-\alpha} k^{\alpha}$$

where y is output per worker and A is labour-augmenting technological progress.

$$\Delta A = \mu_n(\gamma - 1)A + \mu_m(A^* - A)$$

where μ_n and μ_m are the frequencies with which, respectively, 'leading-edge' and 'catch-up' innovations occur, $(A^* - A)$ is the technology gap with the leader and γ is multiple by which technology improves with a leading-edge innovation. Growth is increased by institutions and policies which increase μ_n and/or μ_m. Countries which are close to (far from) the frontier need to concentrate on developing a configuration that is good for μ_n (μ_m).

It should be noted that institutions and policies which are conducive to leading-edge innovations may be less effective or even adverse for catch-up innovations. Strong product-market competition policy may be a case in point, according to Aghion and Howitt (2006). For close-to-frontier situations encouraging entry threats stimulates innovation which will allow the domestic firm to survive whereas in far-from-frontier cases entry will lead to exit of the domestic firm whether it has innovated or not. As I explore below, a permutation on this idea with salience for economic history is that the institutions and policies that are good for one technological era (say, Fordism) are less appropriate for another era (say, ICT). The parallel with the Gerschenkronian perspective is readily apparent. It will be desirable to reform and for institutions and policies to evolve as countries progress through a process of catch-up. This may not be easy.

c) The Golden Age of European Economic Growth, 1950-1973

The Golden Age of European economic growth was an episode of strong β-convergence, as Table 8 suggests. Abramovitz and David (1996) explained this in terms of increased 'social capability' and 'technological congruence' compared with the post-World War I period.[11] With regard to the former, an important aspect was the corporatist capitalism, highlighted by Eichengreen (1996), that underwrote an investment boom. With regard to the latter, the point is that by now American technology was more appropriate for Europe as factor-price differences narrowed and European markets became more integrated (Nelson and Wright, 1992).[12] The strengthening of competition together with trade liberalization also underpinned rapid TFP growth based on reductions in inefficiency (cf. Table 3).

The most striking hypothesis to explain enhanced social capability in postwar Europe is that of Eichengreen (1996) who argued that the high investment rates which allowed successful exploitation of catch-up opportunities were facilitated by social contracts which sustained wage moderation by workers in return for high investment by firms. These 'corporatist' arrangements provided institutions to monitor capitalists' compliance and co-ordinated wage bargaining which protected high-investment firms and prevented free-riding by sub-sets of workers.[13] In addition, the state provided 'bonds' that would be jeopardized if labour

[11] The decomposition of the TFP gap provided by Jerzmanowski (2007) suggests that this claim about technological congruence is plausible (cf. Table 5).
[12] A formal model of conditional convergence which incorporates appropriate technology shows that a 'growth miracle' phase can happen as accumulation of capital drives factor endowments into the range where the production function has improved and technology transfer suddenly becomes profitable (Basu and Weil, 1998).
[13] 'Corporatist' industrial relations were quite common (Crouch, 1993); in other cases, such as France and Italy, government intervention achieved similar results (Toniolo, 1998).

defected on the agreements in the form of an expanded welfare state. Not all countries succeeded in achieving the co-operative equilibrium; West Germany did but the UK did not. Co-ordinated wage bargaining can be shown to have promoted investment and growth up to 1975 but not thereafter (Gilmore, 2009). The central foundation of a high investment/wage moderation equilibrium is that both sides are willing to wait for jam tomorrow. By the 1970s, there were good reasons for patience to be much lower, including the greater mobility of capital and the productivity slowdown (Cameron and Wallace, 2002).

Although all countries grew rapidly by their own historical standards, some seized the opportunities of the Golden Age better than others. Table 8 suggests that West Germany out-performed and the UK under-performed relative to the predictions of an unconditional convergence regression; Table 3 points to weaker TFP growth in the UK as a key aspect. This reflects differences in social capability.

First, it is clear that West Germany was much more successful in human and physical capital accumulation. In 1973, capital per hour worked in West Germany was 35 per cent above the UK level and in 1978/9 only 34.5% of West German workers were low skill compared with 72.8% in the UK (O'Mahony, 1999). This strong record of accumulation was based on corporatist institutions and an 'insider' financial system that fostered relationship-specific long-term investments (Carlin, 1996). Second, there was a major difference between the two countries in terms of industrial relations; whereas West Germany established a system of industrial unions, multiple unionism was quite prevalent in the UK. Multiple unionism makes the 'hold-up problem' for investments in fixed capital much more serious and encourages free-riding by unions; Bean and Crafts (1996) show that this exerted a significant penalty in terms of productivity growth for the UK. Third, there was weaker competition in the UK partly because of slower liberalization of external trade and partly because competition policy was a low priority and badly-designed. Price-cost margins were much higher and supernormal profits more persistent in the UK than in West Germany (Crafts and Mills, 2005; Geroski and Jacquemin, 1988). This mattered because UK firms suffered more from the agency problems that arise where shareholders are weak and for which competition is the antidote.[14] The UK evidence is that weak competition in the absence of a dominant external shareholder was associated with markedly inferior productivity performance (Nickell et al. 1997).

