Volume Title: Globalization in Historical Perspective

Volume Author/Editor: Michael D. Bordo, Alan M. Taylor and Jeffrey G. Williamson, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-06598-7

Volume URL: http://www.nber.org/books/bord03-1

Conference Date: May 3-6, 2001

Publication Date: January 2003

Title: Technology in the Great Divergence

Author: Gregory Clark, Robert C. Feenstra

URL: http://www.nber.org/chapters/c9591

6 Technology in the Great Divergence

Gregory Clark and Robert C. Feenstra

6.1 Introduction

In the late nineteenth century, at the same time that transport and communication costs were declining across the world, there occurred what has recently been dubbed by Ken Pomeranz "The Great Divergence" (2000). Per capita incomes across the world seemingly diverged by much more in 1910 than in 1800, and more in 1990 than in 1910—this despite the voluminous literature on exogenous growth that has stressed the convergence of economies, or, to be more precise, "conditional" convergence. The convergence doctrine holds that economies that are below their steady state should grow more quickly as they converge to the steady state. This approach allows for differences in the steady-state level of per capita income, but its emphasis on convergence has hidden the fact that there has been *divergence* in the absolute levels of income per capita. This has been recently emphasized by Easterly and Levine (2000), who further argue that the divergence of incomes is better explained by appealing to technology differences than by factor accumulation.

In this paper, we examine the changes in per capita income and productivity from 1800 to modern times, and show four things:

1. There has been increasing inequality in incomes per capita across countries since 1800 despite substantial improvements in the mobility of goods, capital, and technology.
2. The source of this divergence was increasing differences in the efficiency or total factor productivity (TFP) of economies.

Gregory Clark is professor of economics at the University of California–Davis. Robert C. Feenstra is professor of economics at the University of California–Davis and a research associate of the National Bureau of Economic Research.

3. These differences in efficiency were not due to the inability of poor countries to *get access* to the new technologies of the Industrial Revolution. Instead, differences in the efficiency of *use* of new technologies explain both low levels of income in poor countries and the slow adoption of Western technology.

4. The pattern of trade from the late nineteenth century between the poor and the rich economies should in principle reveal whether the problem of the poor economies was peculiarly a problem of employing labor effectively.

Results for the first two observations are described in section 6.2, and these are quite consistent with the results of Pomeranz (2000) and of Easterly and Levine (2000). The third observation—that the poor countries had *access* to new technologies—is dealt with in section 6.3. We show that at the same time that incomes were diverging, the ease of technological transmission between countries was increasing because of improvements in transportation, and political and organizational changes. By the late nineteenth century poor countries had access to the same repertoire of equipment, generally imported from the United Kingdom, as the rich. The problem, as we demonstrate in section 6.4 for the case of railways, was inefficiency in the *use* of this new technology in poor countries, even when the direction, planning, and supervision were done by Western experts. Thus, the world was diverging in an era of ever more rapid communication and cheaper transportation, mainly because of mysterious differences in the efficiency of use of technology across countries.

In the last sections of the paper we develop an analytical method that in principle should allow us to say more about the source of these production inefficiencies in poor countries, an area where economists have made little progress. Some have argued that the key is poor management in the low-income countries, and an inability to absorb best-practice technology from the advanced economies because of low levels of education, externalities, or learning by doing. There is just a generalized inefficiency in poor countries. But others, including one of the authors (Clark 1987; Wolcott and Clark 1999), have argued that the problem lies in the poor performance of production workers in low-wage countries and not in management, which in much of the world in the late nineteenth century was relatively easily imported. For ease of reference we call the first hypothesis on efficiency differences *generalized inefficiencies.* The second we refer to as *labor inefficiencies,* or, more generally, *factor-specific inefficiencies.*

Testing which of these possible explanations is correct is not easy. Without knowledge of the parameters of the production function for each industry, how can we say whether the observed inefficiency of the poorer countries stemmed from labor problems or from generalized inefficiencies? Here we make use of results from international trade theory, in particular

Trefler (1993, 1995), to test whether the efficiency differences across countries circa 1910 were of the generalized sort that could come from management or technology absorption problems, as opposed to specific problems in the use of labor. Under this approach we make use of the observed trade patterns of countries to infer the underlying productivities of factors.

Some evidence on the patterns of trade, in historical and modern times, is summarized in section 6.5. We show, for example, that India, at least as of 1910, was a net exporter of land-intensive commodities, which is quite puzzling. This fact can perhaps be explained, however, if its efficiency of land exceeded that of labor. We show in section 6.6 that the factor-content equations from the Heckscher-Ohlin-Vanek (HOV) model allow us to place some bounds on the relative efficiency of factors across countries, so that the trade data can be reconciled. In section 6.7 we explore this issue empirically using the sign pattern of trade, circa 1910 and 1990. Conclusions and directions for further research are given in section 6.8.

6.2 Incomes Per Capita

As noted above, recent research by Pomeranz and others suggests that in 1800 differences in income per capita were modest around the world. In part this result is unsurprising. In a Malthusian world of slow technological advance, living standards themselves reveal nothing about an economy's level of technology or its direction. Thus, the Europeans who visited Tahiti in the eighteenth century were astonished by two things (in addition to the islands' sexual mores)—the stone-age technology of the inhabitants, who so prized iron that they would trade a pig for one nail, and the ease and abundance in which they were living. But that abundance was purchased by a high rate of infanticide, which ensured a small number of surviving children per couple and consequently good material conditions. Tahiti was not a candidate for an industrial revolution, no matter how well fed its inhabitants.

The claim for the sophistication of Chinese and Japanese technology in the eighteenth century lies more properly with their ability to maintain more people per square mile at a high living standard than any European economy could. The low level of Tahitian technology in the late eighteenth century is evident in Tahiti's capacity to support only 14 people per square mile as opposed to England's 166.[1] Japan was supporting about 226 people per square mile from 1721 to 1846, and the coastal regions of China also attained even higher population densities: in 1787 Jiangsu had an incredible 875 people per square mile. It may be objected that these densities were based on paddy rice cultivation, an option not open to most of Europe. But

1. These population figures for Tahiti come from the years 1800 to 1820, when there may already have been some population losses from contact with Europeans. See Oliver (1974).

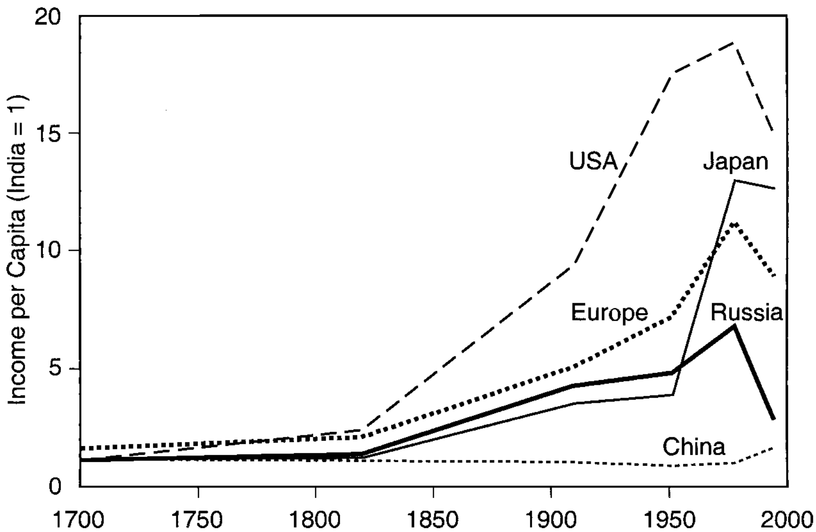

Fig. 6.1 Incomes per capita relative to India

Sources: 1700, 1820, Maddison (1989); 1910, Prados de la Escosura (2000) and Maddison (1989); 1952, 1978, and 1992, Penn World Tables.

even in the wheat regions of Shantung and Hopei, Chinese population densities in 1787 were more than double those of England and France. China had pushed preindustrial organic technology much further by 1800 than anywhere in Europe. The West was clearly behind.

Yet by 1910 the situation had reversed itself, and incomes per capita began to diverge sharply between an advanced group of economies and an underdeveloped world whose most important members were India and China. Figure 6.1 portrays this divergence, showing income per capita in the United States, Japan, Europe, Russia, and China relative to India in 1700, 1820, 1910, 1952, 1978, and 1992. Table 6.1 shows the income per capita of a variety of countries relative to India in 1910, using in part new data assembled by Prados de la Escosura (2000). Income relative to India from the Penn World Tables in 1990 is also shown. In 1910 India and China seem to have been the poorest countries in the world, and income per capita varied by a factor of about 9 to 1 around the world. By 1990 the income in some sub-Saharan Africa countries was no higher than in India in 1910, and incomes per capita by then varied by a factor of about 30 to 1 around the world.

