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Growth Theory and Industrial Revolutions in Britain and America

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Abstract: Long run economic growth has again become a major focus of economic theory. A perception of technological change as an economic process with externalities has motivated the development of aggregate models that generate different steady state growth paths. Economic history has also long been interested in long-run economic growth. This paper engages in a dialog between growth theory and the historical literature on the industrial revolution in Britain and America's surge to international economic leadership in the late nineteenth century. It concludes that economists' recent thinking about the microeconomics of technological change has provided fruitful material for the economic historian of growth. Unfortunately, the models of endogenous growth, on the other hand, present too aggregated a view of the economy to prove helpful when confronted with the details of economic history.
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> "The Industrial Revolution marks the most fundamental transformation of human life in the history of the world recorded in written documents."
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> Hobsbawm, E. J. *Industry and Empire* (1968)
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> "The consequences for human welfare involved in questions [of growth rate differences] are simply staggering: Once one starts thinking about them, it is hard to think about anything else."
>
> Lucas, R. E. Jr. "On the Mechanics of Economic Development" JME 22 (1988)

Eric Hobsbawm and Bob Lucas explore the emergence of modern economic growth and its uneven incidence from two very different traditions. Hobsbawn, a traditional economic historian, grounds his understanding firmly in documented evidence. In contrast, Lucas, an economic theorist, creates an analytical framework to represent the growth process and then explore the implications of the analytical model. Neither of these approaches seems entirely adequate. Hobsbawm invokes telling examples to support a narrative. Lucas relies on scarcely tested aggregate models. I want to present an historian's short contribution to dialog between these two traditions.

Were I limited to Hobsbawm's or Lucas' approach, I would probably side with Lucas. After all, economic growth is an aggregate process and failure to keep the aggregate clearly in mind leads to confusion. We are not, however, so limited. Economic history tied to national income concepts, but not confined to examination of simple aggregates, has contributed to our understanding of economic growth and I want to highlight some historical literature within the context of "new" growth models. It is not my intention to contribute to growth modelling here, but I do want to explore relationships between recent trends in growth modelling, conceived very generally, and the economic history of two of the most significant historical examples of the emergence of modern economic growth – that of Britain during the industrial revolution and that of the United States as it achieved per capita income dominance in the late nineteenth century. The disruption of ordinary growth patterns between

1914 and, say, 1970 by the twentieth century's wars and their consequences imparts particularly relevance to examination of this historical period as it constitutes a significant part of the record of modern economic growth that we have available.

1. Growth models

I see two fundamental motives in modern growth economics, one that we might term microeconomic and one macroeconomic. Growth economics in the 1950s and 60s yielded the Solow (1956) neoclassical growth model (and its variants) that explored the implications of capital formation. Such a growth model tends, rather quickly, towards a steady state with a constant capital labour ratio and constant per capita income. In steady state, growth in per capita income occurs as unexplained technological change increases the effective stock of labour per capita. Empirical growth accounting exercises in the spirit of these growth models – starting with Solow (1957) article – showed that a simple neoclassical model did not explain much of twentieth century per capita income growth. Rather, most growth came from an unexplained 'residual'. This residual connects, somewhat loosely, to technological change. To have the main cause of economic growth unexplained and exogenous was clearly unsatisfactory. The revived growth economics in the late 1980s focused on technological change and its implications. Growth economics, although motivated by the microeconomics of innovation, has focused predominately on macroeconomic aggregate growth models in which differences in steady state growth rates arises from explicitly modelled features.

David Romer points out in his recent textbook (2001, p.98) that new growth models "differ from the earlier models in explicitly interpreting the effectiveness of labor as knowledge and in formally modeling its evolution over time. We will analyse the dynamics of various views concerning how knowledge is produced and what determines the allocation of resources to knowledge production." Study of the nature and origins of new technology has long been a mainstay of economic history and new growth analysis has advanced our understanding by systematically explored a number of issues. First and foremost, innovation is seen as a purposeful economic activity that involves an investment of resources in anticipation of future payoff. Technology is not, however, a simple commodity. Its discovery inherently involves fundamental uncertainty (Rosenberg, 1998). Market failure arises form the public-good nature of new knowledge that reduces the payoff that innovators can capture. Consequently, investment tends to be under provided. Patent rights and public provision of basis research provide offsets. Some models see innovation produced by a decreasing-cost technology (due to large initial sunk costs) and explore the implications of the monopolistic competition that can arise. Other work explores technological change in a network framework that focuses on externalities arising from initial breakthroughs. These externalities often give advantages to the original developers of a technology that latecomers find it hard to overcome. On the other hand, the path dependence that provides advantages in developing a particular line of technology may also inhibit the development of new ideas. The creation of new technology with externalities, path-dependence, monopolistic competition and increasing returns to scale create the possibilities of multiple equilibria and provide fruitful stories for historians to explore.

Macroeconomists' new growth theory has not dwelt on the microeconomics of innovation but mainly takes the form of aggregate models. Observation that recent growth experience has been "divergence big time" (Prichett, 1997) motivates a focus on dynamic models whose structure can generate different steady-state growth paths. The models incorporate investment in innovative activity with some form of technological externality that yield varying endogenous steady-state growth rates thus potentially providing appropriate tools to study of the effect of possible policy or environmental changes on growth performance.

Analytical tractability, of course, places constraints on theorists' models. The models, with sophisticated dynamic behavioural assumptions, are highly aggregated. Usually output is modelled as a single good (although for some purposes some tractable desegregation is introduced) and technology change assumed to act very broadly on production of the aggregate good – that is to say in Harberger's (1998) terms, technology acts like a yeast, leavening the entire economic process, rather than like mushrooms popping up here and there. A representative agent (usually) owns factors of production and make long term allocation and consumption decisions either as an infinitely lived agents (what Solow (2000) refers to as infinitely lived peasant families) or in the context of an overlapping generations model. There is, of course, room to question the realism of the *ad hoc* modelling assumptions adopted to achieve tractability.