Two points should be taken from this discussion. First, incentive structures do matter for the effective assimilation of new technology and for productivity growth and these have varied significantly across advanced European countries in the recent past. Second, the UK had problems in the areas of corporate governance with an extreme degree of separation of ownership and control which allowed bad management to continue and in industrial relations with a tradition of craft control of effort bargains. Both these historical legacies were sustained by weak competition and were serious handicaps to the effective assimilation of American technology in the UK but policy-makers were unwilling to address these issues.

d) A Historical Perspective on the ICT Era

[14] West Germany relied much less on public joint stock companies where these issues are likely to matter most. German companies almost always had a shareholder with 25% of the company whereas in UK only a small percentage did (Carlin, 1996, p. 488).

It is well-known that the United States has enjoyed a labour productivity growth revival since the mid-1990s and that, for the first time in the postwar period, this has outpaced average western European performance. About the same time, it became very clear that the Solow Productivity Paradox no longer applied as the ICT contribution to American productivity growth increased. A standard American perspective on recent European growth is that it has been handicapped by too much taxation, too much regulation and too little competition (Baily and Kirkegaard, 2004). It is clear that this is an accurate description of the average of European countries compared with the United States; it was, however, equally true for the 20 years or so prior to 1995 during which productivity growth in Europe was well above that in America and the European productivity catch-up continued (Crafts and Toniolo, 2008).

ICT has played a big part in the recent discrepancy between European and American productivity performance, as is reflected in Table 9. Both ICT-capital deepening and TFP growth were much stronger in the United States than in the large continental European economies, as was the contribution made by service sectors that use ICT intensively (such as retailing) to labour productivity growth. Investment in ICT capital also has a strong lagged effect on TFP growth in the same sector in the United States (Basu and Fernald, 2007). This seems to reflect re-organization of production, workforce training and learning-by-using within firms (Brynjolfsson and Hitt, 2003).[15]

Recent research has found that the adverse effects of regulation on productivity performance are strongest in the face of new technological opportunities and have impacted strongly on the diffusion of ICT. Cross-country regression evidence shows that employment protection deters investment in ICT equipment (Gust and Marquez, 2004) because re-organizing working practices and upgrading the labour force, which are central to realizing ICT's productivity potential, are made more expensive. Restrictive product market regulation has deterred investment in ICT capital directly (Conway et al., 2006) and the indirect effect of regulation through raising costs has been relatively pronounced in sectors that use ICT intensively. There has been a strong correlation between product market regulation and the contribution of ICT-using services (notably in distribution) to overall productivity growth (Nicoletti and Scarpetta, 2005). Stronger competition in close-to-frontier economies would have been beneficial in the recent past, as Aghion and Howitt (2006) argued, but perhaps the strongest reason for this would have been favourable effects on implementing technology transfer rather than creating leading-edge innovations.

Table 10 shows that regulation has been more tighter in Europe than in the United States. At the same time, the picture is one of moves towards de-regulation in Europe in the last 20 years or so. Thus, the story is not that regulation has become more stringent but rather that existing regulation has become more costly in the context of a new technological era based on ICT. The UK has experienced a relatively strong contribution to productivity growth from the regulation-sensitive ICT-using services sector and ICT capital deepening has been above the EU average. As a lightly-regulated economy characterized by strong competition, since the Thatcher reforms the UK has been better positioned than the other big European economies to prosper in the ICT era. This has been reflected in TFP growth and relatively strong contributions to productivity growth from both ICT-using services and ICT capital

[15] This implies that it may be necessary to re-think growth accounting estimates to make explicit the role of investment in intangible capital which has probably been much larger in the 'New Economy' era than before. This will probably account for part of what is captured by TFP in conventional growth accounting, as is found by a pioneering study for the United States (Corrado et al., 2009).

deepening. In a sense, this can be seen as an unexpected bonus from the failure to establish a successful corporatist model in an earlier generation. By the same token, the downside of success based on corporate capitalism in the Golden Age is also apparent.

4. Conclusions

Growth accounting has been widely used by economic historians and some important findings have emerged from the research of the past three decades. First, it is clear that it is not generally the case that 7/8ths of labour productivity growth comes from technical change and this famous result in Solow (1957) now appears to be a bit of an outlier. Across other countries and in other time periods, capital deepening accounts for rather more than 1/8th of labour productivity growth. Moreover, particularly when Solow's Residual is big, technical change only accounts for part of TFP growth while reductions in inefficiency play an important part. Second, we now know that even really important new technologies only have a small impact on productivity growth in the early days. This was the message as long ago as the study of railroads by Fogel (1964) but the weighting scheme inherent in growth accounting clarifies why this is the case. ICT is historically remarkable and the Solow productivity paradox was a mirage. Third, it is well worth considering to whom and how the benefits of new technology accrue. This draws attention to the point that, in the medium term, the users are typically the big gainers and that some of their consumer surplus comes from the 'new-good' attributes of the technology.