Why did income per capita decline in poor countries such as India and China relative to the advanced economies such as the United States since 1800? We argue that the overwhelming cause was a decline in the efficiency of utilization of technology in these countries relative to the more successful economies such as those of Great Britain and the United States. Conventional estimates report that about one-third of the difference in incomes

Table 6.1 **Income Per Capita, 1910 and 1990**

	GDP per Capita Relative to India		Calculated Efficiency (TFP)		
			1910:	1990:	1990:
	1910	1990	$\alpha = 0.33, \gamma = 0$	$\alpha = 0.33, \gamma = 0.1$	$\alpha = 0.50, \gamma = 0$
Country	(1)	(2)	(3)	(4)	(5)
United States	9.4	14.3	3.9	4.4	2.7
Australia	9.2	11.4	2.9	3.5	2.1
Canada	9.1	13.6	3.6	3.8	2.3
Great Britain	8.0	10.5	4.4	3.8	2.5
New Zealand	7.9	8.9	3.1	—	—
Argentina	7.6	3.7	4.0	2.3	1.7
France	7.2	11.0	3.9	3.6	2.2
Germany	7.0	11.6	4.2	3.4	2.1
Sweden	6.0	11.7	3.6	3.3	2.0
Italy	4.9	9.9	3.1	3.8	2.4
Spain	4.8	7.6	2.8	3.4	2.2
Ireland	4.8	7.5	2.9	—	—
Finland	4.6	11.1	2.8	3.0	1.7
Russia	4.2	—	2.2	—	—
Portugal	3.7	5.9	2.5	2.8	2.1
Japan	3.5	11.3	2.8	2.7	1.6
Ottoman Empire	3.3	3.0	2.0	—	—
The Philippines	2.4	1.3	1.8	—	—
Thailand	1.6	2.8	1.3	1.5	1.3
Korea	1.5	5.3	1.5	2.4	1.6
Indonesia	1.3	1.6	1.2	—	—
China	—	1.0	—	—	—
Zimbabwe	—	0.9	—	0.6	0.5
Zambia	—	0.5	—	0.7	0.8

Sources: Prados de la Escosura (2000); Penn World Tables (PWT 5.6).
Notes: TFP in column (3) is computed assuming full capital mobility between countries, according to equation (5). TFP in columns (4) and (5) is computed from equation (1′). Dashes indicate data are not available.

per capita between countries comes from capital (conventionally measured), and the rest from efficiency (TFP) differences.[2] But this assumes that differences in capital per worker across countries, which are very highly correlated with differences in income per capita and measured TFP since World War II, were exogenous. In a world where capital can flow between economies, capital/worker should be regarded as an endogenous variable, and it would itself *respond to* differences in the country productivity levels.

6.2.1 Perfect Capital Mobility

As a first approximation, we believe that the rental cost of capital was effectively equalized across rich and poor countries by international capital

2. See, for example, Easterly and Levine (2000).

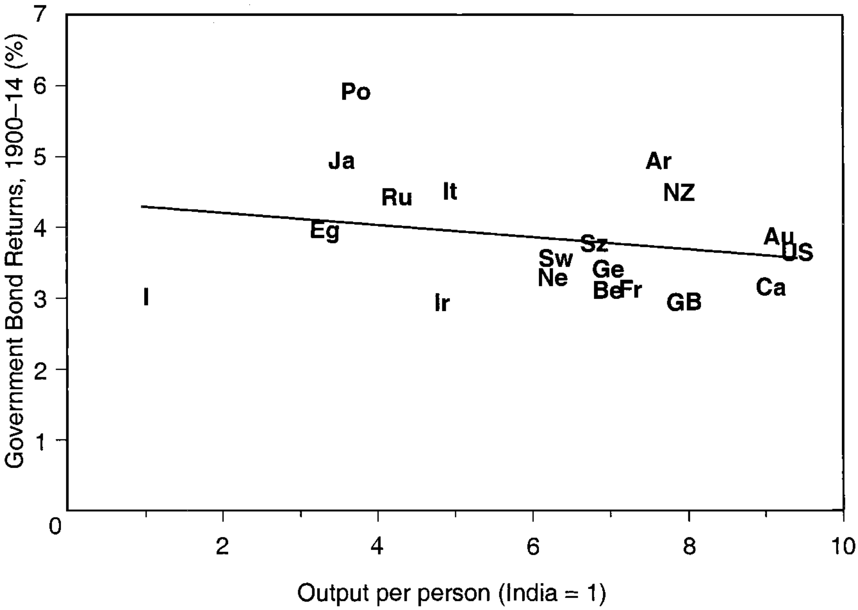

Fig. 6.2 Government bond returns, 1900–1914

Sources: Table 6.1. India and New Zealand: Edelstein (1982). Great Britain, Ireland, United States, France, Germany, Belgium, the Netherlands, Canada, Italy, and Switzerland: Homer and Sylla (1996). Argentina, Egypt, Japan, Russia, Sweden, Portugal, and Australia (sterling bonds in London): Mauro, Sussman, and Yafeh (2001).

Notes: Output per person is measured as an index with India set equal to 1. For the United States, municipal bonds yields were used. Egyptian income per person was asumed the same as the Ottoman Empire. Irish returns were assumed the same as British returns. Indian and New Zealand returns are from 1870–1913. The symbols used are as follows: Au (Australia), Ar (Argentina), Be (Belgium), Ca (Canada), Eg (Egypt), Fr (France), Ge (Germany), GB (Great Britain), I (India), Ir (Ireland), It (Italy), Ja (Japan), Ne (the Netherlands), NZ (New Zealand), Po (Portugal), Ru (Russia), Sw (Sweden), Sz (Switzerland), and US (United States of America).

movements by the late nineteenth century. Figure 6.2, for example, shows rates of return on government bonds in nineteen countries at a variety of income levels in 1900–1914 as a function of the relative level of output per capita in each country in 1910. There was variation in the rates of return on these various government bonds in the range of about 2 to 1. But, importantly, this variation had little correlation with the income level of the country. Indeed, if we regress government bond rates in 1900–1914 on output per capita though the slope coefficient is negative it is statistically insignificantly different from zero: Rates of return on government bonds seem uncorrelated with income.

We can also get rates of return on private borrowing by looking at returns on railway debentures. Railways were the biggest private borrowers in the international capital markets in the late nineteenth century, and their capital needs were so great that if they were able to borrow at international rates

Table 6.2 Rates of Return on Railway Debentures, 1870–1913

Country or Region	Relative Output Per Capita (India = 1)	Rate of Return (%)
United States	9.4	6.03
Canada	9.1	4.99
United Kingdom	7.9	3.74
Argentina	7.6	5.13
Brazil	—	5.10
Western Europe	6.1	5.28
Eastern Europe	4.1	5.33
British India	1.0	3.65

Source: Table 1 in Edelstein (1982, 125).
Note: Dash indicates data are not available.

of return it would help equalize rates of return across all assets in domestic capital markets. Table 6.2 shows the realized rates of return earned by investors in railway debentures in the London capital market between 1870 and 1913. Again, there are variations across countries. But, importantly for our purposes, this variation shows no correlation with output per person. Indeed, India, one of the poorest economies in the world, had among the lowest railway interest costs because the Indian government guaranteed the bonds of the railways as a way of promoting infrastructure investment. This rough equalization of returns to poor and rich countries was achieved by significant capital flows into these countries. By 1914 Egypt, the Ottoman Empire, Argentina, Brazil, Mexico, and Peru had all attracted at least £10 per head of foreign investment (Pamuk 1987).

In a world of rapid capital mobility, how should we calculate TFP? Suppose as an approximation that the production function is Cobb-Douglas so that

$$Y_i = A_i K_i^{\alpha} L_i^{\beta} T_i^{\gamma}, \tag{1}$$

where T_i denotes land and A_i the efficiency (TFP) of country i. Choose units so that A_i, K_i, Y_i, and T_i are 1 in India. Taking capital stocks as exogenous, the income per capita of other economies relative to India would be

$$\frac{Y_i}{L_i} = A_i \left(\frac{K_i}{L_i}\right)^{\alpha} \left(\frac{T_i}{L_i}\right)^{\gamma}. \tag{2}$$

The rental on capital can be computed by differentiating equation (1). Taking this derivative and assuming the same rental on capital in all countries, then capital per worker in country i relative to India would be[3]

3. The derivative of equation (1) with respect to K_i can be expressed as $R_i = \alpha A_i(K_i/L_i)^{(\alpha-1)}(T_i/L_i)^{\gamma}$. Dividing this entire expression by the same equation for India, which is assumed to have the *same* rental R_i, we therefore obtain $1 = A_i(K_i/L_i)^{(\alpha-1)}(T_i/L_i)^{\gamma}$, where all variables are now expressed relative to India. Then equation (3) follows directly.

$$(3)\qquad \frac{K_i}{L_i} = A_i^{1/(1-\alpha)}\left(\frac{T_i}{L_i}\right)^{\gamma/(1-\alpha)}.$$

The amount of capital employed would thus depend on the level of efficiency of the economy. The more efficient an economy, the more capital it would attract, which would have a second round effect in increasing income per person. Substituting equation (3) into equation (2), we obtain the following expression for output per capita:

$$(4)\qquad \frac{Y_i}{L_i} = (A_i)^{1/(1-\alpha)}\left(\frac{T_i}{L_i}\right)^{\gamma/(1-\alpha)}.$$

Notice that the right-hand sides of equations (3) and (4) are identical, so that capital/worker and output/worker are equal with capital endogenous and rates of return equalized across countries. It follows from equation (4) that we can calculate relative efficiencies in the world economy circa 1910 as

$$(5)\qquad A_i = \left(\frac{Y_i}{L_i}\right)^{1-\alpha}\left(\frac{T_i}{L_i}\right)^{-\gamma}.$$

Thus, in this case we can calculate relative TFP for each country relative to India from just the relative outputs per capita and the relative amount of land per person. Since the share of land in national income, γ, has become very small in recent years, equation (4) suggests that the sole significant cause of differences in income per capita between India and the United States and other advanced economies is differences in TFP.

