Explorations in Economic History 49 (2012) 1–16

Contents lists available at SciVerse ScienceDirect

Explorations in Economic History

journal homepage: www.elsevier.com/locate/eeh

Technology and the great divergence: Global economic development since 1820

Robert C. Allen *

Nuffield College, New Road, Oxford OX1 1NF, United Kingdom

ARTICLE INFO

Article history:
Received 23 June 2011
Available online 16 September 2011

JEL classification:
N10
O11
O47

Keywords:
Technological change
Global history
Great divergence
Economic growth

ABSTRACT

The paper measures productivity growth in seventeen countries in the nineteenth and twentieth centuries. GDP per worker and capital per worker in 1985 US dollars were estimated for 1820, 1850, 1880, 1913, and 1939 by using historical national accounts to back cast Penn World Table data for 1965 and 1990. Frontier and econometric production functions are used to measure neutral technical change and local technical change. The latter includes concurrent increases in capital per worker and output per worker beyond the highest values achieved. These increases were pioneered by the rich countries of the day. An increase in the capital-labor ratio was usually followed by a half century in which rich countries raised output per worker at that higher ratio. Then the rich countries moved on to a higher capital-ratio, and technical progress ceased at the lower ratio they abandoned. Most of the benefits of technical progress accrued to the rich countries that pioneered it. It is remarkable that countries in 1990 with low capital labor ratios achieved an output per worker that was no higher than countries with the same capital labor ratio in 1820. In the course of the last two hundred years, the rich countries created the production function of the world that defines the growth possibilities of poor countries today.

1. Introduction

Since the industrial revolution, the world has become increasingly unequal. In 1820, most of today's rich countries had higher incomes than today's poor countries, but the difference was comparatively small. Since then, the rich countries have grown faster, so the gap between rich and poor has increased. The immediate cause of the divergence is clear enough: the rich countries have invented and adopted technologies that have raised labor productivity enormously. Poor countries, on the other hand, have been slower to adopt modern methods. The reason for their lethargy is usually regarded as a puzzle because the standard view of technological change is that it benefits all economies, whatever their level of development.

The orthodox assumption about technology plays a leading role in the Solow growth model, which is an important point of reference for this paper. This model assumes a constant return to scale neoclassical production function, labor augmenting technical change, and a constant rate of savings out of total output. Labor augmenting technical change means that an improvement in technology shifts the production function upwards at every capital–labor ratio, i.e. the new technology lowers costs under all factor price configurations, so it is profitable to use in poor countries as well as rich countries. The model has other implications, which we will discuss later, but its characterization of technology poses the fundamental riddle: why don't all countries adopt modern technology?

There has been great debate about the answer, and many non-economic factors have been invoked. Cultural explanations are long standing and rooted in early religious views. Weber (1904–5) famously developed this perspective by arguing that the Reformation laid the basis for the 'protestant ethic,' which, in turn, explained why the Industrial Revolution occurred in Britain rather than Italy.

* Fax: +44 1865 278621.
E-mail address: bob.allen@nuffield.ox.ac.uk.

0014-4983/$ – see front matter
doi:10.1016/j.eeh.2011.09.002

Weber's thesis, however, has been subjected to devastating criticism (Lehmann and Roth, 1995). Cultural arguments were also used in the nineteenth century to explain why Europe was richer than Asia and Africa. Colonial ideologues found it easy to imagine that Europeans were more rational, prudent and harder working than other peoples. However, studies of the adoption of innovations, the utilization of labor, and the adjustment to price changes support the contrary view that peasant producers everywhere are rational economic agents (e.g. Berry and Cline, 1979; Blaut, 1993).

Culture being inadequate, economists have turned to institutions to explain economic development. According to this view, the rise of the West was due to good institutions, i.e. secure property rights, limited government, and low taxes, while the lack of development elsewhere was due to arbitrary monarchies, despotic emperors and dictators, poor property rights, high taxes, corruption, and rent seeking (North and Weingast, 1989, North et al., 2000). Some influential interpretations have grounded institutional arguments in geography. Engerman and Sokoloff (2000) traced the different development trajectories of North and South America back to their colonial agrarian systems (family farms versus plantations), which, in turn, depended on the suitability of the land for growing wheat or sugar. Acemoglu et al. (2001) have a similar argument that relates institutions to disease environment: high settler mortality led to extractive institutions that later stifled economic development. Dell (2010) and Nunn (2008) have shown that early modern, extractive institutions like use of forced labor in the Andean silver mines and the slave trade have effects that persist to the present day (although their magnitudes are not large enough to explain underdevelopment). Contradicting the institutionalists, Glaeser et al. (2004) have argued that good institutions are the result of economic development rather than their cause.

This paper explores an alternative explanation of economic development based on the character of technological change itself. While the standard view assumes that technological progress benefits all countries, this paper contends that much technological progress has been biased towards raising labor productivity by increasing capital intensity. The new technology is only worth inventing and using in high wage economies. At the same time, the new technology ultimately leads to even higher wages. The upshot is an ascending spiral of progress in rich countries, but a spiral that it is not profitable for poor countries to follow because their wages are low.

This paper's view of technological change is a historical exploration of the ‘appropriate technology’ theme found in recent theoretical and empirical papers dealing with economic growth. The literature takes off from Atkinson and Stiglitz's (1969) concept of ‘local technical change’. In contrast to the standard view that technical progress increases output per worker with respect to capital per worker at every capital–labor ratio, Atkinson and Stiglitz explored the possibility that shifts in the production function were limited to a neighborhood around the capital–labor ratio that was in use. These local changes have come to be called ‘appropriate technologies’ since they would be adopted only by a firm facing factor prices that led it to operate in that neighborhood. Basu and Weil (1998) have explored the concept in a theoretical growth model in which rich countries invent techniques appropriate to their high wage environment. These are not appropriate for poor countries. They can grow very rapidly, however, if they sharply increase their savings rates, and adopt the capital-intensive technology perfected by rich countries. Several investigators have studied aggregate data to see whether technical change has been local or whether it tends to raise output per worker irrespective of the capital–labor ratio (Färe et al., 1994, Acemoglu and Zilibotti, 2001, Kumar and Robert Russell, 2002, Los and Timmer, 2005, Caselli and Coleman, 2006, Jermanowski, 2007). This research has used post-1960 data. These studies have found uniformly that technical progress has been limited to high capital–labor ratios and reflects the research priorities of high wage countries well endowed with physical and human capital (Acemoglu, 2002, 2003, 2007).

While this conclusion is at variance with the standard view in economics, it resonates with many historical studies. The debate on Victorian entrepreneurship, for instance, focussed on the adoption of specific inventions in the late nineteenth century—ring spinning, the Northrop loom, coal cutting machines and the use of ‘fast driving’ and mechanical hoists in blast furnaces. These were used in the United States but not in Britain. Some argued that this was due to British ‘entrepreneurial failure’ (Landes, 1969). The cliometric response, however, was that the America techniques cut costs under American conditions, but not under British conditions (McCloskey and Sanberg, 1971). The most prominent difference in conditions was in wage rates, which were high in the USA and lower in the UK. Studying the diffusion of inventions highlights the local character of the technical change and disposes economic historians to the ‘appropriate technology’ paradigm. In contrast, economists, who study technical change by fitting production functions that include time as a shifter, are bound to find that technical change cuts costs in all circumstances since that is what time shifters do.

The empirics of this paper begin with Kumar and Russell's (2002) study of 1965 and 1990 cross-sections of national data. These data describe the 57 countries for which the Penn World Table 5.6 reports both output per worker and capital per worker in 1985 international dollars.[1] Fig. 1 plots the data. The diagram has three outstanding features. First, all of the points form a curve that looks like a textbook production function. A Cobb–Douglas function has been fit to these points (Table 1). It is the ‘production function of the world.’ Second, the 1965 curve is a subset of the 1990 curve. The capital–labor ratio in 1990 ranged from $223 to $73,459 with sixteen countries above $30,000. In 1965, only two countries had capital–labor ratios above $30,000. Below that value, the data points in 1965 and 1990 overlap, i.e. there was no upward shift of the production function in this interval, in other words, no technical progress. This stagnation continued through 2000 (Badunenko et al., 2008b and Badunenko et al., 2008a). Since 1965, improvements in technology involved pushing capital–labor ratios above $30,000 and thereby achieving greater output per worker. Third, the function flattens out as the capital–labor ratio rises. This means

[1] Kumar and Russell (2002, p. 531) leave out Iran and Venezuela, which are also in PWT 5.6, on the grounds that they are oil producers. I leave them out likewise, and I thank Bob Russell and Daniel Henderson for providing me with a spreadsheet of the data. They have written two more papers adding education to the data and refining the procedures (Henderson and Russell 2005, Badunenko, Henderson, Russell 2008), but the historical data are not yet available to follow them in these extensions.