The modellers' interest in persistent effects and the desire for tractability usually leads the model to be analysed in its steady state. An economic historian may well ask how well these models help us understand important past growth experience. He may worry about how time is treated. For example, in an overlapping-generations model that takes, say, five periods to approach the steady state after a policy change, we are comparing steady states separated by about a century and a half while assuming unchanged background conditions. More generally, can the aggregations be accepted as reasonable simplifications because the insights that the models provide help deepen understanding? Or should we be cautious about drawing conclusions from these models?

2. British Industrial Revolution

Figure 1 illustrates the historian's perspective on modern economic growth. In the century centred on 1800, the British economy shifted from one dominated by Ricardian forces, where real wages related inversely to population size, to a modern economy, with population and real wages growing simultaneously at unprecedented rates. Much of my research has used economists' tools to study the British industrial revolution that coincided with this shift.

Modern thinking on technological change helps to understand the industrial revolution. The initial breakthroughs in textile, iron and steam technologies arose from concerted search for innovative solutions but the magnitude of the technological gains were often fortuitous and unpredictable. Network economies were central to Britain's increased technological leadership in textiles and iron in the early nineteenth century and the persistence of these sectors as key export industries until the First World War. First mover advantages generated skills and externalities. Network effects allowed high-wage Britain to remain the world's low-cost cotton textile producer at the end of the nineteenth century even though the technology was now well established – even widely available with technical support from British textile machine-builders. The technological networks of the industrial revolution, however, extended over only a limited portion of the economy. Nick Crafts (2002) has recently investigated the extent of the contribution of steam power, often cited as a general-purpose technology, to growth between the industrial revolution and the First World War, in an analysis that considers both the direct effect on total factor productivity and induced investment. He finds that the technology had its greatest impact as railroads expanded in the middle decades of the nineteenth century. Even at its peak contribution between 1850 and 1870, however, steam technology accounted for only about 0.4 percent per year to an aggregate annual growth rate of close to 2.5 percent.

Aggregated growth models, although providing a useful framework and the underlying logic of growth accounting, offer only limited insights into this history. Technology change was just too disaggregated – mushroom-like rather than yeast-like – and, as general equilibrium might predict, market responses to varied to support the kind of aggregation the growth models demand. Nick Crafts and I have analysed the industrial revolution with computational general equilibrium models and find disaggregation indispensable. The computational model, however, allows us to stay in touch with the aggregate economy.

Deane and Cole's (1962, 1967) pioneering estimates of British historical national income indicated that growth accelerated rapidly beginning in the last quarter of the eighteenth century. In the 1960s, analysis of these national income figures, combining aggregate and industry-level total-factor productivity calculations suggested that a widespread process of technological change generated growth. This supported an idea of a generalized (yeast-like) process of technological change consistent with an aggregate production function (Hartwell (1971), McCloskey (1981)). In the early 1980s, however Nick Crafts (1985) and I (Harley (1982; 1993); Crafts and Harley (1992)) separately re-examined the estimates of British growth in the half-century after 1770. Our results (now broadly accepted) challenged the prevailing 'balanced' growth view of the Industrial Revolution. Growth was much more concentrated in the 'famous sectors' (textiles, iron and engineering) in our results and aggregate growth was much slower than economic historians had thought. An implication of this finding was that technological change could not been seen as a generalized process but had only localized (mushroom-like) impact. This view of technological change challenged the utility of thinking in terms of an aggregate production function.

In our view, the Industrial Revolution consisted crucially of structural shift. Technological change was far from general and Britain became an urban industrial society by 1850 not through a process generalized productivity improvement that significant increased living standards, but by a process of specialization and international trade. The export industries, particular cotton textiles, grew rapidly. Britain became a trading nation whose consumption and production diverged significantly and, unusually, British agriculture declined rapidly as a portion of the overall economy. Agricultural products increasingly came from overseas, financed by the exports of a few particular industries that took on important in the economy far beyond their share in domestic consumption. At the same time labour left the farms for the cities but per capita income grew only slowly.

As our attention focused on structural change, it became appropriate to think in general equilibrium terms. Computational general equilibrium models provided a way to proceed and I developed a series of model to think about the evolution of the British economy. I started (1993) with a very simple model, benchmarked on national income estimates for 1841 (the earliest relatively reliable occupational census data), with limited disaggregation. My goal was to reconcile the findings of agricultural and economic historians that technological advanced rapidly in British agriculture during the eighteenth and early nineteenth century– probably more rapidly than total economy total factor productivity growth – with the marked shift in economic structure away from agriculture during the same period. The model contained two economies, Britain and the rest of the world. In each a single representative consumer owned factors and maximized utility. Production in each economy was disaggregated into four sectors: agriculture (with technological change and internationally traded), a 'famous' industrial sector (that experienced rapid technological change and traded with the rest of the world), a non-traded industrial and a service sector (both of which did not experience technological change). The model indicated that agricultural diminishing returns in the face the more than doubling of British population more than offset the effect of agricultural productivity improvements and were a major driving force in structural change.