Economic historians have been right to emphasize the importance of what Abramovitz and David (1996) called 'social capability' and 'technological congruence' in understanding when countries are able to benefit from new technology. Incentive structures are clearly central to understanding the development and, much more importantly, the diffusion and effective assimilation of new technologies. Given that the development of new technology is concentrated in relatively few countries and is influenced by its expected profitability in the home market, it is perhaps not surprising that this technology is sometimes 'inappropriate' in other parts of the world. This is important for the understanding of episodes both of falling behind and of rapidly catching up. Moreover, the effective use of new technologies depends on institutions and it must be acknowledged that the requirements of different technological eras are not the same. As the post-war economic history of Europe shows, the policy implications of this are important but not easy to address.

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Table 1. Sources of US Labour Productivity Growth Over the Long Run (% per year)

	Labour Productivity	*Capital Deepening*	*Crude TFP*
1800-1855	0.4	0.2	0.2
1855-1890	1.1	0.7	0.4
1890-1905	1.9	0.5	1.4
1905-1927	2.0	0.5	1.5
1929-1948	2.0	0.1	1.9
1948-1966	3.1	0.8	2.3
1966-1989	1.2	0.6	0.6
1990-2003	1.8	0.9	0.9

Note: these estimates are obtained by the various authors on the basis of equations using the specification of equation (4).
Sources: Abramovitz and David (2001) except for final period from Bosworth and Collins (2003) updated by authors.

Table 2. Sources of Labour Productivity Growth in Industrializing Economies (% per year)

	Labour Productivity Growth	*Capital-Deepening Contribution*	*TFP Growth*
Austria			
1870-1890	0.90	0.64	0.26
1890-1910	1.69	0.66	1.03
Germany			
1871-1891	1.10	0.39	0.71
1891-1911	1.76	0.58	1.18
Great Britain			
1700-1760	0.40	0.14	0.26
1760-1801	0.20	0.07	0.13
1801-1831	0.50	0.10	0.40
1831-1873	1.25	0.35	0.90
1873-1913	0.90	0.38	0.52
Hungary			
1870-1910	1.65	1.18	0.47
Italy			
1920-1938	0.88	0.38	0.50
1951-1973	4.51	1.61	2.90
Netherlands			
1850-1870	1.02	0.50	0.52
1870-1890	0.94	0.61	0.33
1890-1913	1.35	0.46	0.89
Portugal			
1910-1934	1.17	0.09	1.08
1934-1947	0.78	0.90	-0.12
1947-1973	4.47	2.46	2.01
Spain			
1850-1883	1.2	1.0	0.2
1884-1920	1.0	0.7	0.3
1920-1929	2.0	0.6	1.4
1930-1952	0.0	0.3	-0.3
1951-1974	5.5	1.8	3.7
Sweden			
1850-1890	1.18	1.12	0.06
1890-1913	2.77	0.94	1.83
1913-1950	2.01	0.87	1.14
1950-1973	3.68	1.82	1.86
Korea			
1960-1990	5.06	2.84	2.22
Singapore			
1960-1990	4.97	3.34	1.63
Taiwan			
1960-1990	6.07	3.17	2.90

Notes: all estimates based on standard neoclassical formula and are re-calibrated with á = 0.35; Great Britain is UK after 1831.
Sources: derived from data presented in the following original growth accounting studies: Austria and Hungary: Schulze (2007); Germany: Broadberry (1998); Great Britain: Crafts (1995) and Matthews et al. (1982); Italy: Rossi et al. (1992); Netherlands: Albers and Groote (1996); Portugal : Lains (2003); Spain: Prados de la Escosura and Roses (2009); Sweden: Krantz and Schon (2007) and Schon (2004); Korea, Singapore and Taiwan: Bosworth and Collins (2003).