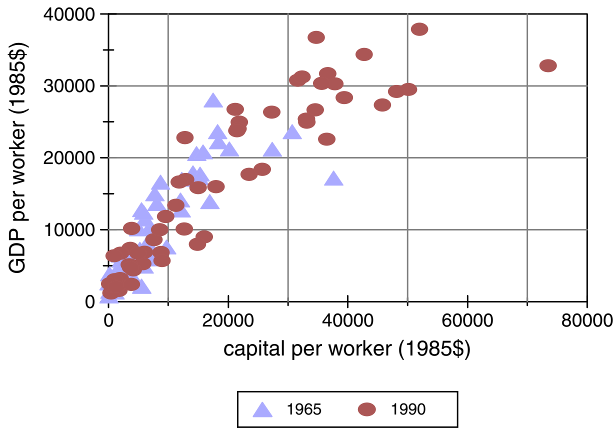

Fig. 1. The 1965 and 1990 cross sections.

that only high wage economies found it profitable to adopt the new technology of 1990. The USA, for instance, found that greater capital intensity paid, and its income rose accordingly. It would not have paid to adopt the new technology in Sierra Leone, however, no matter how good were its institutions, so it was not adopted there, and Sierra Leone remained poor.

The kind of improvement in technology that occurred between 1965 and 1990 cannot be detected by fitting a production function to the data and looking for a structural break (e.g. Table 1, regression 2) or by using a total factor productivity index exact for that production function.

How can this kind of technical progress be detected? Kumar and Russell's solution was to fit frontier production functions to the two cross sections. Their frontiers are shown in Fig. 2. Between 1965 and 1990, there was no technical progress at capital intensities below $17,500 per worker. All of the progress in those years occurred at higher capital–labor ratios and, indeed, pushed those ratios higher. Kumar and Russell reject Hicks neutrality and Harrod neutrality as adequate descriptions of technical change or explanations for the rise in output per worker.

Technological change during the Industrial Revolution can be described in the same terms Kumar and Russell apply to post-1965 technology. Arkwright's spinning mill, for instance, was an advance that significantly raised the capital–labor ratio and output per worker. There was no increase in efficiency at low capital–labor ratios (e.g. the spinning wheel or whorl and drop spindle). The Arkwright mill was only profitable to install where labor was expensive relative to capital (Allen, 2009a). The question is: what happened between the Industrial Revolution and 1965? Was technical change local or neutral? And what are the implications for economic development? This paper aims to find out.

2. Data

These questions will be pursued by extending the 1965 Penn world table data back to the Industrial Revolution. This cannot be done for all countries, but it can be done for enough to provide a historical dimension to the modern cross-sections. This paper uses historical reconstructions for the USA, the UK, the Netherlands, Belgium, France, Germany, Italy, Norway, Denmark, Switzerland, Spain, Japan, Taiwan, South Korea, India, Mexico, and Argentina. Not all of the reconstructions are equally long, but all extend back to at least the First World War.

Maddison (2006)) pioneered this kind of historical reconstruction with his widely used GDP series. He began with a cross section of PPP adjusted GDP estimates (most recently measured in 1990 international Geary-Khamis dollars) and extrapolated them

Table 1
World production function: PWT 1965 and 1990 cross sections.

Dependent variable is ln(Y/L)		T-ratios in parentheses
	(1)	(2)
Constant	3.95	3.94
	(16.4)	(16.1)
ln(K/L)	.59	.59
	(21.6)	(20.6)
d1990		−0.03
		(−0.3)
R^2	.806	.807
Observations	114	114

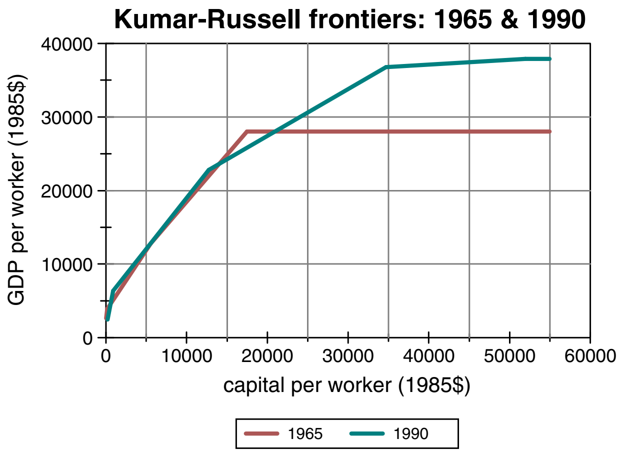

Fig. 2. Kumar–Russell frontier production functions.

backwards with national estimates of the growth of real GDP to produce estimates of GDP in 1990 dollars for hundreds of years into the past. I proceed similarly. GDP and the capital stock (both measured in 1985 international dollars in Penn World Table 5.6) are projected backwards by using national studies and, for GDP, often using Maddison's results. National estimates of the labor force or occupied population are likewise used to extend the number of workers in 1965 back into the past. The result is a data set beginning in the eighteenth century with GDP per worker and capital per worker measured in 1985 international dollars. (See Appendix A for details.) In this paper, I concentrate on cross sections of the data for 1820, 1850, 1880, 1913, and 1939, which are compared with the PWT cross sections for 1965 and 1990.

3. Frontier production functions

Before fitting production functions, it is instructive to look at the data themselves. They show that much progress consisted of concurrent increases in output per worker and capital per worker. Fig. 3 plots output per worker against capital per worker for 1820 through 1913. In 1820, the points are concentrated in the lower left hand corner where the maximum capital–labor ratio was realized in the Netherlands ($3521/worker) and the highest labor productivity in the UK ($4408 per worker). As the nineteenth century unfolded, the points moved upward and to the right. As the leading economies moved beyond a capital–labor ratio, there was no further increase in output per worker at that capital-intensity. Technological change did not 'trickle down' to poor economies-change, in other words, was not neutral.

These patterns continued across the twentieth century (Fig. 4). The predominant pattern from one time period to the next is the movement of points upward and to the right, although some countries remain stuck in the lower left. The countries that did not develop had a capital–labor ratio and output per worker in 1990 that were as low as the ratios characteristic of 1820.

These observations can be formalized by fitting frontiers to the data as Kumar and Russell did. Fig. 5 shows frontiers for 1820, 1850, 1880, and 1913. The pattern is identical to Fig. 2 with all of the change extending the previously highest capital–labor ratio.

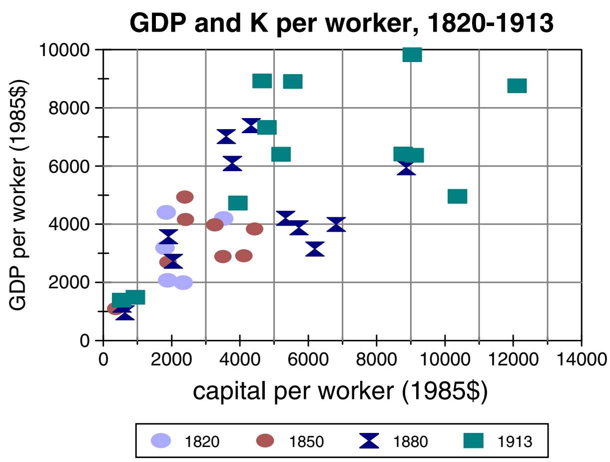

Fig. 3. GDP and capital per worker, 1820–1913.