In 1998, Peter Temin (1998) produced an argument based on a Ricardian trade model that reasserted a more traditional view of broadly based technological change (which is more compatible with macro growth models). He pointed out that mid-nineteenth century Britain's exports were not confined to the 'famous' industries but were broadly based across the industrial spectrum and he inferred broad technical change. In response, Crafts and I (2000) elaborated the CGE model to incorporate more detail in international trade. We disaggregated the manufacturing sector into cotton textiles, other textiles, metal industries, other traded manufactures and non-traded industry to investigate the trade structure in greater detail and to model different productivity advances across industries. In addition, more detailed attention to international trade necessitated explicit modelling of the fact that in 1841 raw cotton, the great cotton textile export-industry's raw material, made up nearly ten percent of British imports. The model showed that (mushroom-like) technological change concentrated primarily in the 'famous' industries was consistent with the observed pattern of British trade and broad-based (yeast-like) technical change probably was not.

Our analysis shows that relative price changes produced by the technological change and by diminishing returns in British agriculture were central. By the 1780s the new spinning technology had lowered cotton textile production costs substantially. Competition, initially often ignoring Arkwright's patents, responded to profit opportunities and output expansion drove down prices. Sales boomed, at home and abroad, in response to lower prices. Technological change similarly affected some other manufacturing industries that also produced exportable goods. At the same time, British population approximately doubled, and the accompanying demand for food potentially placed severe pressure on Britain's land resources. The newly cheap British goods attracted foreign buyers and presented the opportunity to overcome the effects of agricultural diminishing returns, transforming Britain into an urban industrial society in the process. The new exports, however, did not displace exports of traditional industries that had not undergone technical transformation because the falling prices of the growth industries limited the foreign resources they could command. With rising population, imports of food still required other exports. The price and quantity response to technological change, of course, created a classic index number problem that challenges the appropriateness of aggregation.

. Britain's initial technological breakthrough and the subsequent maintenance of leadership in industrial technologies, however, only partially explain the economy's precocious industrialization. Britain's agriculture was as distinctive as its industry and probably played a larger role in causing industrialization and income growth. Computational general equilibrium examination of difference between mid-nineteenth century Britain and the other advanced economies of the time, shows that the great export industries driven by technological explain less than differences in agriculture's retention of labour (Crafts and Harley (2003)). Nineteenth century British agriculture, of course, was unusual. It lacked peasants, so common elsewhere (including America of which I will say more later), and a capitalist structure of landlords, tenants and proletarian labourers dominated the sector. The implications went beyond the sociology of class and greatly influenced economic behaviour and structure.

Some simple statistics provide a starting point to thinking about this issue. In Britain in 1840, the share of the labour force and of national income generated in the primary sector were very nearly equal at 25 percent, implying equal labour productivity in agriculture and the rest of the economy on average. In European economies at Britain's 1841 per capita income, on average 55 percent of the labour force worked in the primary sector but produced only 38 percent of national income (Crafts, 1986, pp. 55-6). Elsewhere in Europe, then, labour productivity in the primary sector was only about half that of the rest of the economy. The difference probably arose because a neoclassical labour market model prevailed in British capitalist agricultural but not in peasant agriculture elsewhere. A peasant farm appears to have retained labour until the earnings per family member fell below the wage in the non-agricultural alternative. As a consequence, British agriculture generated significant land rents (about 40% of agricultural income) and allocated labour between agriculture and the rest of the economy on the basis of the marginal product of labour. Peasant systems, in contrast, tended to dissipate land rents by keeping labour on the farm after its marginal product fell below that elsewhere. We have investigated the role of industrial technology and this difference in the agricultural labour market in Britain's industrialization with our computational general equilibrium model, suitable modified to separate the peasant from non-peasant labour and to recognize a wealth holding class. As Table 1 shows, we find that differences in the agricultural labour market (line 2) had more influence than technological change (line 1) in generating British industrialization. Britain's efficient labour allocation let to an increase in per capita income, but it distributed income to wealth owners and resulted in little gain in real wages.

Despite our desire for parsimonious modelling Crafts and I have found that we have had to disaggregate considerably. We find that we need eight goods/sectors (cotton, other textiles, metal industries, other industrial traded goods, non-traded industrial goods, agriculture, services and imported tropical goods) to model technology and trade. In addition, peasant agriculture has led us to introduce three 'classes' of consumers/factor owners. We have also found it impossible to model cotton textiles simply in value added terms and have had include imported raw cotton as an intermediate good. In addition, since trade was central to industrial Britain, we have considered domestic and foreign production of these various goods as imperfect substitutes (an Armington specification). Higher levels of aggregation eliminate key features of British industrialization. Technology change can not be modelled adequately as neutral shift in an aggregate production function. In addition, the contrast between capitalist and peasant agriculture frustrates simple aggregation of labour.

While theories of innovation help illuminate microeconomic aspects of the industrial revolution, new growth theory then does little to help understand Britain's lead in income and industrialization. In the aggregate, understanding British growth requires a focus on different rates of technological change across economic sectors, the microeconomics of labour markets and the working of allocation mechanisms within the economy. Growth models that focus on a global aggregate have limited explanatory content.

Perhaps, however, growth theory has a contribution and we should take a somewhat different perspective. The technological changes of the industrial revolution were localized and inadequate to generate higher steady state growth rates. But persistent higher growth rates did emerge, and this, as growth models suggest, indicate a shift in the aggregate process generating technology. If we accept this idea, however, it seems unlikely that we will not find the 'yeast' in the actions of firms took to generate specific technology. The important changes seem more likely to have been changes in the institutional structure of the state and society that provided incentives and property rights that encouraged innovation and investment. These changes were to be found in the rise of the particular British constitutional state and were caused by social and political processes not by the mechanical inventions we usually focus on (North (1981); North and Weingast (1989)).