Table 3. Accounting for Growth in Maddison's Six-Country Study (% per year)

	France	***Germany***	***Japan***	***Netherlands***	***UK***	***USA***
1913-1950						
Y/HW Growth	2.01	1.05	1.72	1.58	1.57	2.42
K/HW	0.59	0.19	0.62	0.43	0.42	0.43
TFP	1.42	0.86	1.10	1.15	1.15	1.99
Capital Quality	0.45	0.45	0.45	0.45	0.45	0.45
Labour Quality	0.36	0.22	0.61	0.27	0.32	0.35
Capacity Use	0.00	-0.13	-0.24	0.00	0.00	0.00
Labour Hoarding	0.00	-0.20	-0.56	0.00	0.00	0.00
Catch-Up	0.00	0.00	0.00	0.00	0.00	0.00
Structural	0.09	0.20	0.62	0.00	-0.04	0.29
Foreign Trade	0.01	-0.04	0.02	0.05	0.00	0.01
Scale	0.03	0.04	0.07	0.07	0.04	0.08
Other	0.00	0.00	0.00	0.00	0.00	0.00
Unexplained	0.48	0.32	0.13	0.41	0.38	0.81
1950-19 73						
Y/HW Growth	5.12	5.96	7.82	4.44	3.18	2.50
K/HW	1.10	1.64	2.02	1.09	1.04	0.65
TFP	4.02	4.32	5.80	3.35	2.14	1.85
Capital Quality	0.56	0.53	0.58	0.57	0.52	0.51
Labour Quality	0.35	0.18	0.52	0.40	0.09	0.29
Capacity Use	0.00	0.25	0.39	0.00	0.00	0.00
Labour Hoarding	0.00	0.32	0.90	0.00	0.00	0.00
Catch-Up	0.52	0.68	1.02	0.38	0.14	0.00
Structural	0.46	0.36	1.22	-0.07	0.10	0.12
Foreign Trade	0.19	0.21	0.26	0.65	0.16	0.05
Scale	0.15	0.18	0.28	0.14	0.09	0.11
Other	-0.02	-0.02	-0.02	0.22	-0.02	-0.04
Unexplained	1.81	1.63	0.64	1.06	1.06	0.81

Source: derived from Maddison (1987).

Table 4. Decomposition of Cross-Country Differences in GDP per Person, 2005. (USA = 100)

	Y/P	***TFP***	***HK/L***	***K/Y***	***L/P***
USA	100	100	100	100	100
Canada	83.5	72.0	103.3	105.8	106.0
Australia + NZ	78.3	64.1	101.5	114.8	104.5
Japan	72.6	52.6	100.4	130.7	105.1
EU27 + EFTA	64.7	67.8	91.2	114.1	91.3
Russia	28.6	31.5	84.9	97.4	99.3
Brazil	20.5	29.3	70.1	103.1	96.8
China	9.8	13.6	57.3	105.2	119.5
India	5.2	12.7	47.7	98.3	87.1
Rest of World	12.3	20.9	59.7	103.6	81.7
World	22.8	27.9	64.2	104.2	95.8

Notes: Y/P is measured at PPP.
Estimates derived by imposing the production function $Y = K^{\alpha}(AhL)^{1-\alpha}$ where h is human capital per worker.
This can be re-written as $Y/L = (K/Y)^{\alpha/(1-\alpha)}Ah$ so that $Y/P = (K/Y)^{\alpha/(1-\alpha)}Ah(L/P)$ which is the formula used for the decomposition.
Source: Duval and de la Maisonneuve (2009).

Table 5. Technology and Efficiency as Sources of TFP Growth, 1960-1995 (% per year)

a) Rates of Growth

	TFP Growth	*Efficiency*	*Technology*
Ireland	1.95	0.92	1.03
Italy	1.54	0.60	0.94
Spain	1.38	0.39	0.99
Hong Kong	3.06	2.08	0.98
Japan	1.83	0.96	0.87
Korea	2.05	0.81	1.24
Singapore	2.57	1.75	0.82
India	0.75	0.20	0.55
Congo	-2.93	-2.52	-0.41
Tanzania	-0.17	-0.79	0.62
Zambia	-1.51	-1.52	0.01

b) Levels

	1960			***1995***		
	TFP	***E***	***T***	***TFP***	***E***	***T***
Ireland	0.51	0.55	0.93	0.74	0.76	0.98
Italy	0.67	0.71	0.94	0.84	0.88	0.96
Spain	0.64	0.74	0.86	0.76	0.85	0.90
Hong Kong	0.41	0.47	0.88	0.89	0.98	0.91
Japan	0.48	0.56	0.86	0.68	0.79	0.86
Korea	0.33	0.37	0.88	0.49	0.49	0.99
Singapore	0.47	0.54	0.87	0.85	1.00	0.85
India	0.30	0.41	0.74	0.29	0.44	0.67
Congo	0.38	0.58	0.65	0.10	0.24	0.41
Tanzania	0.15	0.22	0.69	0.11	0.17	0.64
Zambia	0.30	0.34	0.88	0.13	0.20	0.67

Note:
The decomposition is based on assuming a production function $y_i = A_i k_i^{\alpha} h_i^{1-\alpha}$, $A_i = T_i E_i$ and $T(k_i, h_i)$ as in Figure 1b. α is assumed to be 0.33 and efficiency, E_i, is calculated from a data envelopment analysis. Then, technology, T_i, is backed out from $= A_i/E_i$ where all variables are measured relative to the United States = 1.