6.2.2 Evidence from 1910

Even without reliable data on capital stocks across countries, we can calculate TFP from equation (5) if there is mobile capital. Column (3) of table 6.1 and figure 6.3 show the implied TFP of the various countries in the world in 1910 for which we have data, relative to India, assuming the share of capital in national income was 0.33 and that of land was 0.1. Differences in the land endowment per person were great enough that even assuming land had only a 10 percent share in output we seem to be overcorrecting for the effect of land on income per capita. Thus there is no reason to believe that the efficiency of the U.S., Canadian, or Australian economies was really below that of Great Britain in 1910. What we also see is that in a world of free-flowing capital, modest differences in the efficiencies of economies get translated into much bigger differences in income, through generation of additional savings by higher income and the movement of capital to the high-efficiency areas.

The assumption that capital invested was constant per unit of gross domestic product (GDP) might be regarded as unreasonable for 1910. Perhaps then capital was not so mobile as now, so that poorer economies typically

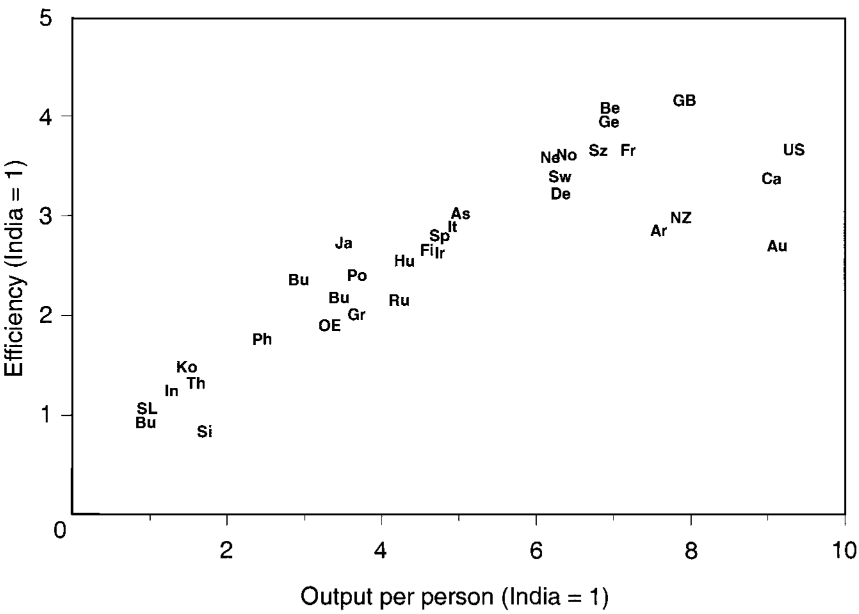

Fig. 6.3 Calculated differences in efficiency (TFP) circa 1910

Notes: Output per person is measured as an index with India set equal to 1. Efficiency is measured as an index with India again set to 1. The country symbols are as follows: A (Austria), Au (Australia), Ar (Argentina), Be (Belgium), Bu (Burma), Ca (Canada), De (Denmark), Fi (Finland), Fr (France), Ge (Germany), GB (Great Britain), Gr (Greece), Hu (Hungary), I (India), In (Indonesia), Ir (Ireland), It (Italy), Ja (Japan), Ko (Korea), Ne (the Netherlands), NZ (New Zealand), OE (Ottoman Empire), Ph (the Philippines), Po (Portugal), Ru (Russia), SL (Sri Lanka), Sp (Spain), Sw (Sweden), Sz (Switzerland), Th (Thailand), and US (United States).

had smaller stocks of capital relative to output and higher returns on capital. This proposition is difficult to test, but one partial measure is afforded by the amount of railway line per unit of GDP observed. Railways were huge sinks of capital in the late nineteenth century and a popular vehicle for foreign investment. If capital was really scarce in the poor countries, then along with other investments the stock of rail line per unit of income should be smaller the lower the income level per person. Figure 6.4 shows railway line per unit of income as an index versus GDP per capita for a variety of countries in 1910. If we were to exclude the low-population-density settler colonies of North America, Argentina, and Australasia, we would find that poor countries had as many miles of railway line per unit of GDP as rich countries.

6.2.3 Evidence from 1990

The assumption here that capital will be proportional to output finds support in the international economy of the 1990s. Using a sample of coun-

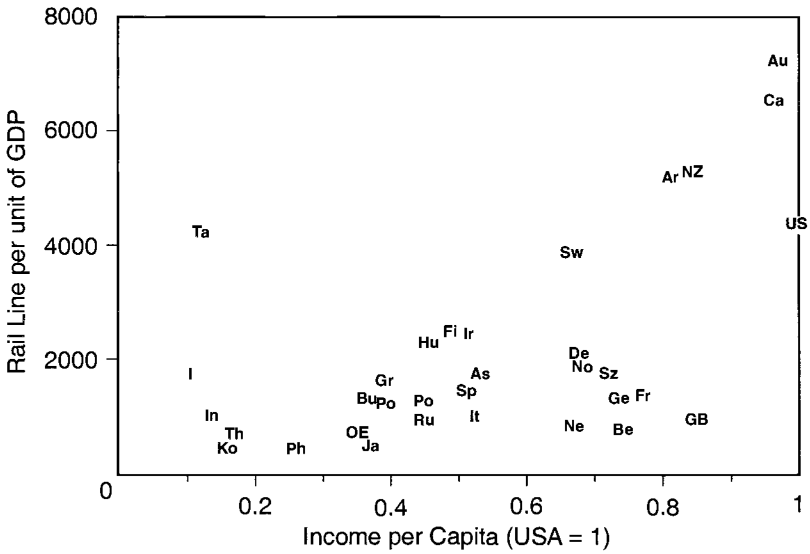

Fig. 6.4 Railway line per unit of GDP, 1910
Note: Country symbols are as in figure 6.3.

tries including those in table 6.1 for 1990, figure 6.5 shows capita per worker versus GDP per worker, with both measured relative to India. Recall from equations (3) and (4) that these should be equal with full capital mobility, and from figure 6.4, capital is clearly closely proportional to output. Regressing the log of capital per worker on the log of GDP per capita on all countries of the Penn World Tables (PWT) for which capital is available for 1990, we find

$$\ln\left(\frac{\text{capital}}{\text{worker}}\right) = \underset{(0.11)}{-0.01} + \underset{(0.07)}{1.32}\ln\left(\frac{\text{GDP}}{\text{worker}}\right), \qquad N = 60,\ R^2 = 0.85.$$

The coefficient on ln(GDP/worker) is somewhat higher than unity, but still seems consistent with the hypothesis that capital is roughly proportionate to output, as implied by full capital mobility with Cobb-Douglas production functions across countries.

How important are efficiency differences in explaining income differences in 1990? For the 1990 data, since land rents are so small a share of income by then, we ignore these. Since PWT does not provide us with data on the share of national income received by labor and capital, in order to estimate α, we rewrite equation (1) as $\ln(Y_i/L_i) = \ln A_i + \alpha \ln(K_i/L_i)$, and regress real GDP per worker on real capital stock per worker. Running this regression over all countries and years for which data are available in PWT, 1965–90, and including fixed effects for countries, we obtain $\alpha = 0.50$ (stan-

Fig. 6.5 Capital per worker versus GDP per worker, 1990
Source: Penn World Tables (5.6).

dard error = 0.01). Performing the same regression in first differences, which still include fixed effects for countries, we obtain $\alpha = 0.34$ (s.e. = 0.04). Thus, the interval [0.33, 0.5] gives an adequate range for the share of national income going to capital, and this is quite consistent with our priors for the capital share across various countries. In the final columns of table 6.1 we report the calculation of TFP using these values of α and the formula

$$(1') \qquad TFP_i = A_i = \frac{(Y_i/L_i)}{(K_i/L_i)^{\alpha}},$$

where all variables are measured relative to those in India.