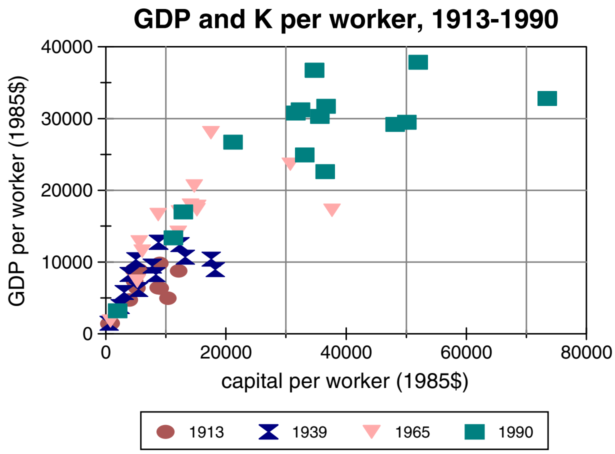

Fig. 4. GDP and capital per worker, 1913 -1990.

There was no improvement in output per worker at lower capital intensity. Fig. 6 shows twentieth century frontiers, and again both patterns are repeated. Biased technical change amounting to the extension of the production possibilities to higher and higher capital–labor ratios has been a fundamental feature of economic growth since the industrial revolution. Conversely, there has been no improvement in labor productivity for countries that did not accumulate capital.

There are three ways that a country can increase output per worker in the Kumar–Russell framework. First, a country below a frontier could increase its efficiency by rising to the frontier (efficiency improvement). Second, a country could raise capital per worker by moving along a frontier to the right (capital accumulation). Third, a country could jump vertically to a higher frontier (technical progress). The latter two are relevant to long run economic growth. What is their relative importance? Suppose we compare the UK in 1820, which realized $4408 per worker with $1841 capital per worker, to the USA in 1990 with output per worker of $36,701 and capital per worker of $34,705. Each was on the frontier and defined a high corner, so efficiency improvement does not apply. There are two sequences to convert the UK in to the USA. One is to first increase capital per worker to $34,705 by moving along the 1820 frontier and then to jump vertically to the 1990 frontier. In this case, the increase in capital per worker causes no increase in output per worker, and the entire difference in output per worker between the two cases is due to improvements in technology. The second way to raise output per worker in the UK is, first, to jump to the 1990 frontier and then to move along it by accumulating capital. In 1990, a capital–labor ratio of $1841 implies output per worker of $7672. Along this path, technical progress raises output per worker by $3264 (=$7672–$4408), which is 10% of the difference between the UK in 1820 and the USA in 1990. The remaining 90% of the difference is due to capital accumulation. One path attributes economic growth to technical change, the other almost entirely to capital deepening. When technical progress and capital accumulation occur concurrently, separate contributions cannot be identified. Standard growth accounting rules out this possibility by assuming the technical progress is Hicks neutral (Hulten, 1973).

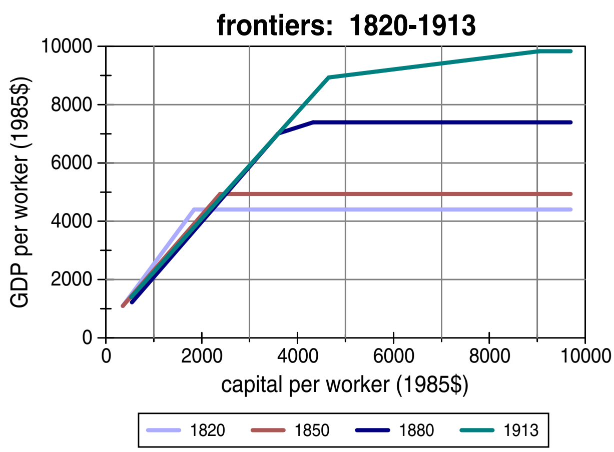

Fig. 5. Frontier production functions: 1820–1913.

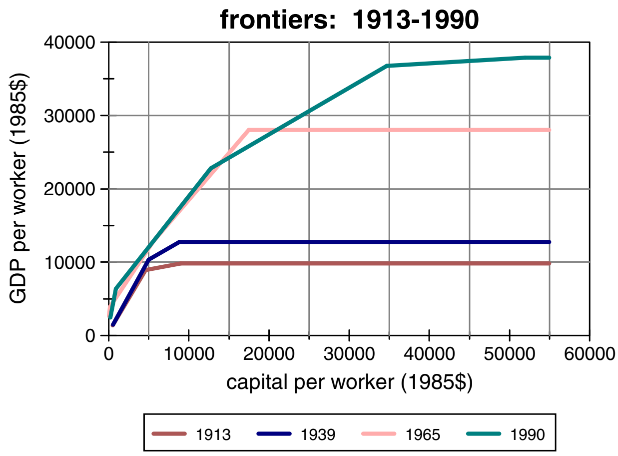

Fig. 6. Frontier production functions: 1913–1990.

The frontier production functions suggest two related conclusions. First, technical improvements have been limited to upward shifts in the production function only at the highest capital–labor ratios in use. Second, as a corollary, there have been no improvements in efficiency at any capital labor ratio once the locus of advance has moved to a higher capital–labor ratio.

4. Frontiers and the stylized facts

These conclusions could be challenged with an alternative interpretation based on the standard Solow growth model. The initial rising portions of the various frontiers in Figs. 5 and 6 are almost on top of each other and suggest that the capital–output ratio was constant, one of Kaldor's (1957, p. 592) stylized facts of economic growth. This 'fact' can be explained with a simple growth model consisting of a constant returns to scale neoclassical production function, labor augmenting technical change, and a constant savings rate out of total output. That model implies a steady state growth path with a constant capital–output ratio. Since labor augmenting technical change is a maintained assumption, Figs. 5 and 6 are consistent with labor augmenting technical change as well as with the biased and local technical change suggested by the movements of the frontiers.

This interpretation is not sustained, however, if we analyze all of the data points rather than the outliers that define the frontiers. The hypothesis that the capital output ratio is a constant can be tested econometrically. Since $Y/K = a$ (a constant), $(Y/L)/(K/L) = a$, or, in logarithms, $\ln(Y/L) = \ln(a) + \ln(K/L)$. This is a special case of the Cobb–Douglas function $\ln(Y/L) = \ln(a) + b^*\ln(K/L)$ where $b = 1$. The function estimated from the 1965 and 1990 cross sections in Table 1 had $b = .59$, which was 15 standard deviations (.027) below 1, so the hypothesis that $b = 1$ is easily rejected. The same is true with the other versions of this function we discuss.

5. Technical progress and capital intensity: another look

In addition to fitting frontier production functions to the historical data, they could be analyzed by fitting a Cobb–Douglas function to see if the pattern over time was similar to the modern pattern across space in 1965–90, as shown by the regressions in Table 1. The answer is, indeed, affirmative. The coefficient of $\ln(K/L)$ estimated from the historical data ranges from .57 to .71 (bracketing the value of .59 in Table 1) depending on whether time and/or country fixed effects are included in the historical regressions. Neutral technical change is detected especially between 1880 and 1965.[2]

These results, however, are not as impressive as they appear, for the Cobb–Douglas function constrains the rate of technical improvement to be the same at all capital–labor ratios. This was manifestly not the case. We can see this by dividing the sample into three groups defined by the capital labor ratio – less than \$5000 per worker, \$5000–\$10,000, and more than \$10,000 per worker – and estimating Cobb–Douglas functions estimated over each ranges (Table 2).

The regressions show that the rate of productivity growth increased with the capital–labor ratio. Perhaps the most surprising result is for the sub-sample with a K/L ratio less than \$5000. This range includes the poorest countries today and of the early phase of industrialization in today's richest countries. The time dummies in the estimated production function are insignificant indicating that today's poor countries are no more efficient than the rich countries at the beginning of their growth experience. This remarkable finding is illustrated by Fig. 7, which plots the data for these countries. The successive cross sections for the last two centuries overlap impressively.

[2] The regressions are reported in Allen (2011, Table 2).

Table 2
Perfection of technology at various capital–labor ratios historical panel data set.

Dependent variable is ln(Y/L) in all regressions	(1)	T-ratios in parentheses (2)	(3)
	K/L ≤ $5000	$5000 ≤ K/L ≤ $10,000	$10,000 ≤ K/L
Constant	3.36	6.60	6.14
	(4.6)	(4.3)	(4.1)
ln(K/L)	.59	.27	.35
	(7.0)	(1.5)	(2.3)
D1820	−.31		
	(−1.2)		
D1850	−.25		
	(−1.1)		
D1880	−.17	−.94	
	(−.8)	(−4.1)	
D1913	−.06	−.57	−.80
	(−.3)	(−3.4)	(−5.7)
D1939	.08	−.33	−.54
	(.5)	(−2.7)	(−5.9)
D1965	−.09		(−.6)
R^2	.982	.998	.979
Observations	37	20	30

Note: All regressions include country fixed effects.