Source: derived from Jerzmanowski (2007); additional observations kindly provided by author.

Table 6. Steam and ICT Contributions to Labour Productivity Growth (% per year)

a) Steam in UK

	1760-1800	*1800-30*	*1830-50*	*1850-70*	*1870-1910*
Capital Deepening	0.004	0.02	0.16	0.20	0.15
TFP Growth	0.005	0.00	0.04	0.21	0.16
Total	0.01	0.02	0.20	0.41	0.31

b) ICT in US

	1973 -95	*1995-2000*	*2000-2006*
Capital Deepening	0.46	1.09	0.61
TFP Growth	0.28	0.75	0.51
Total	0.74	1.84	1.12

Note: 'steam' includes stationary steam engines, railways and steam ships; 'ICT' includes semi-conductors, computer hardware and software and telecommunications equipment. Estimates based on a growth accounting formula which distinguishes between ICT or steam capital deepening and other capital deepening with appropriate factor-share weights, and, using Domar weights, between TFP growth in ICT or steam power production and other TFP growth.

Sources: Crafts (2004); Oliner et al. (2007)

Table 7. Social Gains from Railways, 1912 (%GDP).

	Spain	***UK***
User Benefits	4.3	12.5
Supernormal Profits	0.3	-0.5
Memorandum Item		
Net Revenue	1.6	1.9

Source: Herranz-Loncan (2006), Mitchell et al. (2009).

Table 8. Levels and Rates of Growth of Real GDP/Person in Western European Countries ($1990GK and % per year)

	1950	*1973*	*1950-1973*
Switzerland	9064	18204	3.08
Denmark	6943	13945	3.08
UK	6939	12025	2.42
Sweden	6739	12494	3.06
Netherlands	5971	13081	3.45
Belgium	5462	12170	3.54
Norway	5430	11324	3.24
France	5271	13114	4.04
West Germany	4281	13153	5.02
Finland	4253	11085	4.25
Austria	3706	11235	4.94
Italy	3502	10634	4.95
Ireland	3453	6867	3.03
Spain	2189	7661	5.60
Portugal	2086	7063	5.45
Greece	1915	7655	6.21

Source: Maddison (2003)

Table 9. ICT and Post-1995 European Productivity Growth

a) Decomposition of Labour Productivity Growth, 1995-2004 (% per year)

	Labour Productivity Growth	***Labour Quality***	***ICT Capital Deepening***	***TFP Growth***	***Knowledge Economy***
France	2.0	0.4	0.5	0.8	1.7
Germany	1.6	0.1	0.5	0.3	0.9
Italy	0.5	0.1	0.3	-0.4	-0.1
Spain	0.2	0.4	0.3	-0.9	-0.2
UK	2.7	0.5	1.0	0.7	2.2
USA	3.0	0.3	0.8	1.4	2.5

Note: estimates are for market sector and knowledge economy is sum of labour quality, ICT capital-deepening, and TFP.

Source: van Ark et al. (2008)

b) Contribution of ICT-Using Services to Aggregate Labour Productivity Growth, 1996-2001 (% per year)

France	-0.1
Germany	0.1
Italy	0.1
Spain	0.1
UK	0.8
USA	1.3

Note: ICT-using services include financial services and distribution.
Source: Nicoletti and Scarpetta (2005).

Table 10. Regulation Indices (0-6)

a) Product Market Regulation

	1978	*1988*	*1998a*	*1998b*	*2003*	*2008*
France	6.0	5.8	4.3	2.52	1.75	1.45
Germany	5.2	5.1	2.8	2.06	1.60	1.33
Italy	5.8	5.8	4.7	2.59	1.81	1.38
Spain	5.0	4.9	3.5	2.55	1.68	1.09
UK	4.8	3.8	1.4	1.07	0.82	0.84
USA	3.7	2.4	1.6	1.28	1.01	0.84