In figure 6.6, we graph real GDP per capita against TFP, using the intermediate value of $\alpha = 0.4$. There is quite clearly a strong positive relationship between these measures of technology and income for the sample of countries we have used. We saw above that capital per worker and GDP per worker are also closely linked. When GDP per capita is regressed against both these variables for 1990, we obtain

$$\ln(\text{GDP per capita}) = \underset{(0.04)}{-0.02} + \underset{(0.07)}{1.06}\ln(\text{TFP}) + \underset{(0.03)}{0.43}\ln\left(\frac{\text{capital}}{\text{worker}}\right),$$

$$N = 60,\ R^2 = 0.96.$$

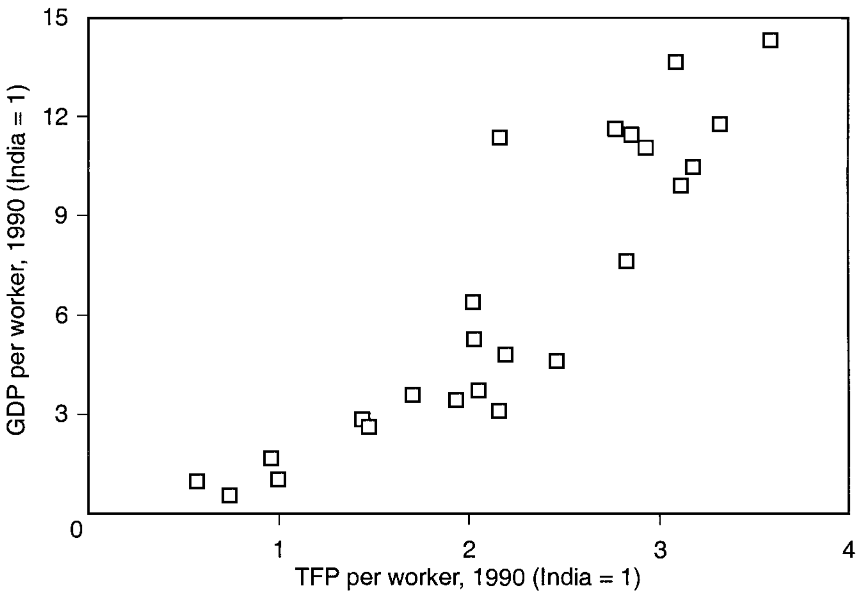

Fig. 6.6 GDP per capita versus TFP, 1990
Source: Penn World Tables (5.6).

From this regression, it appears that both TFP and capital are important determinants of national income. The relative contributions of each in explaining GDP per capita can be computed by expressing this regression in terms of variances:

$$\text{var(GDP per capita)} = 1.06^2 \text{ var(TFP)} + 0.43^2 \text{ var}\left(\frac{\text{capital}}{\text{worker}}\right) + 0.91 \text{ cov} + \text{var(error)},$$

where all variables are expressed in logs, and the covariance is between TFP and capital/worker. Using the sample values for these variances, we find that TFP explains one-quarter of the variance in GDP per capita, and capital/worker explains one-third of this variation, but the *covariance* between TFP and capital/worker explains nearly 40 percent of this variation! This reinforces our argument that capital/worker should be regarded as an endogenous variable, itself *responding to* differences in the level of productivity across countries.

We can test for the endogeneity of capital by using equation (3), while ignoring land ($\gamma = 0$). Running this regression for 1990, we obtain

$$\ln\left(\frac{\text{capital}}{\text{worker}}\right) = \underset{(0.21)}{0.55} + \underset{(0.27)}{1.86} \ln(\text{TFP}), \qquad N = 60, R^2 = 0.46.$$

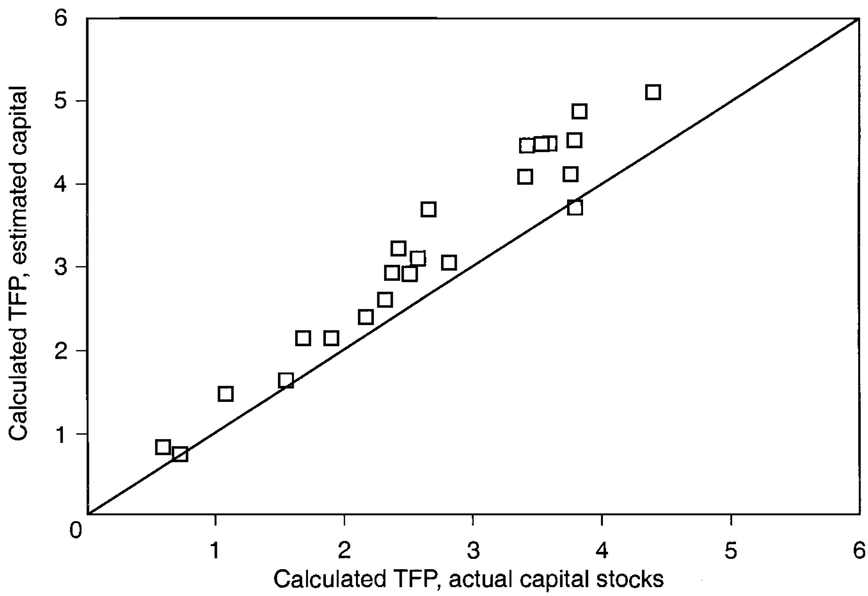

Fig. 6.7 TFP calculated with and without capital stock information, 1990
Note: TFP calculated using $\alpha = 0.33$.

The implied capital share is $\alpha = 1 - (1/1.86) = 0.46$, which is quite close to the value $\alpha = 0.4$ used to construct TFP in this regression. That is, the hypothesis of perfect capital mobility, with equalization of rentals across countries, receives some support from the coefficient on ln(TFP) in this regression. However, the fact that the constant term is significantly different from zero indicates that *full* capital mobility, with Cobb-Douglas production functions across countries, does not appear to hold.

If capital is indeed mobile, then we should really take the regression above, explaining capital/worker, and substitute this into the previous regression, explaining GDP per capital. In other words, let us treat TFP as the only underlying determinant of income, and use this to obtain

$$\underset{}{\ln(\text{GDP per capita})} = \underset{(0.10)}{0.21} + \underset{(0.13)}{1.85}\ln(\text{TFP}), \qquad N = 60,\ R^2 = 0.79.$$

According to these estimates, TFP has a *magnified* impact on income per capita, with an elasticity of 1.85, via its direct effect and its induced effect on capital flows. This is exactly what we expect from equation (4).

As a final check for 1990, we can compute TFP according to equation (3), without using data on capital stocks but assuming full capital mobility. Then, as shown in figure 6.7, we find a very close correlation between TFP calculated using the capital stock information, and TFP calculated assuming that capital per worker is proportional to GDP per worker. The observations mostly lie above the 45-degree line because India has a relatively small capital stock, and output per worker and capital per worker are both measured relative to India. The correlation coefficient between the two measures is 0.96. Thus, by 1990 it seems plausible to regard TFP as the primary driver of differences in income per capita across countries, with capital playing a secondary and derivative role.

6.2.4 Imperfect Capital Mobility

Above we assumed perfect capital mobility. Since there likely were and are frictions in international capital markets, let us consider whether our conclusion that income differences were driven by TFP differences has to be weakened once we allow for imperfect capital mobility, and therefore differences in the rental on capital across countries. To see how differences in the rental cost of capital modify our analysis, again compute the rental on capital by differentiating equation (1). Allowing this to differ across countries, and expressing all variables in country i relative to India, we obtain[4]

$$(3') \qquad \frac{K_i}{L_i} = \left(\frac{A_i}{R_i}\right)^{1/(1-\alpha)} \left(\frac{T_i}{L_i}\right)^{\gamma/(1-\alpha)}.$$

Thus, the amount of capital employed will vary inversely with its rental, which now appears on the right of equation (3′). Substituting equation (3′) into equation (2), we obtain the following expression for output per capita:

$$(4') \qquad \frac{Y_i}{L_i} = (R_i)^{-\alpha/(1-\alpha)} (A_i)^{1/(1-\alpha)} \left(\frac{T_i}{L_i}\right)^{\gamma/(1-\alpha)}.$$

Comparing equations (3′) and (4′), we see that capital/worker and output/worker differ by exactly the rental term, so that

$$(5') \qquad \frac{K_i}{L_i} = \frac{(Y_i/L_i)}{R_i}.$$

Countries with lower rentals will attract more capital. Note that relative TFP (with $\gamma = 0$) can still be calculated as in equation (1′). The rental of capital is, of course, the product of the rate of return on capital in each country and the purchase price of capital goods. The evidence we have on the purchase price of capital goods for 1910 is the cost of fully equipped cotton spinning and weaving mills per spindle. This is a reasonably good general index of the cost of capital goods in these countries because cotton mills generally embodied imported machinery and power plants combined with local construction of the buildings. We also saw above little sign

4. From note 3, the rental on capital is $R_i = \alpha A_i (K_i/L_i)^{(\alpha-1)} (T_i/L_i)^{\gamma}$. Now divide this by the same equation for India and express all variables relative to India, to obtain, $R_i = A_i (K_i/L_i)^{(\alpha-1)} (T_i/L_i)^{\gamma}$. Then equation (3′) follows directly.