3. The Second Industrial Revolution and American Leadership

The industrial revolution created an urban industrial society in Britain but was more clearly structural change in an open economy than accelerated growth. To be sure, as Figure 1 shows, Britain broke the inverse connection between population growth and real wages at this time; even though real wages did not increase much between 1770 and 1840 population doubled. Greg Clark (2001) has recently suggested that perhaps this should be seen as a regional concentration of activity rather than the beginnings of modern growth. Britain came to resemble a giant urban area within Western Europe, fed by imported foodstuffs from Ireland and the Baltic and with a cotton industry whose imports of raw materials freed it from constraints of land. He prefers to see the aggregate technological breakthrough to modern economic growth in the late nineteenth century and centred in the United States.

Certainly, as Table 2 shows, acceleration of per capita income, even in Britain, dates from the middle of the nineteenth century rather than to the late eighteenth century. On average the Western European economies began to converge on British levels of per capita income only late in the century and American growth surged after the Civil War. Convergence of European levels of per capita presents no surprise in the context of a Solow-type growth model. Economic historians (e. g. Landes (1969), Pollard (1981)) have emphasized technological diffusion as the driving force, which Gerschenkron (1962) elaborated with a theory of endogenous institutional change. America's surge to world economic leadership, however, does not fit the simple growth model and is thus much more interesting. In 1870 America's real per capita income lagged nearly a quarter below that of Britain, although it exceeded the European average by a fifth. A simple catching-up model would predict that the United States would have grown somewhat faster than Britain as it caught up, but somewhat slower than the Continental economies with their larger productivity gap. In fact, America overtook Britain and grew faster than Europe. In 1913 America's real per capita income exceeded Britain's by some eight per cent and had increased it lead over the Western European average to more than forty percent (Maddison, (2003)). America's surge, of course, continued in the twentieth century but the world wars and their consequences complicate analysis. Nonetheless, in 1950, American real per capita income was forty percent above that of the United Kingdom and close to double that of the average of the European economies. The data on America's surge to per capita income dominance will not surprise anyone familiar with the narratives of the economic history of the late nineteenth and early twentieth century. This was, after all, the period in which Americans developed mass-production techniques culminating in 'Fordism' and American firms developed new industrial organization that supported large, integrated firms capable of exploiting economies of scale and scope (Chandler (1977; 1997)).

America's surge to international dominance has long interested economic historians and some of their ideas connect to central ideas in growth theory. It is useful to organize the literature into three strands (although some of the most interesting contributions span more than one area). First, there were studies that drew on the basic neoclassical models of growth and trade. Second, disaggregate studies have traced relative national income growth. Third, the strand I find most interesting, has focused on the nature of technological change and argued that initial conditions and network economies directed technical change in America in a unique direction with important productivity consequence.

3.1 Neoclassical aggregate traverse

American growth accelerated dramatically after the Civil War ended in 1865. Aggregate output, supported by population growth of over two and a half percent annually, grew at close to five percent per year in the 1870s and 1880s. Growth rates slowed somewhat in the following decades but America continued to grow decisively faster than the rest of the world. Peter Temin (1971) pointed out that this growth could be seen as the traverse of a neoclassical economy in which investment dramatically increased. Robert Gallman (1986) showed that capital formation rates nearly doubled from between 14 and 16 percent of national income before the Civil War to between 22 and 28 percent thereafter. A sudden increase in capital formation, as occurred in the United States, will initiate a growth traverse from an initial steady state to a new higher income steady state. Capital per worker initially increases rapidly generating growth per capita. As the capital stock grows, however, its rate of growth slows, even though investment remains a high share of income, and the economy's growth rate returns to its steady state – set by labour force growth and technological advance. Nineteenth century America appears to have followed such a path (Table 3). Late nineteenth century aggregate growth was high because population growth was high and because the investment rate increased leading to a near doubling of the ratio capital stock per capita despite the rapid population growth. As the economy approached its steady state at the end of the century, the rate of growth slowed. Aggregate total factor productivity growth did accelerated during this period, but accounted for only about a fifth of the total growth of the economy, although, to be sure, it contributed much more to the growth of per capita income. Even so technological change explained less than half the growth of per capita income (Abramovitz and David (2001), A11-14).

The traverse caused by increased capital formation raises obvious questions about the changed rate of investment. Jeffrey Williamson (1974a, b) attributed acceleration of capital formation principally to Civil War financing. The North financed the war by debt and money issue along with increased taxation. After the war, taxes remained high and federal budget surpluses, after a brief period of retiring the greenback monetary issue, retired interest-bearing debt. Williamson argues the debt retirement "crowded in" investment in physical capital as wealth holders replaced claims on the government with claims on the physical capital stock. He did not does not consider issues of "Ricardian equivalence" – the fact that assets in the form of government liabilities create an offsetting liability in the form of the present value of future taxes. He pointed out, however, that the taxes retained from the Civil War, largely tariffs and excises, fell principally on consumption goods. Consequently future tax liabilities lay on a large base of taxpayers who accumulated few assets while a rich minority held the government debt. The higher savings rate was augmented by a sharp decline in the relative price of investment goods, allowing each dollar of savings to purchase a larger amount of physical capital. Williamson finds Civil War financing policy also caused the relative price change, pointing out that the tariffs increased consumption goods prices relative to capital goods.