It was a different story at higher capital–labor ratios. 1880 was the first cross section in which any county was operating with a capital–labor ratio above $5000 per worker. Today's rich countries had capital–labor ratios between $5000 and $10,000 for the next fifty to seventy-five years, and they were joined by middle income countries in this period. There was a steady upward shift in the production function in this K/L range between 1880 and 1965. No further improvements in efficiency have been made since then, however.

This process was replicated at K/L ratios above $10,000. Today's rich countries began operating in this region in the 1913 cross section. Productivity increased in successive cross sections until 1965. Between 1965 and 1990, there were no further improvements.[3]

6. The process of technical change

We can learn more about the roles of neutral and local technical change by looking at the way in which today's world production function was created. It was invented by a limited number of rich OECD countries—the UK, USA, Netherlands, Germany, France, Belgium, Norway, and Switzerland (although only the first five are present in the 1820 sample). They increased the capital–labor ratio in steps. The general pattern is shown in Fig. 8, while Fig. 9 provides a more detailed look at the nineteenth century, which is too compressed to analyze in Fig. 8. Between 1820 and 1850, the average position of the leading economies moved upward and to the right, but there was little increased in maximum output per worker. Considerably larger shifts in a northeasterly direction occurred in 1850–1880, when capital–labor ratios between $5000 and $9000 where first explored, and in1880–1913, when capital per worker rose to $9000–$12,000. Output per worker rose little between 1913 and 1939, but capital intensity was pushed to $20,000 per worker. Between 1939 and 1965, output per worker was pushed to new heights and capital per worker was raised to $40,000. By 1990, the pioneers increased capital per worker to over $73,000 per worker, and output per worker reached $38,000.

Different countries played different roles in this upward progression. We can distinguish high flyers from accumulators. In the period 1850–80, three countries kept capital per worker at about $4000 but raised output per worker to about $7000. These countries were the USA, the UK, and the Netherlands, and they remained leaders over the entire period. These high flyers defined the corners of the frontiers—the UK and the USA in 1880 and 1913, the UK and the Netherlands in 1939, and the USA in 1965 and 1990. In these years, the UK and the Netherlands were just below the frontier. The high productivity of these countries stands out if their growth trajectories are plotted against the background of the 1965 and 1990 cross sections. The UK trajectory runs along the top of these points, and the USA trajectory jumps above them when the USA overtook the UK (Fig. 10).

The inventiveness of the high flyers was underpinned by favorable institutions. The US and the UK had modern patent systems throughout. The Netherlands operated without patents from 1869 to 1912. In all three countries, businesses and government agencies carried out research. Universities in these countries, as well as in countries like Germany, also undertook basic and applied research. Professional and trade associations created research networks that contributed to progress. Collective invention in

[3] Similar conclusions are supported by specifications which include time as a continuous variable rather than as a series of dummies (See Allen 2011, Tables 4 and 5). When the K/L ratio is less than $5000, productivity grew at 0.2% per year. Statistically, the coefficient is on the border of significance, but it is so small as to be negligible. With high K/L, productivity grew faster and was historically important. The progression is particularly striking in the regressions with fixed effects. In these, the productivity growth rate increased uniformly with the K/L ratio from 0.2% per year to 1.7%. When the regression was estimated across the whole sample (column 1), the estimated rate of productivity growth was in the middle of the rates for the various K/L ranges.

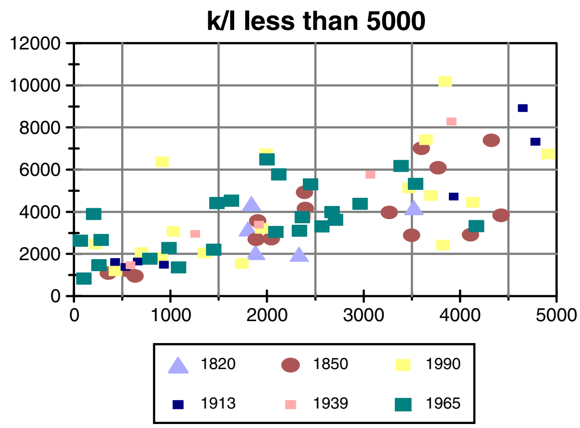

Fig. 7. Output per worker versus capital per worker when capital–labor ratio is less than $5000.

which firms shared technical information and built on each others' successes was also important (Allen, 1983). As the twentieth century progressed, governments spent more and more money on research, often with military applications in mind. Some technological advance was due to scientific breakthroughs, but most improvements were either the result of 'learning by doing' or were produced by research and development projects aimed at solving immediate problems or, more generally, increasing the profitability of the firms undertaking the research (Nelson and Wright, 1992). As a result, the new technology was most appropriate for the factor prices and other circumstances of the rich countries doing the inventing.

The second group of leading countries – Germany, Belgium, France, Norway, and Switzerland – were the accumulators. Their movements were more horizontal than vertical. The accumulators operated with higher capital–labor ratios and realized lower output per worker than the high flyers. Investment banks were more important sources of industrial finance in continental Europe than they were in the UK or USA, and that institutional difference may be the reason that capital–labor ratios were higher on the continent (Gerschenkron, 1962, Fohlin, 2007).

The greater emphasis on the role of capital accumulation in the continental countries means that their growth trajectories were on the low side of the scatter of point defined by the 1965–90 PWT cross section. Germany and Switzerland are cases in point (Fig. 11).

One to two generations were spent perfecting the technology at one capital–labor ratio before the leading countries moved on to greater capital intensity. In 1850, for instance, the pioneers got about $4000 per worker from a capital stock of $3000–5000 per worker. By 1880, the high fliers realized close to $8000 per worker with the same stock. By 1913, this had increased to $9000, but by then inventive activity had shifted to higher capital–labor ratios. Much of this improvement was realized by the accumulators who gained on the high fliers. An important case was Germany's catching up with Britain. France also made considerable progress at the same time. Because the capital–labor ratios of the accumulators were at least as great as those of the high flyers, there was little difference between the accumulators and the high fliers in their relative factor prices. As a result, technology was easily transferable among them. The catch-up of the accumulators corresponds to some of the convergence among OECD countries that has been measured (Baumol, 1986).

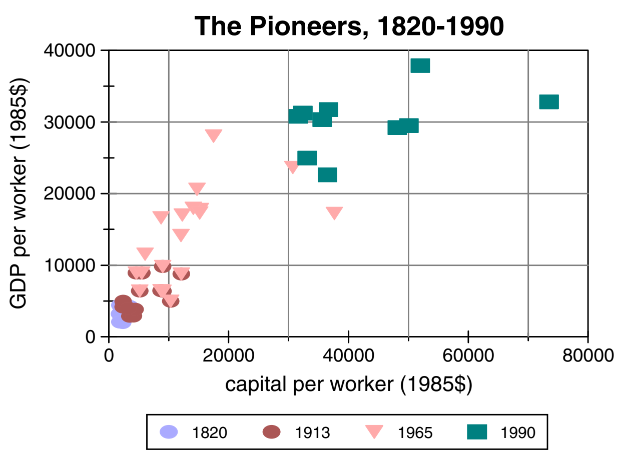

Fig. 8. The Pioneers, 1820–1990.

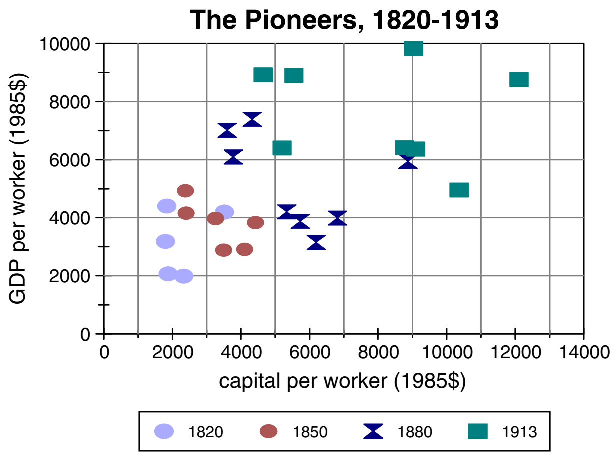

Fig. 9. The Pioneers, 1820 -1913.