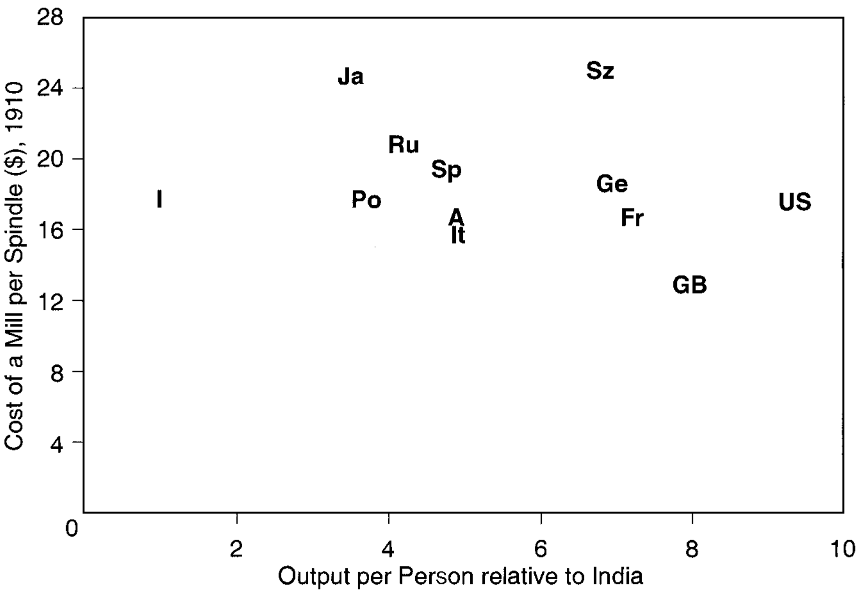

Fig. 6.8 The estimated purchase price of capital in 1910
Sources: Table 6.1 and Clark (1987).
Notes: Output per person is measured as an index with India set equal to 1. The symbols used are as follows: A (Austria), Fr (France), Ge (Germany), GB (Great Britain), I (India), It (Italy), Ja (Japan), Po (Portugal), Ru (Russia), Sp (Spain), Sz (Switzerland), and US (United States).

that rates of return on capital correlated with output per person in 1900–14. Thus the purchase price of capital goods in 1910 should be a reasonably good estimator of the rental cost of capital. Figure 6.8 shows these measures of capital costs relative to output per person in 1910. There is no strong sign in the pre–World War I international economy of any link between rental costs of capital and output per capita. Thus, at least for this period we do not need to worry about restricted capital mobility very much.

The PWT do report significant differences in the purchase prices of capital goods across countries in the post–World War II period, however. For the data in 1990, we can repeat some of our earlier regressions allowing for the effect of capital rental differences. Data on the price of investment goods are taken from the benchmark surveys for the PWT, as described in Jones (1994) and also used in De Long and Summers (1991).[5] Several types of capital goods are available, and we use here the overall price of investment goods. The rental on investment goods is, of course, the interest rate

5. These data are available at [http://emlab.berkeley.edu/users/chad/RelPrice.asc].

times its purchase price. For these years we do not have information on interest rates by country. However, provided that interest rates (and depreciation rates) do not vary with output per capita, we can use the purchase price of investment goods as a proxy for its rental in our estimations.

Regressing the log of capital per worker on the log of GDP per capita and also the log of the rental, we obtain

$$\ln\left(\frac{\text{capital}}{\text{worker}}\right) = \underset{(0.11)}{0.17} + \underset{(0.08)}{1.16} \ln\left(\frac{\text{GDP}}{\text{worker}}\right) - \underset{(0.23)}{0.47} \ln(\text{rental}),$$

$$N = 52,\ R^2 = 0.89.$$

The sample used here is on all countries of the PWT for which capital stocks are available for 1990, and we also have the price of investment goods in 1980 reported in Jones (1994). The coefficient on ln(GDP/worker) is reduced by inclusion of the rental, so that it becomes closer to unity. The rental itself has a negative coefficient, as predicted from (5′), but less than unity; given the measurement error that is present in using the purchase price of investment goods rather than their rental, it is not surprising that this coefficient is biased toward zero.

Computing TFP according to equation (1′) using the value of $\alpha = 0.4$, we can treat this and the rental price of investment goods as the underlying determinants of income, and run equation (4′) to obtain

$$\ln(\text{GDP per capita}) = \underset{(0.08)}{0.27} + \underset{(0.12)}{1.65} \ln(\text{TFP}) - \underset{(0.18)}{0.67} \ln(\text{rental}),$$

$$N = 52,\ R^2 = 0.87.$$

Once again, we find that TFP has a *magnified* impact on income per capita, with an elasticity of 1.65, via its direct effect and its induced effect on capital allocation. The relative contributions of TFP versus the rental in explaining GDP per capita can be decomposed from this regression according to

$$\text{var(GDP per capita)} = 1.65^2\ \text{var(TFP)} + 0.67^2\ \text{var(rental)} - 2.21\ \text{cov} + \text{var(error)},$$

where the covariance is between TFP and the rental on investment goods. Using the sample values for these variances, we find that TFP explains fully two-thirds of the variance in GDP per capita, whereas the rental only explains 5 percent of this variation, with the *covariance* between TFP and the rental explaining another 16 percent of this variation. This, including the rental on capital across countries, does not change our conclusion that TFP is the driving force behind differences in GDP per capita, with capital/worker *responding to* differences in the level of productivity.

Where do these differences in productivity come from? Some recent authors have argued that geography or climate (Sachs 2001), or institutions (Acemoglu, Johnson, and Robinson 2001), or social capital (Jones and Hall 1999) plays an important role. We do not dispute that these may be important, but our approach is different. Rather than looking for some external cause for countries to differ in their efficiency levels, we will instead look internally at productivity itself, and ask whether the cross-country variation in TFP should be attributed to the *access* to or to the *use of* technologies.

6.3 Access to Technology

We see that the increased disparity in income per capita across the world stemmed largely from an increased disparity in the efficiency of economies, the amount of output produced per unit of input. The next thing we show is that little of this disparity stemmed from differences in *access* to technology. Economic growth since the Industrial Revolution has been largely based on an expansion of knowledge. The fact that the Industrial Revolution came from an increase in knowledge, rather than from capital accumulation or from the exploitation of natural resources, seemed to imply that it would spread with great rapidity to other parts of the world, for although developing new knowledge is an arduous task, copying innovations is much easier. Also, although some of the new technology eventually was very sophisticated, some of it was relatively simple, or required little technical expertise to operate. Thus, artificial fertilizers in the late nineteenth century, and new strains of crops in the twentieth, for example, which dramatically boosted agricultural yields, were both relatively simple technologies for poor countries to adopt. Further, given the possibilities of specialization in international trade, the poorer countries did not need to acquire all the new Western technology. They could instead adopt the simplest and most easily transferable techniques, and import products embodying more sophisticated processes from the more economically advanced countries. In textiles, for example, spinning coarse yarn was much easier technically than spinning fine yarn. Countries such as India could thus specialize in coarse yarn, and import finer cloth.

Further, there were a series of interrelated technical, organizational, and political developments in the nineteenth century that made technological transmission much easier. The important technological changes were the improvements in transport through the development of railways, steamships, the Suez and (later) Panama canals, and the telegraph. The organizational change was the development of specialized machine-building firms in Great Britain and later the United States. The political changes were the extension of European colonial empires to large parts of Africa and Asia, and the political developments within European countries. By the eve of World War I the first great globalization of the world economy was complete. Political and economic developments in the twentieth century disrupted that earlier globalization, but even by 1914 it was clear that differences in the efficiency of economies could not be attributed just to differences in the type of technology employed.

6.3.1 Transport and Communication

In the course of the nineteenth century, land transportation, even in the poorest countries, was revolutionized by the spread of railways. Table 6.3 shows the miles of railroad completed in selected countries by 1850, 1890, and 1910. The great expansion of the rail network in the late nineteenth century, even in very poor and underdeveloped countries such as Russia and India, improved communication between the coast and the interior immensely (remember, the circumference of the earth is only 26,000 miles). Railroad development was associated with imperialism. Thus, independent countries such as China had little railway development before 1914.

Ocean transport was similarly revolutionized in this period by the development of the steamboat. In the 1830s and 1840s, although steamships were faster and more punctual than sailing ships, they were used only for the most valuable and urgent cargo, such as mail, because of their very high coal consumption. The huge amount of coal that had to be carried limited the amount of cargo they could hold on transoceanic voyages. To sail from Bombay to Aden in 1830 the *Hugh Lindsay* "had to fill its hold and cabins and pile its decks with coal, barely leaving enough room for the crew and the mail" (Headrick 1988, 24). The liner *Britannia* in the 1840s required 640 tons of coal to cross the Atlantic with 225 tons of cargo. Thus, even in the 1850s steam power was used only for perishable and high-value cargoes.