Moses Abramovitz and Paul David (1973; 1996); David, (1977)) provided a somewhat different perspective on the roles of "thrift and the progress of invention" in the post Civil War growth spurt. They, too, see an investment-induced traverse in an aggregate growth model. However, their explanation of its underlying nature differs considerably from Williamson's because they integrate savings behaviour with technological change. They point out that interest rates fell only slightly in response to the doubling of the reproducible capital stock per capita during the late nineteenth century, and that the share of national income accruing to capital actually increased. They argue that the aggregate production function (at any particular level of technology) is unlikely to be characterized by an elasticity of substitution between capital and labour that exceeds unity. They propose, therefore, that technological change in late nineteenth century America had a capital-using bias that increasing the marginal product of capital (and profits) thereby providing an underlying cause of accelerated capital formation. As they conclude (1973, p. 437):

> In the terms of our parable of a single-sector economy, the long disequilibrium passage to higher wealth-income proportions which characterized the U.S. nineteenth century experience, therefore, is not properly regarded as the consequence of the greater exercise of Trift. To be sure, the real gross savings rate (conventionally defined) did rise dramatically, from about 10 percent before 1840 to 16 to 20 percent in the decades immediately preceding the Civil War, and thence to the 25 to 30 percent level in the period 1869-1899. And without the entailed rise in the net capital formation proportion, the approximate doubling of the capital-output ratio could not have been achieved. Yet, to conceive of this grand traverse simply as an equilibrating adjustment to an autonomous, exclusively supply-driven rise in the savings rate in relation to the growth rate of population and the labor supply would overlook the very reason for its having a potent effect in lifting the level of labor productivity instead of simply drastically depressing the real rate of return on capital. The historically conventional capital-deepening bias of technological progress, by exerting upward pressure on the real rate of return, in our view must have played some direct part in eliciting and maintaining the higher real savings rate established over the course of the century.

They also point out the historically specific nature of their characterization of the late nineteenth century growth. Capital-using technological change stimulating the formation of physical capital gave way in the twentieth century to technological change that increased the value of human capital. Human capital using technology, in a similar manner, supported massive increases in educational attainment that have characterized twentieth century America (and other advanced economies).

3.2 Neoclassical globalization

In the late nineteenth century trade expanded and impressive globalization occurred. Kevin O'Rourke and Jeffrey Williamson (2000), with other contributors, have examined the era in terms of neoclassical trade theory. They observe that real incomes, and particularly real wages, converged among the countries that now make up the OECD that they attribute relative income movements in the late nineteenth century to globalization. Product markets integrated as falling transportation costs and reductions of trade barriers caused product prices to converge – in particular European food prices fell. Specialization of production increased, raising the real incomes of abundant factors, and factor prices converged. Globalization of labour markets and the resulting emigration from densely populated Europe to the New World caused an even more convergence of real wages. Globalization of capital markets furthermore contributed to convergence, but with somewhat smaller impact.

O'Rourke and Williamson draw strong conclusions about the strength of neoclassical convergence forces primarily from a series of panel regressions among countries. Close examination reveals that the wage experience of a few countries drive the regression relationship and globalization forces were much less apparent elsewhere. In Ireland, Sweden and, at the very end of the pre-war years, Italy – all initially poor – emigration was associated with significant real wage increases relative to rich regions. At the other end of the wage spectrum, Australia, the richest country of the late nineteenth century, experienced real wage stagnation in conjunction with immigration flows. In most of Europe, however, there was little connection between globalization and income. In particular, Britain experienced very heavy immigration, which O'Rourke and Williamson see as the most powerful force affecting real wages, but also slow real wage gains.

Most strikingly, however, America's experience belies the neoclassical globalization story. To be sure, America's relative land prices rose in response to exports of land-intensive goods, but American relative real wages also rose in spite to the import of labour-intensive goods and, more importantly, massive inflows of immigrants. It is certainly hard to rely on a neoclassical analysis of nineteenth century globalization that emphasizes forces leading to convergence when the most important economy in the globalization does not conform.

Globalization effected America differently than O'Rourke and Williamson's neoclassical analysis predicts. As they make clear, falling transportation cost, which arose from technological change in iron production and steam power, drove globalization but neoclassical trade theory, which implicitly treats countries as single points, poorly captures the effects of these innovations in America. In America, globalization stimulated divergence forces rather than triggering convergence. Transportation cost driven globalization increased the relative resource abundance of already resource abundant American dovetailing well with Abramovitz and David's characterization of nineteenth century American technology as capital-using. Lower transportation costs gave value to America's vast interior resources, stimulating enormous investments in railroads, urbanization and other capital-using infrastructure in the decades after the Civil War. In America, technology opened opportunities in the continental interior that could be exploited in the increasingly globalized economy. At the same time, American industry developed new technologies and organization to take advantage of the continental market.

3.3 disaggregated growth analysis

Neoclassical studies at the aggregate level of growth or trade models hide important causal factors that acted in America at more disaggregated levels. Steven Broadberry (1997a, b, c) has examined America's overtaking British levels of output per capita and Germany's catch-up to Britain in greater detail. In both cases he finds that understanding the process requires disaggregated productivity analysis and that compositional features of national income played key roles. He finds, contrary to most expectation, that America's surge to international leadership during the late nineteenth century did not stem principally from faster growth of productivity in manufacturing. American manufacturing industries had already achieved labour productivity levels nearly twice that of their British counterparts by 1870. This productivity lead increased by about a quarter during the first half of the twentieth century but made only a small contribution to the surge that took America's aggregate output per employee from about 86 percent of Britain's in 1870 to 154 percent in 1950. Part of America's faster growth came from faster increases in productivity in agriculture and mining and services. Of equal importance, however, was the shift of labour in America from low productivity agriculture to higher productivity employment in manufacturing and elsewhere.

