Technology and Convergence

Andrew B. Bernard
Department of Economics
M.I.T.
Cambridge, MA 02139

and

Charles I. Jones
Department of Economics
Stanford University
Stanford, CA 94305

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Abstract

The empirical convergence literature envisions a world in which the presence or lack of convergence is a function of capital accumulation. This focus ignores a long tradition among economic historians and growth theorists which emphasizes technology and the potential for technology transfer. We suggest here that this neglect is an important oversight: simple models which incorporate technology transfer provide a richer framework for thinking about convergence. Empirically, differences in technologies across countries and sectors appear to match differences in labor productivity and to exhibit interesting changes over time.

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The debate over convergence has lost its way. From its initial concerns about the paths of output for poorer nations, it has gotten mired down in a debate about 2% per year convergence rates and their robustness or lack thereof. In spite of work showing that convergence itself is not sufficient to distinguish among important alternative growth models, two lines of thought remain dominant in the convergence debate: that which believes convergence is a robust phenomenon and signals the primacy of the neoclassical growth model and the dominant roles of aggregate capital accumulation in determining relative output levels and growth rates, and that which is skeptical of the world-wide convergence finding and focuses on the possibility of multiple steady states and output paths for similarly endowed countries. However, regardless of the camp one aligns with, both sides have remained fixated on the role of capital, either physical or human, in determining long-run outcomes.

This is perhaps best seen in the oft-cited work of Mankiw, Romer, and Weil (1992) who aim to explain both cross-country differences in output levels and growth rates with a Solow-style growth model in which countries have identical exogenous rates of technological change. The exercise is one of pushing the simple model of capital accumulation to its logical limit, adding only a second capital type when the estimated factor share for physical capital seems too large. Barro and Sala-i-Martin (1992) and Barro, Mankiw, and Sala-i-Martin (1995) argue from a similar perspective.[1]

Almost completely forgotten by the empirical literature is the role of technology. Technology, at best, is allowed to index differences in an initial multiplicative factor, and all economies are assumed to accumulate technology at the same rate. In such a capital-based world, differences in growth rates stem from differences in capital accumulation. Technological choices, through adoption and accumulation, are completely assumed away in ex-

[1] A notable early exception to this characterisation is Dowrick and Nguyen (1989) who examine the convergence of total factor productivity in the OECD.

plaining both relative output levels and growth rates, hence convergence. To the extent that the adoption and accumulation of technologies is important for convergence, the empirical convergence literature to date is misguided.

Section I of this paper makes the simple observation that technology is featured prominently in almost every other analysis of economic growth except for the convergence literature. Economic historians, technologists, and advocates of the "new" growth theory all emphasize the importance of technology for understanding growth, development, and convergence. In Section II, we consider the meaning of technology in the production function and argue for a broader definition of technology than is traditionally recognized in the analysis of the production function. Section III summarizes some evidence on convergence in labour productivity and technology and argues that the evolution of technology is an important driving force behind convergence in the OECD. Finally, Section IV offers our view of where the literature should go in the future.

I. What happened to technology?

The focus on capital accumulation in the recent empirical literature ignores a long tradition among economic historians and technologists and lags behind much of the "new" growth theory. Economic historians have long emphasized the importance of technological progress as a driving force behind economic growth and as one of the key advantages associated with Gerschenkron's "relative backwardness" (Gerschenkron, 1952; Abramovitz, 1986). For example, "innovation-sharing" was one of the primary explanations cited by Baumol (1986) for the convergence he documented among advanced economies. Rosenberg (1982) cautions that technological backwardness may not be unambiguously beneficial, but he nevertheless highlights the prominence of technology transfer in the history of economic growth:

> Francis Bacon observed almost 400 years ago that three great mechanical inventions — printing, gunpowder, and the compass — had "changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation." What Bacon did not observe was that none of these inventions, which so changed the course of human history, had originated in Europe, although it was from that continent that their worldwide effects began to spread. Rather, these inventions represented successful instances of technology transfer... (p. 245).