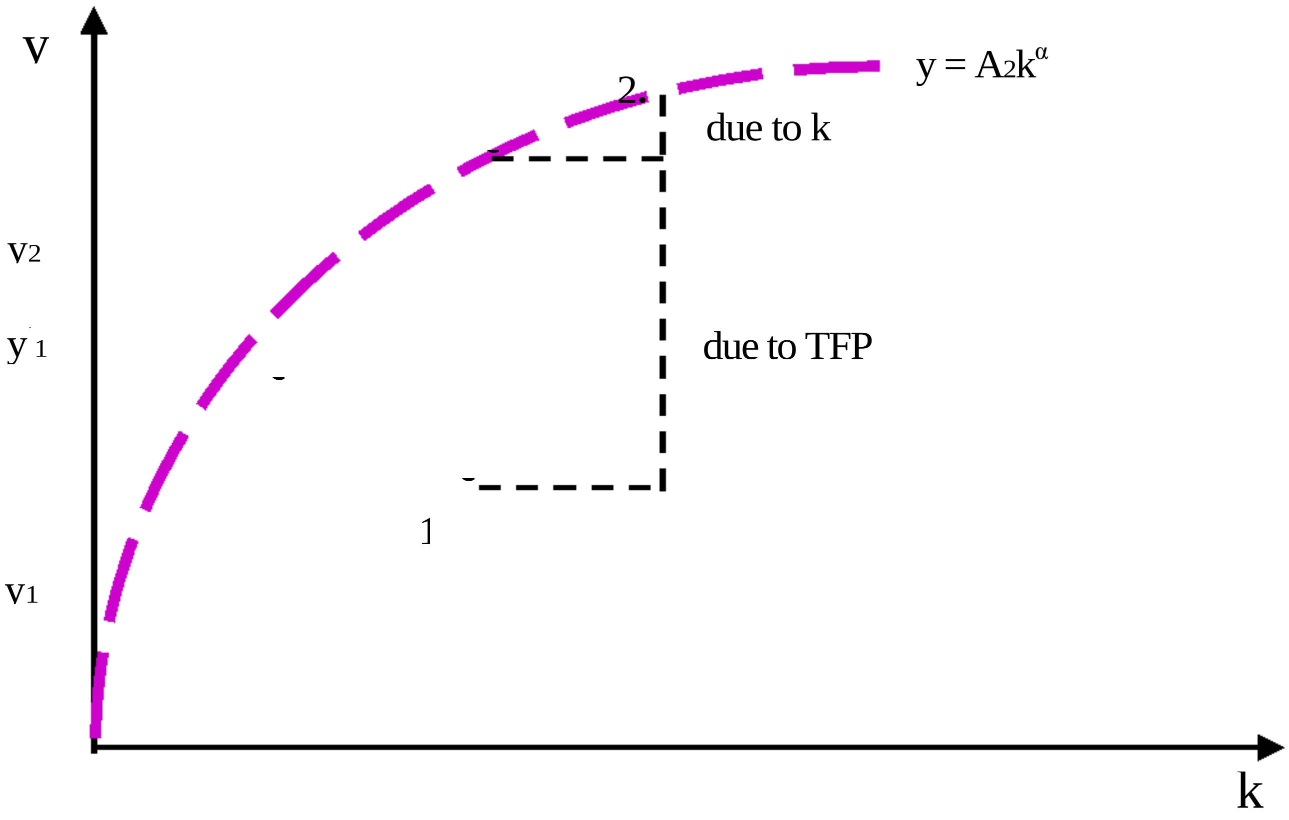
Note: the years 1978 through 1998a and 1998b through 2008 are each on a comparable basis; product market regulation is conceptualized as regulation that inhibits competition. A higher score indicates more regulation.
Sources: Conway and Nicoletti (2006); Wolfl et al. (2009)

b) Employment Protection

	1960-4	*1973 -9*	*1988-95*	*1998*	*2003*
France	1.11	3.63	4.23	4.20	4.20
Germany	1.35	4.95	4.56	3.90	3.36
Italy	5.76	6.00	5.67	4.50	2.91
Spain	6.00	5.97	5.22	4.20	4.50
UK	0.48	0.99	1.05	1.05	1.05
USA	0.30	0.30	0.30	0.30	0.30