But in the 1850s and 1860s four innovations lowered the cost of steam transport. These were the screw propeller, iron hulls (iron-hulled boats were 30–40 percent lighter and gave 15 percent more cargo capacity for a given amount of steam power), compound engines that were much more fuel efficient, and surface condensers (previously steamboats had to use seawater to make steam, which produced corrosion and fouling of the engine). These last two innovations greatly reduced the coal consumption of engines per horsepower per hour. In the 1830s it took 4 kg of coal to produce 1 hp-hour, but by 1881 the quantity was down to 0.8 kg. This directly reduced costs, but since it also allowed ships to carry less coal and more cargo there was a further reduction in costs. Real ocean freight costs fell by nearly 35 percent

Table 6.3 Railway Mileage Completed

Year	Britain	United States	Germany	France	Russia	India
1850	6,088	9,021	3,639	1,811	311	0
1890	17,291	208,152	26,638	20,679	19,012	16,918
1910	19,999	351,767	38,034	25,156	41,373	32,789

from 1870 to 1910. In 1906, for example, it cost 8 shillings to carry a ton of cotton goods by rail the thirty miles from Manchester to Liverpool, but only 30 s. to ship those goods the 7,250 miles from Liverpool to Bombay. This cost of shipping cotton cloth was less than 1 percent of the cost of the goods. By the late nineteenth century industrial locations with good water access that were on well-established shipping routes—Bombay, Calcutta, Madras, Shanghai, Hong Kong—could get access to all the industrial inputs of Great Britain at costs not very much higher than many British firms. In part this was because, since Great Britain's exports were mainly manufactures with high value per unit volume, there was excess shipping capacity on the leg out from Great Britain, making the transport of industrial machinery and parts to underdeveloped countries such as India relatively cheap.

While freight costs fell, these technical advances also increased the speed of travel across the oceans. The fastest P&O (Peninsular and Oriental Steam Navigation Company) liner in 1842, the *Hindustan,* had a speed of 10 knots per hour. By 1912 P&O's fastest boat, the *Maloja,* could do 18 knots. The speed of travel across oceans was further enhanced by the opening of the great canals, the Suez canal in 1869 and the Panama canal in 1914. The Suez canal alone saved 41 percent of the distance on the journey from London to Bombay and 32 percent of the distance on the journey from London to Shanghai. Thus, although in the 1840s it took sailing ships from five to eight very uncomfortable months to get to India, by 1912 in principal the journey could be done in fifteen days.

The last of the important technical innovations in the late nineteenth century was the development of the telegraph. For the poorest countries of Africa and the East the key development was the invention of submarine cables for the telegraph. In the 1840s if an Indian firm bought British textile machinery and ran into problems with it, it would take the firm at best ten months to receive any return communication from the machine builders. In 1851 the first submarine telegraph cable was laid between France and England. By 1865 India was linked to Great Britain by a telegraph system partly over land that could transmit messages in twenty-four hours, and in 1866 a successful transatlantic telegraph service had been established. Thus, by 1866 orders and instructions could be communicated halfway across the world in days.

These changes together made the world a much smaller place in the late nineteenth century than it had been earlier. Information could travel much faster. We know, for example, that the average time it took news to travel from Rome to Cairo in the first three centuries A.D., when Egypt was a province of the Roman Empire, was about one mile per hour. As late as the early eighteenth century it had taken four days to send letters 200 miles within Great Britain. With the telegraph, rail, and steamship it was possible to send information across the world in much less time. The steamship and railroad also made travel faster and much more reliable for people and goods. And the development of the steamship made the cost of reaching far-flung places quite low as long as they had good access to ocean navigation. The technological basis for the export of Industrial Revolution technologies to almost any country in the world thus seemed to have been completed by the last quarter of the nineteenth century.

6.3.2 Organizational Changes

In the early nineteenth century a specialized machine-building sector developed within the Lancashire cotton industry. These machinery firms, some of which (such as Platt) were exporting at least 50 percent of their production as early as 1845–70, had an important role in exporting textile technology. These capital goods firms were able to provide a complete package of services to prospective foreign entrants to the textile industry, which included technical information, machinery, construction expertise, and managers and skilled operatives. By 1913 the six largest machine producers employed over 30,000 workers (Bruland 1989, 5, 6, 34). These firms reduced the risks to foreign entrepreneurs by such practices as giving them machines on a trial basis and undertaking to supply skilled workers to train the local labor force. As a result, firms like Platt sold all around the world. Table 6.4 shows the number of orders for ring-spinning frames Platt took (each order typically involved numbers of machines) for a sample of nine years in each of the periods 1890–1914 and 1915–1934. Indeed, for ring frames England was a small share of Platt's market throughout these years.

Similar capital goods exporters developed in the rail sectors, and later in the United States in the boot and shoe industry. British construction crews completed railways in many foreign countries under the captainship of such flamboyant entrepreneurs as Lord Brassey. The reason again for the overseas exodus was in part the saturation of the rail market within Great Britain by the 1870s after the boom years of railway construction. By 1875, in a boom lasting just forty-five years, 71 percent of all the railway line ever constructed in Great Britain was completed. Thereafter the major markets for British contractors and engine constructors were overseas. India, for example, got most of its railway equipment from Great Britain, and the Indian railway mileage by 1910 was significantly greater than the British, as table 6.3 has shown.

6.3.3 Political Developments

A number of political developments should have speeded up the export of technology in the nineteenth century. The most important of these was the expansion of the European colonial territories. By 1900 the European powers controlled as colonies 35 percent of the land surface of the world, even excluding from this reckoning Asiatic Russia. Thus, of a world area of 57.7 million square miles Europe itself constitutes only 3.8 million square

Table 6.4 **Platt Ring Frame Orders by Country, 1890–1934**

Country	Sales, 1890–1914 (9 years)	Sales, 1914–36 (9 years)
Austria	4	0
Belgium	17	15
Brazil	95	43
Canada	15	17
China	5	64
Czechoslovakia	14	10
Egypt	0	5
England	110	74
Finland	1	0
France	41	31
Germany	47	6
Guatemala	1	1
Hungary	0	4
India	66	132
Italy	69	29
Japan	66	117
Mexico	75	7
The Netherlands	7	2
Nicaragua	2	0
Peru	7	0
Poland	41	8
Portugal	8	0
Russia	131	23
Spain	95	35
Sweden	3	0
Switzerland	3	0
Turkey	0	6
United States	2	0
West Africa	0	2

Source: Lancashire Record Office.

miles, but by 1900 its dependencies covered 19.8 million square miles. The British Empire was the largest, covering 9.0 million square miles; the French had 4.6 million, the Netherlands 2.0 million, and Germany 1.2 million.

Even many countries formally outside of the control of European powers were forced to cede trading privileges and special rights to Europeans. Thus, China was forced in the course of the nineteenth century to cede various treaty ports, such as Shanghai. The political control by countries such as Great Britain of so much of the world allowed entrepreneurs to export machinery and techniques to low-wage areas with little risk of expropriation. Thus the great increase in the scope and effectiveness of British political power in the course of the nineteenth century made it easier to export capital from Great Britain to support new textile industries. Most of the Indian subcontinent and Burma was brought under British administrative control in 1858, and Egypt fell to Britain in 1882. In 1842 the British secured Hong Kong from China, and in 1858 they achieved a concession in Shanghai. These were all localities with very low wage rates and easy access to major sea routes. The joint effect of these technological and political developments was to create by 1900 an expanded British economy spanning the globe. British policy within its empire was to eliminate barriers to trade and to allow economic activity to proceed wherever the market deemed most profitable. In India, for example, despite protests from local interests the British insisted on a free trade policy between Great Britain and India. Any manufacturer who set up a cotton mill in Bombay was assured of access to the British market on the same terms as British mills.

The nature of British imperialism also ensured that no country was restrained from the development of industry up until 1917 by the absence of a local market of sufficient size. Because of the British policy of free trade pursued in the nineteenth century, Great Britain itself and most British dependencies were open to imports with no tariff or else a low tariff for revenue purposes only. The large Indian market, which took a large share of English textile production, for example, was open on the same terms to all foreign producers. There was a 3.5 percent revenue tariff on imports, but a countervailing tax was applied to local Indian mills at the insistence of Manchester manufacturers. The Chinese textile market, at the insistence of the imperial powers, was also protected by a 5 percent ad valorem revenue tariff.

6.4 Efficiency in the Use of Technology

Although railways, cotton mills, and other advanced technologies spread rapidly around the world by the late nineteenth century as a result of the above factors, the efficiency with which this technology was used differed greatly across countries. It was this inefficiency in use that in practice limited the spread of new production technologies. We illustrate this using the example of the railroads, but an equivalent story can be told for cotton textiles (Clark 1987; Wolcott and Clark 1999).