A similar development occurred at capital–labor ratios between $15,000 and $20,000 per worker in the twentieth century. There was a small advance between 1913 and 1939 and a very much greater increase in output per worker between 1939 and 1965. This was achieved with only a small increase in capital per worker. After that, the pioneer countries moved to higher capital–labor ratios, and improvement ceased at capital–labor ratios below $30,000 per worker.

The high flyers led the advances among the pioneer economies, and the accumulators were always playing 'catch up'. One should not, however, exaggerate the backwardness of the accumulators. Their productivity was never static, and they did not fall far behind. Technological histories of these countries emphasize the creativeness of their science and engineering. It is difficult to say what they would have done without the example of the high fliers, but the accumulators were never very far behind them.

7. Economic growth in late developers

While the accumulators began to grow in the early nineteenth century, economic growth in most countries did not begin until the late nineteenth or twentieth centuries. An important group are the convergers who have successfully industrialized and become rich themselves. This group includes peripheral countries in Europe (Italy, Spain, Denmark) as well as in East Asia (Japan, S. Korea, and Taiwan). The convergers have never pushed output per worker or capital per worker beyond existing limits. Instead, they have grown by accumulating capital and moving up the world production function. This is shown by plotting their growth trajectories against the 1965–90 cross sections.

The late developers have faced a problem, which has grown over time; namely, the inappropriateness of the technology invented by rich countries. This problem is manifest in the curvature of the world production function. The technology invented today, with its very high capital–labor ratio, is only cost effective when the wage is high relative to the price of capital. The easiest technology for poor countries to adopt is that of the nineteenth century, which was invented when wages were much lower relative to the price of capital. Indeed, the export industry that is most successful in most poor countries is clothing and apparel. The basic implement is the sewing machine, which was developed in the 1850 s. Electric sewing machines were first marketed in

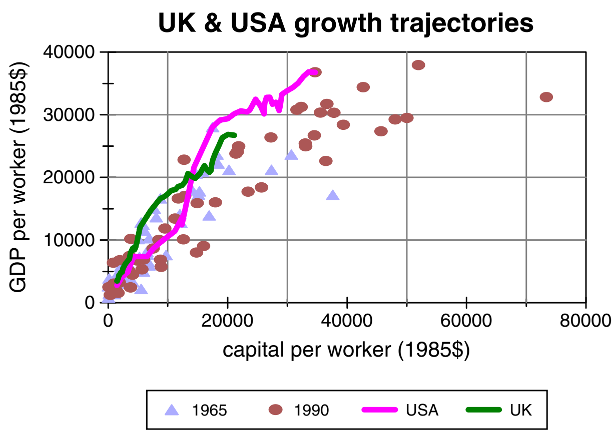

Fig. 10. UK and USA growth trajectories.

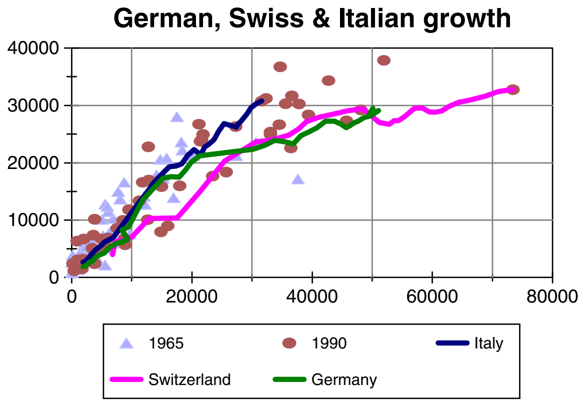

Fig. 11. German, Swiss, and Italian growth trajectories.

1889. This technology was invented in rich countries when their wages were low and is the basis of industrial development in many poor countries today—because it is appropriate to their conditions.

The European convergers began to grow when these differences were less than they are today. Italy is a case in point. Fig. 11 shows the history of output per worker and capital per worker arrayed against the background of data points from the 1965 and 1990 cross sections. Italy's growth follows the pattern defined by the world production function. From 1861 to 1951, the Italian economy grew mainly by importing technology from advanced countries, and this required the concurrent accumulation of capital. Investment banks facilitated accumulation by channeling cheap capital to large scale industry. Productivity was always about two-thirds of the value implied by the Cobb–Douglas production function in Table 1. The only period in which neutral productivity growth played a major role was 1951–73 when TFP in Italy rose to 35% above the level implied by the Cobb–Douglas production function. That shift is noticeable in Fig. 11 when the Italian growth trajectory shifts from the low side to the high side of the scatter of points. Post-1973, Italy achieved similar output per worker to Germany, while using considerably less capital per worker.

Some of the convergers are famous for the speed of their catch-up. These bursts were preceded by longer periods of slow growth. Japan, for instance, had a capital–labor ratio of only $569 in 1870. Growth over the next seventy years raised this to $2409 in 1940. This was a radical enough transformation to generate a vast literature on the economic consequences of the Meiji restoration. Capital per worker was, however, still no higher than it had been in the UK in 1860.

Japan followed an unusual technology policy in this period, which has been called 'labor-intensive industrialization.' (Sugihara 2012) The first state initiatives to import Western technology in the 1870s were commercially unsuccessful since foreign plants were too capital-intensive for Japan. Systematic efforts were made to alter western technology to increase the productivity of capital, the scarce input. The changes spanned the gamut from increasing the number of hours per day that cotton mills operated to standardizing products with the aim of boosting output per machine to redesigning equipment. These changes increased output per worker at low capital–labor ratios by allowing modern methods to be used in a less capital-intensive manner (Otsuka et al., 1988). Likewise, agricultural research aimed to raise land productivity rather than mechanize farming (Hayami and Ruttan, 1971). This also boosted output per worker without increasing capital per worker. The results were manifest in an unusual increase in total factor productivity: in 1870, Japan operated at only 38% of the efficiency implied by the world production function; by 1940, the country's productivity rose to 77% of that standard.

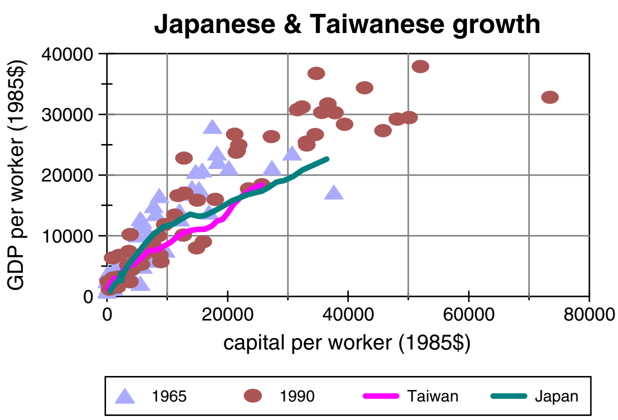

Fig. 12. Japanese and Taiwanese growth trajectories.

The theoretical literature on appropriate technology indicates that a rise in the savings rate can have unusually powerful effects on growth since it allows a country to jump up to a higher point on the world production function. Japan's post-war growth was a big push from this gradually accumulated base, as Fig. 12 suggests. Output per worker, however, sagged during the great catch-up. The rapid growth of Taiwan and South Korea since 1965 was also preceded by a period of gradual economic growth when they were Japanese colonies. Rapid growth was realized by accumulating capital and moving up the world production function rapidly, although Taiwan shows a tendency to low efficiency like Japan (Fig. 12).

The final group of countries are the slow movers that have not grown rapidly. India is the most extreme example in the data set (Fig. 13). Between 1860 and 1990, it accumulated little capital and achieved little growth. Its capital–labor ratio in 1990 ($1946) and labor productivity ($3235) were like Britain's in 1820 ($1841 and $4408, respectively). Mexico and Argentina have grown more but not caught up with the leading economies. Both countries have exhibited above average efficiency for many years (Fig. 14) but have not imported enough advanced technology nor accumulated enough capital to catch up with the leaders. On the contrary, Argentina was a rich country before the first World War. The immediate reason it fell behind was because its capital stock per worker in 1965 ($5555) was little above its 1913 value ($4779). These countries need to accumulate capital in the massive way that East Asian economies have done since 1960 in order to close the gap with the West.