Reduction in agricultural employment was central to America's surge to leadership and harks back to comments I made about peasant agriculture earlier. In Britain, you will recall, output per worker in agriculture in the middle of the nineteenth century equalled that of workers elsewhere in the economy. In the aggregate statistics, American agriculture resembled Continental peasant agriculture. In the 1880s labour productivity in agriculture was only about sixty percent of that elsewhere in the economy. At the same time nearly half the labour force worked in agriculture. By 1929, although the labour productivity in agriculture remained about half productivity elsewhere in the economy, the proportion of the agricultural labour force had declined to just over a fifth of the total. Some of the lower output per worker in agriculture reflected cost of livings differences and compensation for higher unemployment elsewhere (Hatton and Williamson (1991a; 1991b)) but there also seems to have been a 'peasant' labour allocation similar to that in Europe. It seems paradoxical to see America agriculture, with its undoubted international comparative advantage and leadership in the application of labour saving farm machinery, as a peasant sector excessively hoarding labour, but statistics seem to indicate that this was the case. At any particular time, the productivity of labour in American agriculture was a declining function of its labour force. At the extensive margin in the western prairies additional labour may not have been less physically productive but it produced output of lower value because of the higher transportation costs when farming moved to more remote areas. At the intensive margin, a higher labour/land ratio lowered productivity. Family control of the "means of production" encouraged labour to remain on the farm until the earnings per family member of the farm fell below the wage in the non-farm sector. This dissipated the farm's rent and drove the marginal product per worker in agriculture below that in the non-agricultural sectors. As the farm sector became less important less potential income was dissipated and national income increased.

Broadberry's findings of the importance of compositional changes in America's growth surge highlight the need to consider compositional aspects of the economy and their evolution in analysing growth even over long periods of time. Similar aggregate growth from labour reallocation occurred in Continental Europe's rapid growth in the second half of the twentieth century (Denison (1967), Kindleberger (1967)) and in the rapidly growing Asian economies at the end of the century. However, although Broadberry's work directs attention to the composition of national income and the implications of sectoral redistribution, when all is said and done, America's success rested on high productivity outside of agriculture.

3.4 America's technological network

Although Broadberry shows that American manufacturing already had very high relative levels of productivity at the middle of the nineteenth century that increased only slightly over the next century, it is important to keep in mind that maintaining industrial leadership meant that American firms continuously developed new high productivity technologies. The manufacturing sector, which consisted of textiles and raw material processing at mid-century, developed new machinery-making and iron and steel sectors before the First World War and consumer durable industries in the twentieth century. Continued success in developing high productivity techniques in new industries suggests that we should seek yeast-like characteristics of technology that transcended individual sectors. Some of the most interesting research in American economic history has gone in that direction.

Mass-production manufacturing (Fordism) developed in America and historians have traced its development to distinctive American engineering practices before the Civil War. Although we take mass-production with interchangeable parts to be the natural method of industrial production, in fact, it took on its present form only with Ford's introduction of the moving assembly line for his Model T in 1913. Mass-production's roots are found much earlier, however. American techniques, particularly in gun-making and woodworking where machine-formed parts were replacing individually fitted parts, impressed British observers in the 1850s (Hounsell (1984)). An historical literature analyses why advanced machine technologies emerged in America in the early nineteenth century, where overall industrial techniques were relatively backward, before they appeared in Britain, whose engineering firms were undisputed technology leader. The modern discussion dates from Hrothgar Habakkuk's (1962) analysis of the American technological trajectory. He argued that land-abundance created high wages and led American firms to choose capital-intensive methods of production. He then proposed an endogenous process of technological change, rather in the style of Arrow's learning by doing, that led American technological change on a different path than that followed by the British. Leaning by doing with American capital-intensive technology proved particularly fruitful and led to technological leadership.

Peter Temin (1966) pointed out, however, that Habakkuk's argument contained a logical flaw. In an early application of a three-factor trade model, he demonstrated that Habakkuk's analytic structure contained two constant-returns sectors – agriculture used land and labour and land abundance led to high real wages; while industry used labour and capital. In this kind of model, the American manufacturing sector depended on tariff protection to raise manufactured goods prices. Real wages in manufacturing (measured in manufactured goods) could only have been higher than in Britain if real capital prices (capital goods, which were American manufactured goods, times the rental rate on capital) were lower. However, interest rates were higher in America than in Britain.

Temin's challenge sharpened the debate, but the prevailing view, although more complex, came to follow Habakkuk's initial surmise. Resolution arose from considering the choice of techniques in America more closely and extending the analysis of the manufacturing sector beyond a model of single good produced by two inputs (Ames and Rosemberg (1968), Rosenberg(1982; 1984)). Several elements caused American firms initially to choose different methods of production and continued to influence American practice throughout the century. American firms, protected by tariffs, developed techniques of production that favoured local factor prices and product markets. Temin correctly pointed out that capital was not particularly cheap in America. However, natural resources were abundant and cheap while skilled labour was expensive relative to the unskilled immigrants who made up most of the American industrial labour force after the 1840s (Harley (1974)). In addition, American's relatively high real wages (in terms of consumption goods) and modest class differences created a mass market for standardized manufactured goods. The 'American system of manufacturing' developed under these conditions. Firms adopted mechanized production because machine techniques, although they used expensive capital and were wasteful of (cheap) raw materials and energy, economized on expensive skilled labour. In addition, the economies of the machine techniques depended on high throughput of standardized goods. The tariff and America's income distribution provided a market for such goods. European firms did not find it profitable to follow the American lead. Raw materials were more expensive, skilled labour cheaper and mass markets for standardized products less developed.

A number of important studies have explored America's early nineteenth century technological choices and their implications in the establishment of a particular American technology in the nineteenth century (David (1975), Rosenberg (1963; 1982; 1994), Nelson and Wright (1992), Wright (1990; 1999)). The history of American technology exhibits characteristics central to endogenous growth. Gavin Wright has recently emphasized two features: "First, that technological progress was a network phenomenon, growing out of the actions of large numbers of interacting people–not necessarily in formally structured institutions of coordination. Second, that these networks were strongly national in character." (1999, p. 295). American industrialization began with the cotton industry, which consciously developed machines that could spin and weave coarse cloth while tended by young girls without depending on the British industry's skilled mule spinners and handloom weavers (Saxonhouse and Wright (1984)). America's engineering industry emerged from the machines the cotton mills built (and from government research in weapons armouries and military contacts). As Nat Rosenberg (1963) points out, the machine-tool firms became the vehicle for diffusion of the machine technology though out the economy. Machine-based production became widespread and when machine-makers solved specific production problems, they adapted the techniques to other uses. The high level of mobility of skilled innovators and their students within the machine-tool industry strengthened the network.