The current omission of technology from the empirical literature on convergence also runs counter to the emphasis of the "new" growth theory. Initially, of course, the empirical convergence literature was read partially as a rejection of the constant returns to accumulable factors associated with the "AK"-style endogenous growth models. Virtually all of the new "new" growth theory, however, focuses instead on the importance of endogenizing technological change, distinct from capital accumulation, in order to understand economic growth. Technology transfer is then logically a potential force behind convergence. This avenue has been emphasized by Romer (1993) and his "idea gaps," as well in more traditional analysis by Grossman and Helpman (1991), and Parente and Prescott (1994), among others.

II. What is technology?

Since we do not intend to settle the ongoing debates about the most appropriate growth modeling strategy, we will make our points within the context of a constant returns Solow growth model without necessarily endorsing it. Suppose the aggregate production function is given by

$$Y_i = K_i^{\alpha_i} \left(A_i L_i\right)^{1-\alpha_i} \Rightarrow y_i = A_i^{1-\alpha_i} k_i^{\alpha_i} \tag{1}$$

where lower case letters denote per capita quantities and the factor weights, α_i, and the levels of labour-augmenting technological change, A_i, are allowed to vary across countries. The variation in A across countries needs no further explanation. The variation in α, though, may appear slightly strange. Traditionally, technology is represented as a single labour-augmenting factor in the production function. However, in the general $F(K, L, t)$ production function, there is no reason to think that technology need enter multiplicatively. The notion of technology we argue for here is broadened to include the exponents of the production function: two economies with the same K, L, and even A will produce different quantities of output if the α's differ. Economically, we can interpret this difference as arising from the heterogeneity of goods that are produced within an economy. Such heterogeneity may be particularly important if we examine the convergence of productivity at the sectoral rather than aggregate level, for example.

Accumulation takes place in both capital and labour-augmenting technology. Net capital accumulation is is a constant fraction of output

$$\dot{K}_i = s_i Y_i - \delta_i K_i. \tag{2}$$

For the growth rate of technology in country i, we make the simplest assumption possible regarding technology transfer to illustrate the results:

$$\frac{\dot{A}_i}{A_i} = \xi_i \left(\frac{A_w}{A_i} \right) \tag{3}$$

where ξ_i indexes the ability of a country to adopt the most productive labour-augmenting technology, A_w, which is assumed to grow exogenously at rate $g \equiv \xi_w$. One can solve this differential equation to find that the steady state technology ratios are given by

$$\frac{A_i}{A_w} = \frac{\xi_i}{\xi_w}. \tag{4}$$

As usual, steady state growth rates for output per capita and the capital-labour ratio for each country will equal the growth of the world labour-augmenting technology

$$g_{y_i} = g_{k_i} = g_{A_i} = g. \tag{5}$$

Relative steady state levels of output per capita in this framework depend on more than just the relative savings rates, depreciation rates and population growth rates. They also hinge upon the ability of countries to adopt the frontier level of technology and on the aggregate factor shares:

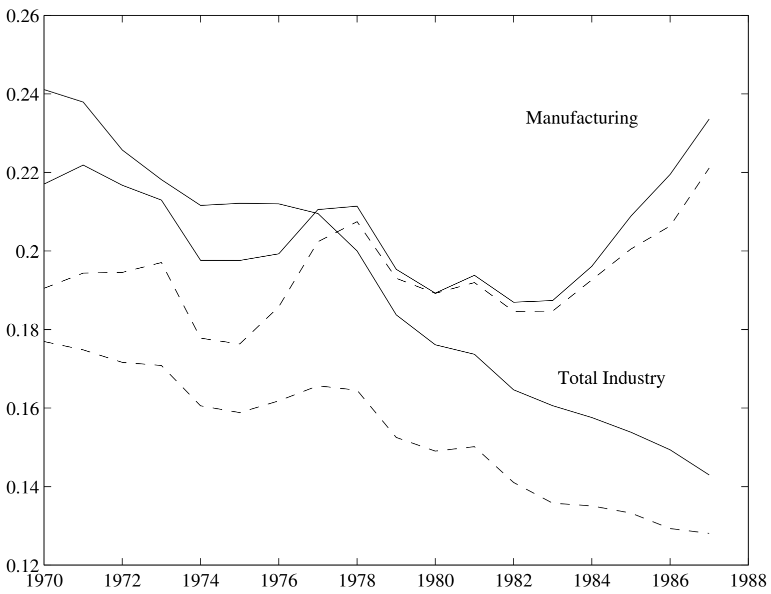
$$\frac{y_i^*(t)}{y_{us}^*(t)} = \frac{\xi_i}{\xi_{us}} \cdot \frac{\left(\frac{s_i}{n_i+g+\delta_i}\right)^{\alpha_i/1-\alpha_i}}{\left(\frac{s_{us}}{n_{us}+g+\delta_{us}}\right)^{\alpha_{us}/1-\alpha_{us}}}. \tag{6}$$