8. Conclusion

The PWT data set for 1965 and 1990 does act as a world production frontier for the period 1820–1990. The frontier was not known to people in 1820, however. It was discovered in the nineteenth and twentieth centuries.

The process of discovery had earlier roots. Already in 1820, income per head was considerably higher in northwestern Europe and the United States than it was elsewhere in the world. Capital intensity was also much higher. The USA and the countries of northwestern Europe all used several thousand dollars of capital per worker. India and Japan in the mid-nineteenth century were only using about $500. The effects of high capital intensity were also visible in the labor market: real wages were much higher in England, the Netherlands, and the USA than elsewhere in the world (Allen, 2001, 2007, 2009a, Allen et al., 2011).

The nineteenth and twentieth centuries saw great improvement in technology. Advance was accomplished in two stages: First, pioneer economies invented technology that was more capital intensive and had higher labor productivity than was used previously. Second, labor productivity was pushed up as the newly invented technology was perfected. This phase of improvement lasted several generations. After it was completed, there were no further improvements in efficiency at the level of capital intensity in question. The production function has been stable at less than maximal levels of capital intensity since only the rich invent new technology. Once they have progressed beyond a particular capital–labor ratio, they stop investing in technological improvements below that ratio. The result is the ‘world production function’ defined by the 1965 and 1990 PWT cross sections. The invention of the world production function was the result of upward leaps to higher and higher capital–labor ratios (the local technical change emphasized by Kumar and Russell) followed by half a century of increases in output per worker in that K/L range (which shows up as the neutral improvements in Tables 2).

The pioneer economies over these centuries have been the UK, the USA, and the Netherlands. The first two are the usual suspects; the Dutch are a surprise. The Dutch Republic, however, was the wonder economy of the seventeenth century, and the country had a very high income into the nineteenth century. Perhaps because they had no domestic cotton industry and lacked coal, the Dutch did not invent the technology of the industrial revolution. Instead, high incomes yielded high savings that were invested in low profit projects like land reclamation. This was manifest in the high capital–labor ratio in 1820 (De Vries and van der Woude, 1997). However, that imbalance was overcome by 1850, and the Dutch joined the Americans and Brits in pushing capital-intensive technology forward.

It is not a surprise why these economies were the leaders. They had supportive institutions and culture, but they also had powerful economic incentives leading them on. It is very important in this regard that technological progress has been local. If it were neutral,

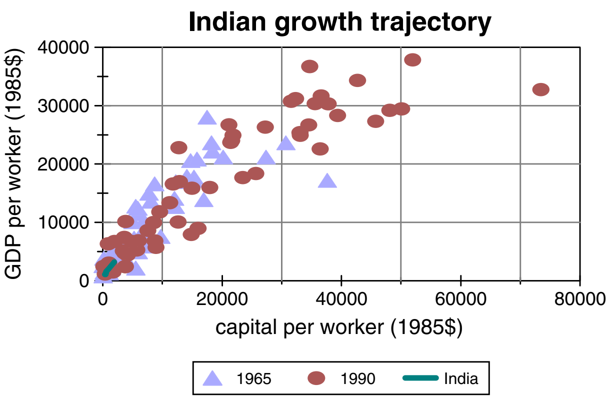

Fig. 13. Indian growth trajectory.

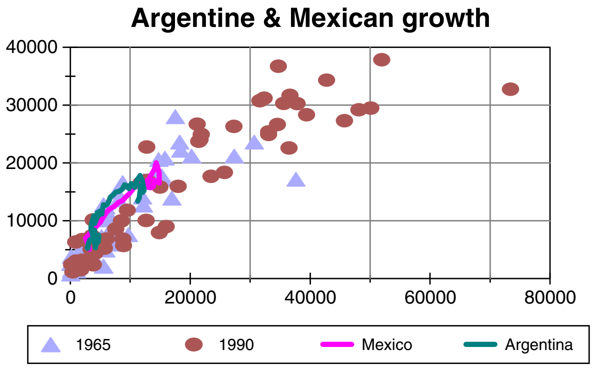

Fig. 14. Argentine and Mexican growth trajectories.

then every country in the world would have faced the same incentive to invent it since costs would have fallen whatever the factor prices. With local technical change, however, the cost saving depends on the factor prices. The technology invented in the West cut costs more where wages were high relative to capital costs than where wages were low. Furthermore, invention was never free: the economic benefits of new technology had to be set against the R&D costs of inventing it. At the end of the eighteenth century, the economies with high wages were England, the USA, and the Low Countries. Those were the places in the world where it paid to invent labor saving technology (Allen, 2009a).

The process of development became self-reinforcing. The wide-spread adoption of the new technology raised wages in northwestern Europe and North America. Higher wages created an incentive to invent even more capital-intensive technology. The result was a ascending spiral of progress.

The spiral led to unequal development since the newly invented technology was not cost-effective in low wage economies. There have been exceptions: Sometimes techniques have been perfected enough to lower costs even when labor is cheap. Then some economic growth happens on the periphery. Otherwise, the poor countries can only grow by accumulating capital and crawling up the world production function estimated in Table 1. The most successful countries have developed institutions to lower the cost of capital to industry, thereby making capital-intensive technology more profitable than it otherwise would have been. Investment banks performed that function in countries like Italy. In East Asia, where the challenges were greater because the countries were further behind at the start of their industrialization, a panoply of government industrial and financial policies have played the same role.

Appendix A. Data sources

Historical data are backward extrapolations of the 1965 values of two variables in the Penn World Table 5.6. The variables were RDGPW (Real GDP per Worker (1985 international prices)) and KAPW (Capital Stock per Worker (1985 international prices)). Data downloaded from the website of the University of Toronto, Computing in the Humanities and Social Sciences (http://datacentre2.chass.utoronto.ca/pwt56/subjects.html).

To extrapolate the 1965 values backwards, it was necessary to have figures for real GDP, the real capital stock, and the work force for each country. Real GDP per worker and real capital stock per worker were calculated from the national data to extrapolate the 1965 values backwards country by country. Following are the sources for these series and mention of some issues that arose in doing the calculations.

USA
labor force:
1800–1860 Weiss (1992, p. 22).
1870ff U.S. Bureau of the Census (1975) series D167.
GDP: Maddison (2006).
Capital Stock: Gallman (1992, p. 89), with some interpolations using Goldsmith 114 (7)

UK
The data were adjusted to produce a uniform series for Great Britain and Northern Ireland to match the 1965 data, which for the UK at that date.
labor force:
1920–1965: working population from Feinstein (1976, T125–7, col. 5)
1860–1920: 1920 figure extrapolated backwards using Feinstein's series for the working population for Great Britain plus Ireland.

1820–1850: occupied population in Great Britain increased by 10%. This agrees with 1860 figure. Great Britain occupied population from Deane and Cole (1969, p. 143). These population figures are for years ending in 1 like 1801 and 1811, whereas my data set is for years like 1800, 1810 and so forth. Figures for 1800 etc. were estimated on the assumption that the occupied population grew at a constant rate over each decade.

GDP: Maddison (2006).

Capital Stock

1920–1965 net capital stock from Feinstein (1976, T97, col 9). The link from interwar (valued in 1938 prices) and post-war (valued in 1958 prices) was effected with the values of the gross stock for 1938 given in both sets of prices in column 5.

1850–1920: 1920 value extrapolated backwards using the real net stock value for the United Kingdom given Feinstein (1988, p. 441, Col. 7).

1820–1850: extrapolated with capital stock values calculated for Great Britain for Allen (2009b).

Germany

labor force

1820–1850: 1850 figure backcast with Maddison's (2006) population for Germany.

1850–1959: Hoffmann (1965, p. 204–6, col. 9) with some minor interpolations to fill gaps

1965: extrapolated from 1959 figure using Maddison's (2006) population for Germany.

GDP

1804–1850: Hoffmann's (1965, pp. 454–5, col. 10) figures for value added in agriculture, industry, and services in 1850 were extrapolated back to 1804 using Prussian real output series for agriculture (gross production minus seed, p. 395), industry (p. 420), and services (assumed proportional to German population according to Maddison, 2006). Some interpolations were made. The estimate of real GDP moves similarly to Maddison's (2006) series for Germany over the period.