Initial conditions of industrialization set the stage for a particularly American learning by doing. America had chosen different techniques, often in industries that served tariff-protected homogeneous national markets. American technology evolved from this beginning. Machine development stimulated metallurgical and energy innovations. American techniques' heavy appetite for raw materials and energy stimulated the exploration and development of American mineral wealth (David and Wright (1997). The national character of the successful technological network partially reflected the relatively poor communications network of the nineteenth century and the lack of international educational and professional ties. More important, however, was the difference in the market conditions. Because American firms operated under different cost and market conditions than prevailed in Britain or elsewhere in Europe, the national character of its network externalities was reinforced. By the late nineteenth century, the America economy was much larger any other – a feature reinforced by the relative homogeneity of American demand. As a result, firms could extend specialization and reap accompanying productivity gains from large-scale operations. Scale effects, an idea that appears in several new growth models, played a significant role.

The American technological network developed new industrial organization to accompany mass-production and mass distribution. Firms increased in size and complexity to manage timely receipt of raw materials and the sale of large quantities of standardized output that characterized high through-put technology. As Alfred Chandler (1977; 1990) points out, large integrated American firms developed managerial structures and cultures to support mass-production. The network process intensified in the twentieth century, as the managerial culture of these large firms institutionalized research and development within the firms. Nat Rosenberg has recently documented network development in chemical engineering technology (Rosenberg, 1998). In the early twentieth century collaboration developed between faculty members at MIT and the petroleum industry that resulted in systematic innovation not only in the petroleum industry but also in other chemical industries. The collaboration between MIT and the petroleum firms established a precedent for networks combining university and industrial research, which have become central to modern industrial innovation.

Despite the important (yeast-like) network effects in American technological development, however, we must not exaggerate their aggregate effect. Machine-building and the associated machine-using industries, although extensive, were a minority of even the manufacturing sector, which itself made up less than a quarter of national income; and the same can be said about chemical engineering. The essentially mushroom-like nature of technological change, of course, is hardly a surprise. After all, Robert Fogel (1964), in an early classic of new economic history, showed that seeing railroads as indispensable to American economic growth was seriously misguided. Nick Crafts (2001) has examined the impact of electrification in America along the same vein as he examined steam power in Britain and found that it could have contributed no more than a fifth to American per capita economic growth between 1899 and 1929. Recent calculations of the impact of the IT revolution in late twentieth century America find the possibility that it contributed as much as three quarters of a percent a year to American growth, but most of this impact arose from capital deepening induced by computer development. (Oliner and Sichel, 2000).

Just as in the British case, the finding of limited impact of identifiable mechanical, chemical and organizational and organizational changes on America growth is disappointing. After all, the economy has achieved a long-run path characterized by faster growth. As the endogenous growth models point out, this cries out for systematic feedbacks that generated faster technological change endogenously. Here again, the most likely answer lies not in engineering technology or industrial organization but in social and political characteristics of America. Much modern research points to the flexibility of the America economy and its ability to respond to opportunities. The potential list of causes is long. We should include such things as de Tocqueville's (1848) identification of the character of American democracy, the importance of constitutional settlement and the tendency of the American courts to interpret property rights in a manner that favoured businesses and economic growth (at least until the New Deal court) (Davis and North (1971)). In addition, we might note the important role of immigrants who had already chosen change and whose presence in the American labour force seems to have aided the adoption of the high wage-high effort bargain that supported mass-production techniques (Wright, 1987).

Lessons

What lessons, then, do the industrial revolutions in Britain and America provide an economist interested in growth? The economics of technological change are certainly central to the historical story. There is ample evidence that externalities and network effects have characterized technological change. However, examination of the impact of specific technological change, even those technologies seen as general-purpose technologies, shows that process and product innovations were mushroom-like rather than yeast-like, pertaining to only a limited part of the overall economy. To be sure, modern economic growth has continued because technological change has become pervasive. The key to this pervasiveness does not seem, however, to lie in technical externalities, but rather in social and political institutions that support continued learning and investment.

The history proves disappointing for highly aggregated models. Understanding the history of the industrial revolutions requires disaggregation. The appropriate level of aggregation is essentially an *ad hoc* decision. In principal we would like both to disaggregate to the level of the individual good, producer and consumer, while at the same time, maintaining an aggregate view. In practice we are unable to carry on analysis in that manner and must compromise between tractability and detail. The appropriate chose will depend on the problem at hand.

In our computational general equilibrium modelling of the British industrial revolution, Nick Crafts and I have found we need at least three ‘classes’ of consumers/factor owners and eight different industries with different technological experiences. At higher levels of aggregation we miss the elements that we see as key to British industrialization. Certainly a neutral shift in an aggregate production function inadequately models technology. In addition, the special nature of British agriculture frustrates simple aggregation of labour.

American growth has been somewhat kinder to aggregate analysis. Abramovitz and David emphasize aggregate feedback between biases in technological change and capital formation. The research on American technology suggests a particular American network of learning with broad implications. America developed a distinctive technology in response to particular initial condition. In addition, as many endogenous growth models suggest would be the case, America benefited from its larger size relative to European economies. Nonetheless, Broadberry’s finds important differences in sectoral experiences and a key role for compositional shifts.