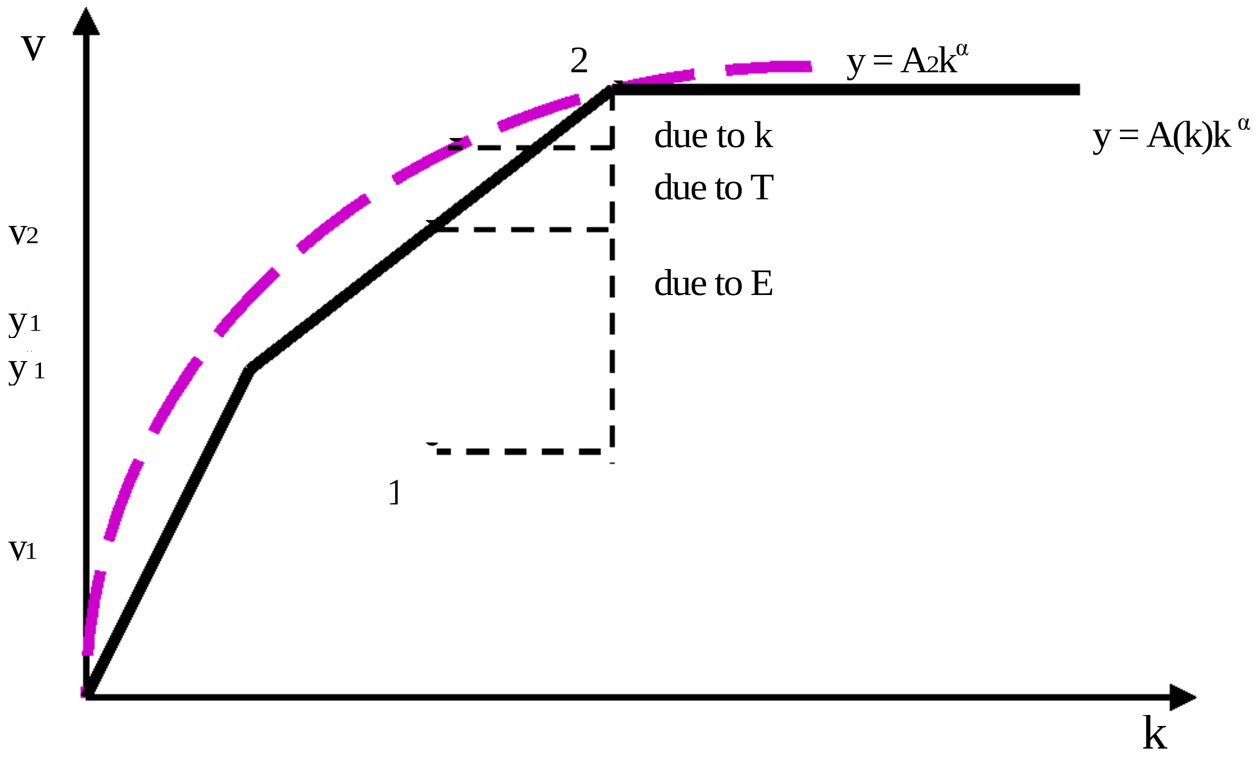
Note: 'employment protection' is conceptualized as equivalent to a tax on labour force adjustment. A higher score indicates more employment protection.
Source: Nickell et al. (2005)

Figure 1a: Decomposition of Output Difference between Countries 1 & 2 under Appropriate Technology



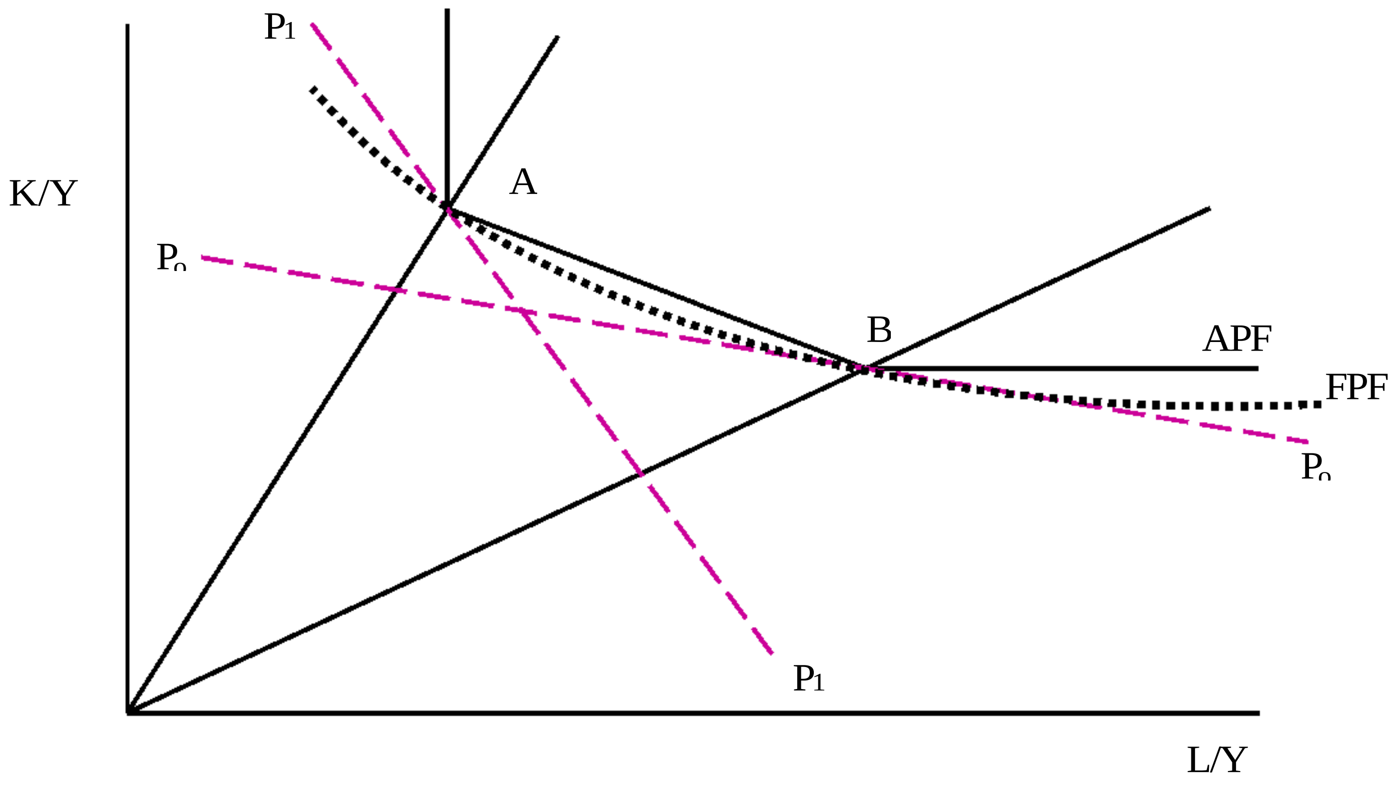
Source: Jermanowski (2007).