1850–1959: Hoffmann (1965, pp. 827–8, col. 5).

1959–1965: Maddison (2006) GDP for Germany

capital stock

1804–1850: Hoffmann, 1965, p. 253, estimates of the components of the capital stock in 1850 were grouped in categories (agriculture, buildings, and railways) and each was extrapolated back to 1804 using Prussian capital stock data. The corresponding Prussian time series were value of livestock (Tilly, 1978, vol. I, p. 392), value of buildings (p. 402, col. 3, and p. 400), railways (p. 416).

1850–1959: Hoffmann (1965, pp. 253–4, col. 7).

India

figures are for undivided India

labor force: assumed proportional to population, which was taken from Heston (1983, p. 394), and Goldsmith (1983, p. 3).

GDP

1820–1868: assumed equal to 1868

1868–1946: Heston (1983, pp. 394, 397–9, 402).

1946 and 1948: real per capita GDP assumed to be equal in undivided India in 1946 and the new country of India in 1948.

1948–1965: Goldsmith (1983, p. 142–3). Figures for independent India

capital stock

1820, 1850: per capita values assumed to equal 1860 per capita value.

1860–1913: The 1913 value of the reproducible net capital stock in 1951 prices (as below) was extrapolated backward with index of real capital stock defined as nominal productive capital stock (structures, equipment, and livestock) deflated by wholesale price index from Goldsmith (1983, pp. 5, 61).

1913–1946: reproducible net capital stock in 1951 prices in Goldsmith (1983, p. 81)

1949: per capita real capital stock assumed to equal 1946 value.

1949, 1960, 1970: 1949 value extrapolated forward using real net stock of reproducible tangible assets on Goldsmith (1983, p. 158).

1965: interpolated from 1960 to 1970 nominal values using time series of national savings on Goldsmith, 1983, pp. 158, 160.

Japan

labor force

1870–1905: the 1905 figure was extrapolated backwards with Maddison's (2006) population estimate.

1905–65: 'gainfully employed population' from Ohkawa and Rosovsky (1973, pp. 310–11)

GDP–Maddison (2006).

capital stock

1870: capital per worker assumed the same as in 1874

1874–1905: Ohkawa (1966), p. 148).

1905–1960: Ohkawa (1966), p. 262).

1960–1965: Ohkawa and Rosovsky (1973, pp. 315).

Argentina

labor force–

1900–1913: extrapolated from 1913 value below with population from Maddison (2006).
1913–1984: Della Paolera and Taylor (2003, CD ROM), series L1
gdp–Maddison (2006).
capital stock
1900–1913: 1913 value below extrapolated back with ECLA series Hofman KE from Della Paolera and Taylor (2003, CD ROM)
1913–1984: Della Paolera and Taylor (2003, CD ROM), series KZI

Netherlands
labor force
1880–1913: persons employed in 1913 extrapolated back with population from Maddison (2006).
1913–1965: persons employed from van Ark and de Jong (1996, pp. 40–1).
GDP
1800–1913: van Zanden, Smits, et al. (2000).
1913–1965: capital stock in 1913 extended with Maddison (2006).
capital stock
1800–1913: van Zanden, Smits, et al. (2000).
1913–1965: capital stock in 1913 extended with van Ark and de Jong (1996, pp. 40–1).

Spain
labor force–assumed proportional to population, which was from Maddison (2006).
GPD–Maddison (2006).
capital stock–Prados de la Escosura and Rosés (2010), Table A-4, col. B. I am grateful to Leandro Prados for providing these data in a spreadsheet.

Taiwan
labor force–assumed proportional to population, which was from Maddison (2006).
GPD
1901–1912: Mizoguchi (2005), Table 1).
1912–1965–Maddison (2006).
capital stock
1901–1940: Mizoguchi (2005), Table 3) provides investment at ten year intervals and annual gdp. Investment rates computed at ten year intervals and intervening values interpolated. Capital stock calculated with perpetual inventory method.
1940: capital output ratio assumed the same as 1951.
1951–1965: Chow and Lin (2002), pp. 513–4), capital stock K1

Korea
labor force–assumed proportional to population, which was from Maddison (2006).
GPD–Maddison (2006).
capital stock–
1911–1940 value back cast with Mizoguchi's (2000) growth rate of the real capital stock.
1940–capital-ouput ratio assumed to be same as 1953
1953–65: Timmer and van Ark (2000, pp. 25–6), GFCS without residences

Mexico, France, Italy, Belgium, Denmark, Norway, Switzerland
The aggregates for these countries were reconstructed in essentially the same way. Real GDP and population were taken from Maddison (2006). It was assumed that the labor force and population grew at the same rate. The capital stocks were estimated by computing the capital–output ratio in nominal prices from Goldsmith (1985, Appendix A). The capital stock was taken to be structures, equipment, and livestock. Generally, Goldsmith's benchmark years are the same as those used here. Occasionally interpolations were necessary.

References

Acemoglu, Daron, 2002. Directed technical change. The Review of Economic Studies 69, 781–809.
Acemoglu, Daron, 2003. Factor prices and technical change: from induced innovations to recent debates. In: Philippe, Aghion, et al. (Ed.), Knowledge, Information and Expectations in Modern Macroeconomcs: In Honor of Edmund Phelps. Princeton University Press, Princeton.
Acemoglu, Daron, 2007. Equilibrium bias of technology. Econometrica 75, 1371–1409.
Acemoglu, Daron, Zilibotti, F., 2001. Productivity differences. Quarterly Journal of Economics 116 (2), 563–606.
Acemoglu, Daron, Johnson, S., Robinson, J.A., 2001. The colonial origins of comparative development: an empirical investigation. The American Economic Review 91 (5), 1369–1401.
Allen, Robert C., 1983. Collective invention. Journal of Economic Behavior and Organization 4, 1–24.
Allen, Robert C., 2001. The great divergence in European wages and prices from the Middle Ages to the First World War. Explorations in Economic History 38, 411–447.
Allen, Robert C., 2007. India in the great divergence. In: Hatton, Timothy J., O'Rourke, Kevin H., Taylor, Alan M. (Eds.), The New Comparative Economic History: Essays in Honor of Jeffery G. Williamson. MIT Press, Cambridge, MA, pp. 9–32.