Growth theory, however, has lesson for economic history. Models of innovation have enriched economic historians’ case studies. In addition, the aggregate growth models, although they seem far too aggregated for detailed historical analysis, direct us to the crucial issue of analysing underlying sources of differences in steady state growth rates. This focus highlights the importance of forces acting broadly, although perhaps indirectly, on the aggregate economy. The economic historian, however, is likely to conclude that these forces are more likely to be social and political than technological.

Table 1
Computational General Equilibrium Simulations:
British Structural Shift in the Industrial Revolution

	Agricultural labour share %	**Real wages**	**Per capita income**
1840 Benchmark Britain	22	100	100
1770 Simulation	32	79	75
<u>Counterfactual Simulations:</u>			
1. No industrial technological advance	24	77	77
2. ? of land peasant owned	47	99	59
3. ? peasant land and un-changed agricultural imports	57	97	55

Source: Crafts and Harley (2003)

Table 2
The Nineteenth Century Growth Transition
(annual average per capita GDP growth)

	1700-1820	1870-1913
Britain	0.34	1.01
Europe	0.06[1]	1.31[2]
United States	0.73	1.80

[1]Simple average of 5 Western European countries (Maddison (2000) p. 90).
[2]Average of Western European 16 (Maddison, 2003).

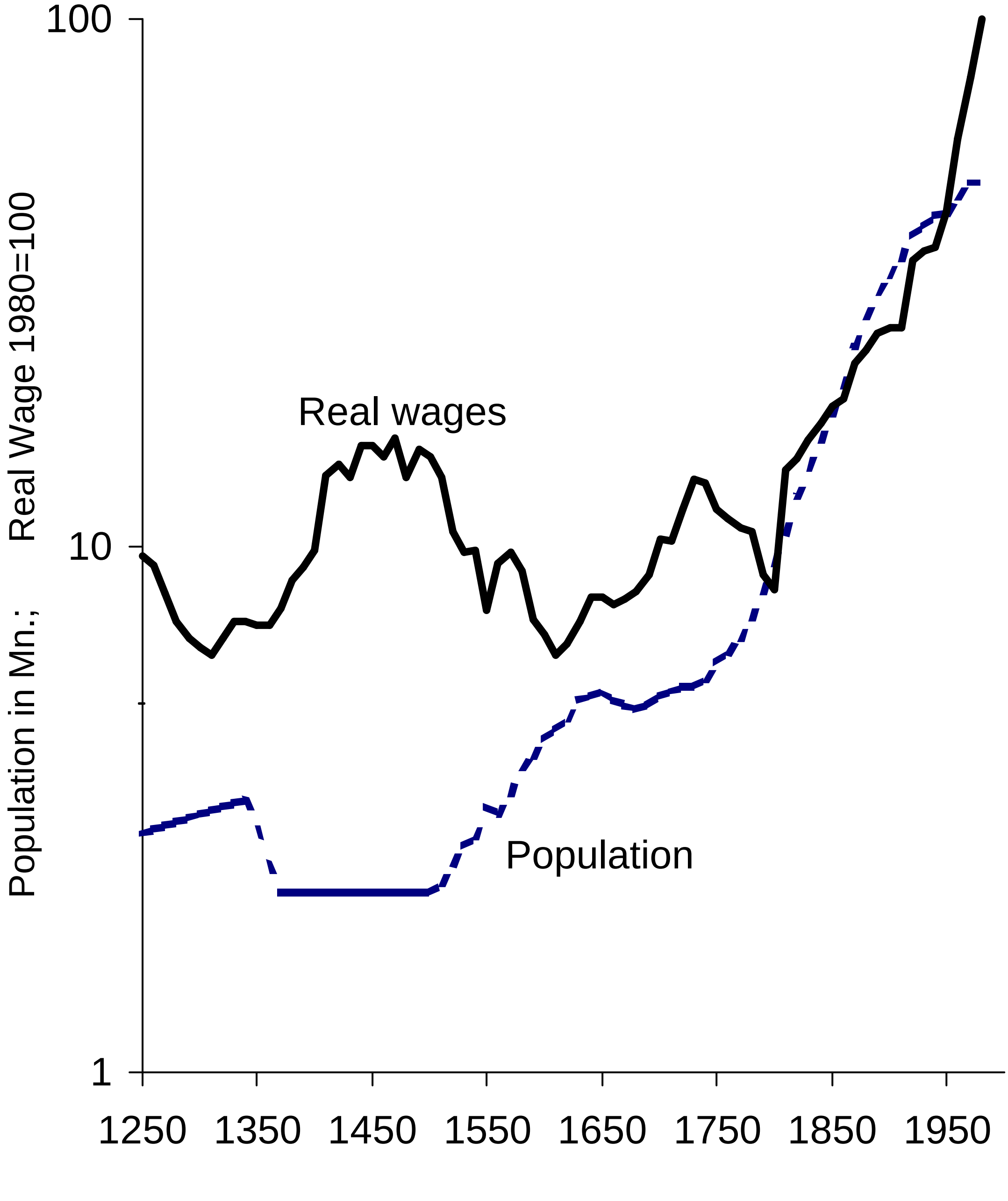
Source: Maddison (2000, 2003).

Table 3
America's Late Nineteenth Century Traverse.

	1800-1855	1871-1890	1890-1905
Total Output Growth	**3.93**	**4.97**	**3.80**
Intensive Growth	**3.51**	**3.05**	**2.40**
Population growth	3.03	2.30	1.91
Manhours per capita growth	0.48	0.75	0.49
Output per Manhour Growth	**0.39**	**1.84**	**1.36**
Capital stock per manhour	0.54	1.83	1.00
Total Factor Productivity	0.20	1.00	0.85

Source: Abramovitz and David (2001), Appendix A.

Figure 1: Population and Real Wages
England, 1250-2000



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