Figure 1b: Decomposition of Output Difference between Countries 1 & 2 under Inappropriate Technology



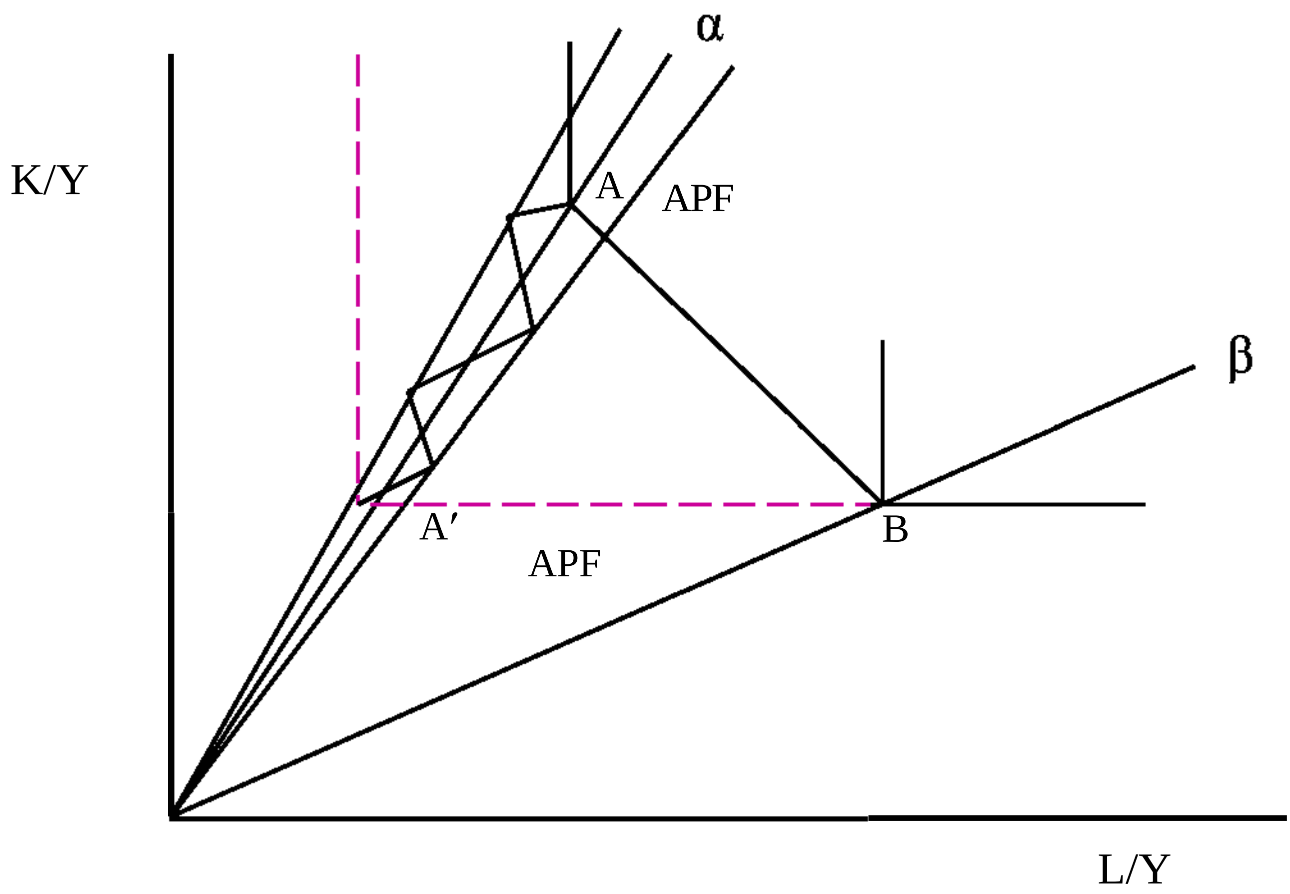
Source: Jermanowski (2007).

Figure 2a: Choice of Technology: the Role of Factor Prices



Source: David (1975).

Figure 2b:Technical Progress: Localised Change



Source: David (1975).