Output in each country is measured as a weighted sum of the number of tons of freight hauled, the ton-miles of freight, and passenger-miles of passengers. Both tons of freight and ton-miles were used because the average length of haul varied greatly and the fixed costs in hauling freight from loading and unloading were substantial compared to the costs of hauling goods another ton-mile.[6] Freight output was thus estimated as (tons $\times$ \$0.285 + ton-miles $\times$ \$0.0066). The quality of passenger service varied greatly, which

6. From freight revenues across countries we estimate that the cost of freight hauling a ton of freight x miles in the United States in 1914 in \$(0.285 + 0.0066z).

Table 6.5 **Railroad Operating Efficiency circa 1914**

Country	Year	Output per Worker ($)	Output per Track Mile ($)	Efficiency (United States = 1)	Miles per Locomotive per Year
Australia	1914	691	4,421	0.41	24,243
Austria	1912	567	9,677	0.61	16,934
Belgium	1912	959	10,332	0.78	18,282
Canada	1914	1,400	5,487	0.62	25,175
China	1916	389	5,495	0.37	30,408
Denmark	1914	709	6,669	0.53	15,006
France	1911	772	7,451	0.59	22,926
Germany	1913	857	11,826	0.81	25,746
Hungary	1912	653	5,443	0.45	—
India	1914	297	4,208	0.28	—
Japan	1914	507	6,488	0.46	27,196
The Netherlands	1912	812	6,982	0.57	32,330
Romania	1913	489	6,738	0.46	23,340
Siam	1914	389	2,128	0.21	17,592
Sweden	1912	739	3,288	0.35	22,442
Switzerland	1913	577	6,831	0.49	—
United Kingdom	1912	898	9,457	0.72	25,854
United States	1914	1,743	10,565	1.00	26,092

Sources: Boag (1912); Bureau of Railway Economics (1915); various national railway statistics.
Note: Our method means that output per worker is measured in the same prices everywhere. Dashes indicate data are not available.

shows up in the revenue generated per passenger-mile. For India, for example, this was 2.4¢ per mile for first class and 0.4¢ for fourth class. We thus adjusted passenger-miles by assuming first class was equivalent everywhere and weighting passenger-miles in other classes according to the relative revenue generated per passenger-mile. This weighted passenger-mile figure was multiplied by $0.023, the average revenue per passenger mile for first class. Table 6.5 shows the implied output per worker and output per track mile in dollars. On this measure, output per worker in the United States in 1914 was six times output per worker in India, even though India was using an equivalent technology.

Since Indian rail equipment was mostly imported from Great Britain, a better comparison might be with the United Kingdom. U.K. output per worker was three times output per worker in India. Figure 6.9 shows output per worker on the railways circa 1914 in the countries for which we can get data, versus real GDP per capita for the same countries in 1910. This low output per worker in the poorer countries has little to do with capital/labor substitution in response to lower wages. One measure of the intensity of capital utilization is the number of miles locomotives were driven per year. This varies much less across countries and is uncorrelated with the level of income of the country. As column (5) of table 6.5 shows, the overall effi-

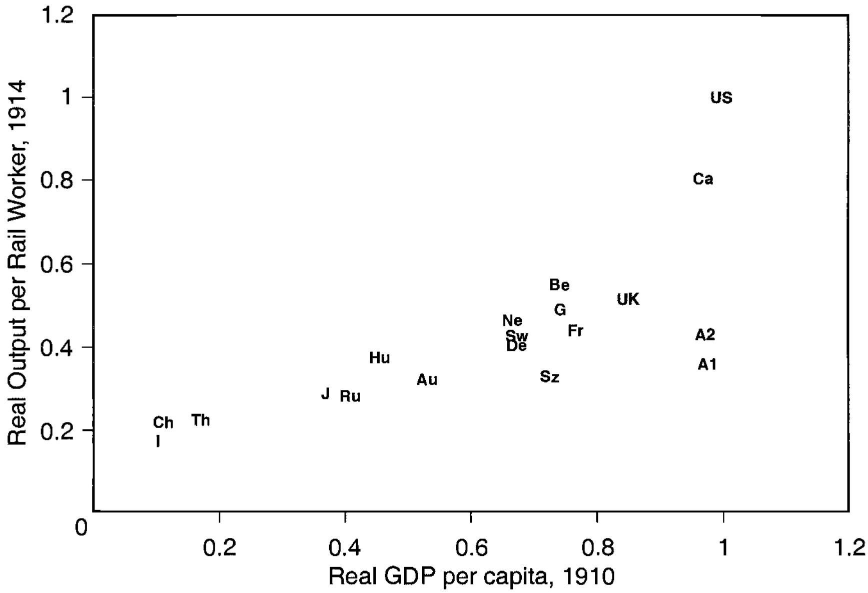

Fig. 6.9 Output per worker on railways versus GDP per capita, 1910

Note: A1 is New South Wales; A2 is South Australia. Otherwise country codes are as in previous figures. Output is measured relative to the U.S., set at 1.

ciency of the rail systems of these countries also varies greatly. The efficiency of the Indian rail system was only 28 percent of that of the U.S. system and 39 percent of that in the United Kingdom. These differences in the efficiency of operation of the rail system between countries like India and the United States and United Kingdom are almost as great as the differences in calculated TFP for these economies as a whole.

Note that the Indian rail system, for example, had extensive British expertise in its operation. In 1910 the Indian railroads employed 7,207 “Europeans” (mainly British) and 8,862 “Eurasians” (principally Anglo-Indians), who occupied almost all the supervisory and skilled positions. Indian locomotive drivers were employed only after 1900, and even as late as 1910 many of the locomotive drivers were British (Morris and Dudley 1975, 202–04; Headrick 1988, 322).

The problem of operating Western technology efficiently in poor countries like India was the main barrier to the spread of this technology. Table 6.6, for example, shows the gross profit rates of Bombay cotton mills by quinquennia from 1905–09 to 1935–39, as well as the size of the Bombay industry and the output per worker in Bombay as an index with 1905–09 set at 100. As can be seen, profits were never great, but the industry grew substantially in the era of modest profits up to 1924. Thereafter, however, profits collapsed (as a result of Japanese competition), and the Bombay indus-

Table 6.6 **The Bombay Industry, 1907–38**

Year	Gross Profit Rate on Fixed Capital	Size of the Bombay Industry (millions of spindle-equivalents)	Output per Worker in Bombay (index)	Output per Worker in Japan (index)
1905–09	0.06	3.09	100	100
1910–14	0.05	3.43	103	115
1915–19	0.07	3.68	99	135
1920–24	0.08	4.05	94	132
1925–29	–0.00	4.49	91	180
1930–34	0.00	4.40	104	249
1935–39	0.02	3.91	106	281

Source: Wolcott and Clark (1999).

Note: Profits and output per worker were calculable only for the mills listed in the *Investor's India Yearbook* (various years).

try soon began to contract. The last column shows what was happening to output per worker in Japan, where, with the same machinery as in India (in both cases purchased from England), output per worker increased greatly.

Thus, the crucial variable in explaining the success or failure of economies in the years 1800–2000 seems to be the efficiency of the production process within the economy. And the differences in the ability to employ technology seemingly got larger over time between rich and poor countries.

6.5 Trade Patterns and the Sources of Inefficiency

Despite the importance of TFP differences, we have very little idea what generates them. We now consider using the pattern of trade to determine whether these TFP differences specifically adhered to labor in poor countries, or lay in some wider managerial failure.

The dominance of Great Britain and its free trade ideology in much of the world circa 1910 meant that trade barriers were low for the countries with the majority of world population in 1910—India (including modern Pakistan, Bangladesh, and Burma), China, Great Britain, Ireland, Egypt, Nigeria, and South Africa. However, the trade patterns for the factors of production within this relatively open world market were often not what we might expect. In particular, the densely populated countries of the East—India, China, and Egypt (counting the cultivable land)—seem to have been net exporters of land and net importers of labor. Table 6.7, for example, shows British India's commodity trade in 1912. The only manufactured good that India exported any quantity of was jute sacking. In the case of cotton the raw material content of India's exports of raw cotton about equaled in value the raw material value of India's imports. Thus India effectively exported its raw cotton to Great Britain to be manufactured there, paying for this with the export of other raw materials. The effective net raw

Table 6.7 The Commodity Trade of British India, 1912–13 (in $ millions)

Commodity	Imports	Exports	Net Exports
Grain, pulse, and flour	0.42	195.64	195.21
Jute, raw	0.00	87.76	87.76
Cotton—raw	7.21	91.20	83.99
Seeds	0.00	73.68	73.68
Hides and skins	0.71	53.11	52.40
Tea	0.23	43.13	42.90
Opium	0.00	36.41	36.41
Oils	16.94	2.78	–14.15
Sugar	46.33	0.00	–46.33
Other raw materials	34.20	64.79	30.58
All raw materials	106.04	648.50	542.46
Cotton—piece goods	195.73	39.58	–156.15
Metals	50.30	3.48	–46.81
Railway plant	20.77	0.00	–20.77
Hardware	17.57	0.00	–17.57
Jute—piece goods	0.00	74.20	74.20
Other manufactures	108.88	5.99	–102.90
All manufactures	393.25	123.26	–270.00

Source: U.S. Department of Commerce, Bureau of Foreign and Domestic Commerce (1915).

material export of India in 1912 was about $460 million. With Indian GDP measured in U.S. prices at about $11.5 billion this implies that exports of raw materials were about 4 percent of Indian GDP. Why was densely populated India poor and agricultural in 1912, as opposed to being poor and industrial?