Allen, Robert C., 2009a. How prosperous were the Romans? Evidence from Diocletian's price edict (AD 301). In: Alan, Bowman, Andrew, Wilson (Eds.), Quantifying the Roman Economy: Methods and Problems. Oxford University Press, Oxford, pp. 327–345 (2009).
Allen, Robert C., 2009b. The British Industrial Revolution in Global Perspective. Cambridge University Press, Cambridge.
Allen, Robert C., 2011. Technology and the great divergence. Discussion Paper No. 548. Oxford University, Department of Economics.
Allen, Robert C., Bassino, Jean-Pascal, Ma, Debin, Moll-Murata, Christine, van Zanden, Jan Luiten, 2011. "Wages, Prices, and Living Standards in China,1739–1925: in comparison with Europe, Japan, and India". Economic History Review 64 (1), 8–38.
Atkinson, A.B., Stiglitz, J.E., 1969. A new view of technical change. The Economic Journal 79, 573–578.
Badunenko, Oleg, Henderson, Daniel J., Robert Russel, R., 2008a. Bias-Corrected Production Frontiers: Application to Productivity Growth and Convergence.
Badunenko, Oleg, Henderson, Daniel J., Zelenyuk, Valentin, 2008b. Technological change and transition: relative contributions to worldwide growth during the 1990s. Oxford Bulletin of Economics and Statistics 70 (4), 461–492.
Basu, S., Weil, D.N., 1998. Appropriate technology and growth. Quarterly Journal of Economics 113 (4), 1025–1054.
Baumol, William J., 1986. "Productivity growth, convergence, and welfare: what the long-run data show". The American Economic Review 76 (5), 1072–1085.
Berry, R.A., Cline, W.R., 1979. Agrarian Structure and Productivity in Developing Countries. Johns Hopkins University Press, Baltimore.
Blaut, J.M., 1993. The Colonizer's Model of the World. The Guildford Press, New York.
Caselli, F., Coleman II, W.J., 2006. The world technology frontier. The American Economic Review 96 (3), 499–522.
Chow, Gregory, Lin, Anloh, 2002. Accounting for economic growth in Taiwan and Mainland China: a comparative analysis. Journal of Comparative Economics 30 (3), 507–530.
De Vries, Jan, van der Woude, Ad, 1997. The First Modern Economy: Success, Failure and Perseverance of the Dutch Economy. Cambridge University Press, Cambridge, pp. 1500–1815.
Deane, Phyllis, Cole, W.A., 1969. British Economic Growth, 1688–1959, 2nd edition. Cambridge University Press, Cambridge.
Dell, Melissa, 2010. "The Persistent Effects of Peru's Mining Mita". Econometrica 76 (6), 1863–1903.
Della Paolera, Gerardo, Taylor, Alan, 2003. A New Economic History of Argentina. Cambridge University Press, Cambridge.
Engerman, Stanley L., Sokoloff, Kenneth L., 2000. History lessons: institutions, factor endowments, and paths of development in the New World. The Journal of Economic Perspectives 14 (3), 217–232.
Färe, R., Grosskopf, S., Noriss, M., Zhang, Z., 1994. Productivity growth, technical progress, and efficiency change in industrialized countries. The American Economic Review 84 (1), 66–83.
Feinstein, CharlesH., 1976. Statistical Tables of National Income, Expenditure and Output of the U.K. 1855–1965. Cambridge University Press, Cambridge.
Feinstein, Charles H., 1988. Part II. National statistics, 1760–1920. In: Feinstein, Charles H., Sidney, Pollard (Eds.), Studies in Capital Formation in the United Kingdom, 1750–1920. Clarendon Press, Oxford, pp. 258–471.
Fohlin, Caroline, 2007. Finance Capitalism and Germany's Rise to Industrial Power. Cambridge University press, Cambridge.
Gallman, Robert E., 1992. American economic growth before the Civil War: the testimony of the capital stock estimates. In: Gallman, Robert E., John Joseph, Wallis (Eds.), American Economic Growth and Standards of Living before the Civil War (Chicago, 1992), pp. 79–120.
Gerschenkron, Alexander, 1962. Economic Backwardness in Historical Perspective. Harvard University Press, Cambridge.
Glaeser, Edward L., La Porta, Rafael, Lopez-de-Silanes, Flornecio, Shleifer, Andrei, 2004. Do institutions cause growth? Journal of Economic Growth 9, 271–303.
Goldsmith, Raymond W., 1983. The Financial Development of India, 1860–1977. Yale University Press, New Haven.
Goldsmith, Raymond W., 1985. Comparative National Balance Sheets: A Study of Twenty Countries, 1688–1978. University of Chicago Press, Chicago.
Hayami, Yujiro, Ruttan, Vernon W., 1971. Agricultural Development: An International Perspective. Johns Hopkins University Press, Baltimore.
Henderson, Daniel J., Russell, R., 2005. Human capital and convergence: a production-frontier approach. International Economic Review 46 (4), 1167–1205.
Heston, Alan, 1983. National income. In: Dharma, Kumar, Meghnad, Desai (Eds.), The Cambridge Economic History of India, Volume 2. Cambridge University Press, Cambridge, pp. 375–462 (c. 1757 - c. 1970).
Hoffmann, WaltherG., 1965. Das Wachstum der Deutschen Wirtschaft seit der Mitte des 19. Springer-Verlag, Jahrhunderts, Berlin.
Hulten, C.H., 1973. Divisia index numbers. Econometrica 41, 1017–1026.
Jermanowski, Michal, 2007. Total factor productivity differences: appropriate technology vs. efficiency. European Economic Review 51, 2080–2110.
Kaldor, Nicholas, 1957. A model of economic growth. The Economic Journal 67 (268), 591–624.
Kumar, Subodh, Russell, R., 2002. Technological change, technological catch-up, and capital deepening: relative contributions to growth and convergence. The American Economic Review 92, 527–548.
Landes, David S., 1969. The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present. Cambridge University Press, Cambridge.
Lehmann, Hartmut, Roth, Guenther, 1995. Weber's Protestant Ethic: Origins, Evidence, Contexts. Cambridge University Press, Cambridge.
Los, Bart, Timmer, Marcel P., 2005. The 'appropriate technology' explanation of productivity growth differentials: an empirical approach. Journal of Development Economics 77, 517–531.
Maddison, Angus, 2006. Historical Statistics of the World Economy, 1–2006 AD. (most recent version available at) http://www.ggdc.net/MADDISON/oriindex.htm.
McCloskey, D.N., Sanberg, L.G., 1971. From damnation to redemption: judgements on the late Victorian entrepreneur. Explorations in Economic History 9, 89–108.
Mizoguchi, Toshiyuki, 2000. Estimating long-term national accounts statistics of Korea: 1911–1990. In: Hwang, Insang, Odaka, Konosuke (Eds.), The Long-Term Economic Statistics of Korea, 1910–1990: International Workshop. Institute of Economic Research, Hitotsubashi University, Tokyo, pp. 1–21.
Mizoguchi, Toshiyuki, 2005. Estimates of Long Term Economic Growth of Taiwan: Based on Revised SNA. Institute of Economic Research, Hitotsubashi University. (Discussion Paper No. 123).
Nelson, Richard R., Wright, Gavin, 1992. The rise and fall of American technological leadership. Journal of Economic Literature 30, 1931–1964.
North, D.C., Weingast, B., 1989. Constitutions and commitment: evolution of institutions governing public choice in seventeenth-century England. The Journal of Economic History 49, 803–832 (1989).
North, Douglass C., William, Summerhill, Barry, Weingast, 2000. Order, disorder, and economic change: Latin America vs. North America. In: de Mesquita, Bruce Bueno, Hilton, Root (Eds.), Governing for Prosperity,New Haven, pp. 17–58.
Nunn, Nathan, 2008. The long-term effects of Africa's slave trades. Quarterly Journal of Economics 123 (1), 139–176.
Ohkawa, Kazushi, 1966. Estimates of Long Term Economic Statistics of Japan since 1868, Vol. 3, Capital, Tokyo.
Ohkawa, Kazushi, Rosovsky, Henry, 1973. Japanese Economic Growth: Trend Acceleration in the Twentieth Century. Stanford University Press, Stanford.
Otsuka, Keijiro, Ranis, Gustav, Saxonhouse, Gary, 1988. Comparative technological choice in development: the Indian and Japanese Cotton Textile Industries, Basingstoke, Macmillan.
Prados de la Escosura, Leandro, Rosés, Joan R., 2010. Capital accumulation in the long run: the case of Spain, 1850–2000. In: Field, Alexander J. (Ed.), Research in Economic History, 27, pp. 141–200.
Sugihara, Kaoru, 2012. In: Sugihara, Gareth Austen Kaoru (Ed.), Labour Intensive Industrialization in Global History. Routledge, London.
Tilly, R.H., 1978. Capital formation in Germany in the nineteenth century. In: Mathias, P., Postan, M.M. (Eds.), The Industrial Economies: Capital, Labour, and Enterprise, Part I, Britain, France, Germany, and Scandinavia. : Cambridge Economic History of Europe, Vol. VII. Cambridge University Press, Cambridge, pp. 382–441.
Timmer, Marcel, van Ark, Bart, 2000. Capital Formation and Productivity Growth in South Korea and Taiwan: Realising the Catch-Up Potential in a World of Diminishing Returns. Groningen Growth and Development Centre.
U.S. Bureau of the Census, 1975. Historical Statistics of the United States, Colonial Times to 1970, Bicentennial Edition, Part 1, Washington, D.C.
Van Ark, Art, de Jong, Herman, 1996. Accounting for economic growth in the Netherlands since 1913. Research Memorandum GD-26, Groningen Growth and Development Centre.

van Zanden, J.L., Smits, J-P., 2006. National Accounts of the Netherlands, 1800–1913 http://nationalaccounts.niwi.knaw.nl/start.htm.
Weber, Max, 1904-5. The Protestant Ethic and the Spirit of Capitalism, trans. by Talcott Parsons. Allen & Unwin, London. (1930).
Weiss, Thomas, 1992. U.S. labor force estimates and economic growth, 1800–1860. In: Gallman, Robert E., John Joseph, Wallis (Eds.), American Economic Growth and Standards of Living before the Civil War (Chicago, pp. 19–78.