In this framework, we allow technology to vary across countries, both because of differential abilities to adopt the leading technology (or because different amounts of resources are devoted to such adoption) and because product and industry composition varies across countries. This leads to a world in which similar steady states outcomes are the exception rather than the rule. Countries that are good adopters fare well. The mix of products and the ability to reap from the efforts of others determine the relative positions of countries in the long-run, even if they have similar population growth rates and investment rates. One could also derive the rates at which countries converge to their own steady state in this model, and it should be obvious that the result will depend on the parameters of the technology transfer equation in addition to the parameters of the production function.

III. Some facts

Our simple theoretical framework suggests that differences in technologies across countries can have important implications for the convergence, or lack thereof, of labour productivity. In this section, we review some empirical evidence from Bernard and Jones (1994a, 1994b) supporting the hypothesis that there are important differences in technology across countries.

Figure 1: Cross-Country Dispersion in Y/L and TTP



Note: Solid Line = Y/L; Dashed Line = TTP. Cross-country dispersion is measured as the standard deviation of the natural log of productivity.

Fig. 1 compares the cross-country dispersion in labour productivity to the cross-country dispersion in technology for fourteen OECD economies.[2] Results are displayed for total industry and for the manufacturing sector. Here, the measure of technology, Total Technological Productivity (TTP), incorporates variation in both A and α across countries. It is thus a complete measure of technology.[3]

Two results are immediately apparent from the figure. First, there is

[2]The data are from the OECD's Intersectoral Database, and the countries included are the United States, Canada, Japan, Germany, France, Italy, the United Kingdom, Australia, the Netherlands, Belgium, Denmark, Norway, Sweden, and Finland.

[3]Bernard and Jones (1994a) discuss this measure in detail. Essentially, it represents the amount of output produced by an economy with a specified quantity of capital and labour. The numbers reported are calculated using the median capital-labour ratio in 1970.

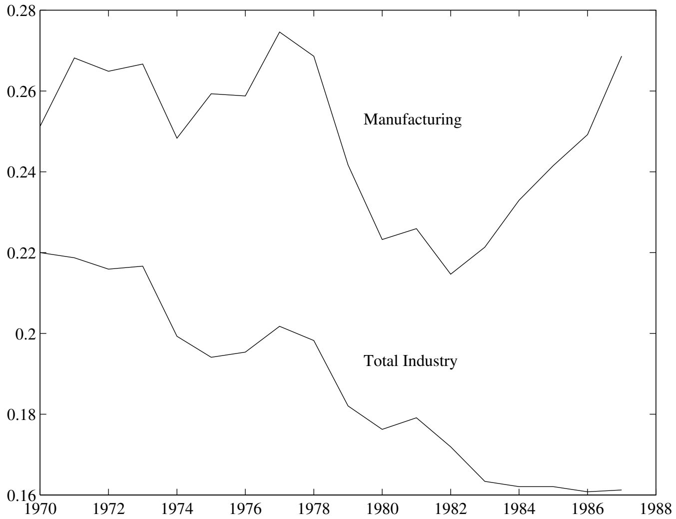
substantial variation in technology across countries, which is roughly the same order of magnitude as the variation in labour productivity. In 1987, the standard deviation of the log of labour productivity is about 0.14 for total industry, and the dispersion of technology is about 0.13. For manufacturing, the two numbers are 0.24 for Y/L and 0.22 for technology. Second, the change in the dispersion of labour productivity over time corresponds closely to the change in the dispersion of technology. For total industry, both measures decline over time, with the decline in the dispersion of labour productivity (from about 0.24 in 1970 to 0.14 in 1987) being slightly more than the decline for TTP (from about 0.18 in 1970 to 0.13 in 1987). For manufacturing, however, both measures exhibit a pronounced lack of convergence and even suggest the presence of an increase in dispersion during the 1980s. The figure suggests that understanding changes in technology may be important for explaining the change in the dispersion of labour productivity over time. It also suggests that the convergence evidence may vary in interesting and informative ways across sectors.

Figures 2 and 3 examine the changing dispersion of technology in more detail by breaking TTP into its components. Fig. 2 examines changes in the labour-augmenting part of technology, A. The figure shows a substantial decline in dispersion for total industry over the 1970s and 1980s, while the pattern for manufacturing is less clear. In the context of the simple model that we outlined before, the results for total industry are consistent with some kind of technology transfer, while the results for manufacturing suggest that technology transfer may be less than automatic.

Fig. 3 illustrates the dispersion in the factor weights that is present in the data. For the purpose of this analysis, we assume that the factor share of income for labour corresponds to its weight in the production function.[4] Another indication of this variation is indicated by the average factor shares

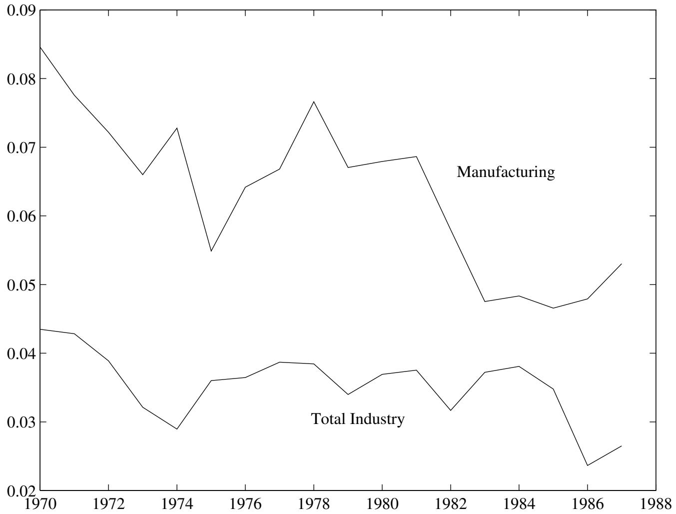
[4] This assumption would be valid under perfect competition and constant returns to scale.

Figure 2: Cross-Country Dispersion in "A"



Note: Cross-country dispersion is measured as the standard deviation of the natural log of productivity.

Figure 3: Cross-Country Dispersion in "α"



Note: Cross-country dispersion is measured as the standard deviation of the labour share of GDP.

over the period 1970-1987. For total industry, the variation is relatively small: the averages for the labour share range from a minimum of 0.61 in Australia and West Germany to a maximum of 0.68 in Denmark and Sweden. In contrast, for manufacturing there is substantial variation: ranging from 0.57 in Japan to 0.79 in the U.K. The figure also indicates little change in the dispersion of factor shares for total industry and some decline in dispersion for manufacturing, particularly in the 1980s.

IV. Where do we go from here?

For the theoretical and empirical reasons outlined here, we think that future work on convergence should focus much more carefully on technology. Why do countries have different levels of technology? How do technologies change over time? How do we measure technology – is it sufficient to simply consider a labour-augmenting technology factor or are other differences in the production function important? How much of the convergence that we observe is due to convergence in technology versus convergence in capital-labour ratios?

A second theme of this paper is that these questions become even more important, and other interesting questions arise, when one considers convergence at the sectoral level rather than the aggregate level. Both for data quality concerns and for theoretical reasons one might be interested in examining convergence in the manufacturing sector. For example, most R&D and international trade occurs in this sector. Yet when one examines the convergence question in this sector, the results look very different from the aggregate results: there is little or no convergence in either labour productivity or technological productivity in the manufacturing sector since the 1970s. Moreover, differences in technology (both in the A's and in the α's) are particularly important in this sector.

This evidence suggests to us that important forces underlying economic growth and the convergence or lack of convergence of labour productivity remain unaddressed by the empirical growth literature. Recent advances in endogenizing technological change have the potential to illuminate these issues, but so far the empirical literature has refrained from exploiting these advances.

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