If we look at the pattern of exports and imports in the cotton industry internationally around 1910 we see other possible anomalies in the pattern of trade. Table 6.8 shows, for example, the flow of manufactured cotton goods internationally. Cotton was the major manufacture in world trade at this time because of its low transport cost relative to price and the existence of a market for yarn and cloth across countries at all income levels. That Argentina, Australia, Canada, and Brazil were net importers of manufactured cotton goods (even though Brazil was a major producer of raw cotton) is entirely expected given that these were land-rich countries. But the substantial importing of cotton goods by densely populated British India, China, and Egypt (all substantial producers of raw cotton) is on the face of it rather puzzling. We turn next to a possible explanation from trade theory for this puzzle.

6.6 The Factor-Content Model

As noted in the introduction, Trefler (1993, 1995) has shown how various forms of generalized versus factor-specific technology differences across countries can be introduced into the HOV model. Such technology differences may help to explain why India was an exporter of land-intensive

Table 6.8 **World Trade in Cotton Textiles, 1910 (in $ millions)**

	All Cotton Goods	Cotton Yarn	Grey Cloth	Colored Cloth
All Net Exporters				
United Kingdom	453.2	83.4	99.8	270.0
Japan	26.2	22.3	4.6	–0.7
Italy	23.9	4.2	2.9	16.8
France	23.4	–2.7	4.3	21.9
Germany	15.0	–11.3	–2.7	28.9
United States	8.5	–3.5	8.3	3.6
Spain	5.9	0.0		(5.9)
Austria-Hungary	3.4	–4.1	0.2	7.3
The Netherlands	3.2	–13.8	7.5	9.5
Russia	2.7	–4.4		(7.2)
Major Importers				
British India	–100.1	17.8	–53.1	–64.8
China	–80.9	–40.8	–10.6	–29.5
Argentina	–28.6	–2.7	–0.9	–25.0
Australia	–24.8	–2.0	–1.2	–21.6
Ottoman Empire	–19.7	–1.1	–7.4	–11.2
Egypt	–18.2	–1.4		(–16.8)
Canada	–11.6	–1.9	–0.8	–8.8
Brazil	–11.1	–2.5	0.0	–8.6

Source: U.S. House of Representatives (1912, vol. 1, appendix A, 212–18).

Notes: Other large net importers were Romania (–9.9), Chile (–9.3), Algeria (–9.2), British South Africa (–7.7), Venezuela (–4.3), and Bulgaria (–4.3). Numbers in parentheses are those where gray and colored cloth is given together.

goods at the turn of the century. Although this fact is consistent with the sheer size of the Indian subcontinent, it seems inconsistent with her very large population. One resolution of this puzzle would be that each worker in India is less productive than those abroad, so the *effective* population there is smaller than otherwise.

The HOV model expresses trade in terms of the factor content of exports and imports—that is, the amounts of labor, capital, land, and so on embodied in the goods that are traded. That is, the factor content of trade for country c is defined as $F_c \equiv AT_c$, where

- $\mathbf{T_c} = \mathbf{Y_c} - \mathbf{D_c}$ is the $(N \times 1)$ vector of net exports of goods $i = 1, \ldots, N$ for country c, where $\mathbf{Y_c}$ is production and $\mathbf{D_c}$ is consumption;
- $\mathbf{A} = [\boldsymbol{a}_{ki}]$ is a $(M \times N)$ matrix giving the amount of primary factor $k = 1, \ldots, M$ used to produce one unit of production in industry $i = 1, \ldots, N$. (This matrix should include the primary factors used both directly and indirectly).[7]

7. If $\mathbf{D}$ denotes the $(K \times N)$ matrix giving the *direct* requirements of primary factors to produce one unit of output in each industry, and $\mathbf{B}$ is the $(N \times N)$ input-output matrix for the country, then the total primary factor requirements are computed as $\mathbf{A} = \mathbf{D(I - B)^{-1}}$.

Focusing on the case in which labor, capital, and land are the primary factors, then $\mathbf{F_c} = (F_{Lc}, F_{Kc}, F_{Tc})$ will have three elements, giving the net exports of these factors for country c. Notice that we have not included a subscript on the matrix **A**, and because it is difficult to obtain the primary factors requirement for many countries, the convention has been to use **A** for a *base* country—say, the United Kingdom. At the same time, we allow for a general pattern of factor-specific productivity differences across countries, so that factor k used in country c has productivity π_{kc}, where these are measured *relative to* the productivity in the base country.

Consistent with the measurement of $\mathbf{F_c}$ using the technology of the base country, Trefler (1995) extends the HOV model to show how the factor-content of trade is related to the *effective* endowments labor, capital, and land, where these are measured in efficiency units π_{kc}. That is, letting $\pi_{Lc}L_c$, $\pi_{Kc}K_c$, $\pi_{Tc}T_c$ denote the effective endowments of the factors in country c, the HOV model predicts that

$$F_{Lc} = \pi_{Lc}L_c - s_c \sum_{j=0}^{C} \pi_{Lj}L_j \tag{6A}$$

$$F_{Kc} = \pi_{Kc}K_c - s_c \sum_{j=0}^{C} \pi_{Kj}K_j \tag{6B}$$

$$F_{Tc} = \pi_{Tc}T_c - s_c \sum_{j=0}^{C} \pi_{Tj}T_j \tag{6C}$$

where $s_c \equiv Y_c / \sum_{j=0}^{C} Y_j$ denotes the share of country c's GDP in world GDP.[8]

To interpret these equations, equation (6A) states that country c will be a net exporter of labor services, $F_{Lc} > 0$, if its effective endowment of labor, $\pi_{Lc}L_c$, *exceeds* its GDP share s_c times the world effective endowment of labor, $\sum_{j=0}^{C}\pi_{Lj}L_j$. Put simply, if country c is abundant in labor (with $\pi_{Lc}L_c / \sum_{j=0}^{C}\pi_{Lj}L_j > s_c$), then it will be a net exporter of labor. A similar interpretation holds for the other factors.

Let us now return to the puzzle: Why was India a net exporter of land-intensive products around the turn of the century? We interpret this statement to mean that if the full factor content calculation were done, India would be found to be a net exporter of land, so that $F_{Tc} > 0$. In addition, we expect that India would be found to be a net importer of either capital, $F_{Kc} < 0$, or labor, $F_{Lc} < 0$. Thus, for India we would write equations (6A)–(6C) as

$$\pi_{Lc}L_c - s_c \sum_{j=0}^{C} \pi_{Lj}L_j < 0, \text{ or} \tag{7A}$$

$$\pi_{Kc}K_c - s_c \sum_{j=0}^{C} \pi_{Kj}K_j < 0, \text{ and} \tag{7B}$$

8. More precisely, s_c denotes the share of country c's consumption in world consumption, but this will equal its share of world GDP if trade is balanced for country c.

(7C) $$\pi_{Tc}T_c - s_c\sum_{j=0}^{C}\pi_{Tj}T_j > 0.$$

Depending on whether inequality (7A) or (7B) holds, these taken together with (7C) imply that

(8) $$\frac{\pi_{Lc}L_c}{\sum_{j=0}^{C}\pi_{Lj}L_j} < s_c < \frac{\pi_{Tc}T_c}{\sum_{j=0}^{C}\pi_{Tj}T_j}, \text{ or } \frac{\pi_{Kc}K_c}{\sum_{j=0}^{C}\pi_{Kj}K_j} < s_c < \frac{\pi_{Tc}T_c}{\sum_{j=0}^{C}\pi_{Tj}T_j}.$$

From the second inequality in each set, the effective land endowment of India, relative to the world, must be *at least as large* as its GDP share in order for it to be a net exporter of land. Data on actual endowments of land, and GDPs, will therefore allow us to make some conclusion about the effective productivity of land, along with capital and labor.

We see that just the *sign pattern* of the factor-content of trade is enough to place some bounds on the factor-specific productivity differences in India.[9] To simplify these inequalities, consider the corresponding equations for the United Kingdom (labeled b). We expect that if the full factor-content calculation were done, the United Kingdom would be found to be a net importer of land, so that $F_{Tb} < 0$, and a net exporter of either capital, $F_{Kb} > 0$, or labor, $F_{Lb} > 0$. That is, these inequalities are just the reverse as obtained for India. Recalling that the efficiency of each factor is normalized at unity for the United Kingdom, then we also obtain the reverse inequalities as in equation (8),

(9) $$\frac{L_b}{\sum_{j=0}^{C}\pi_{Lj}L_j} > s_b > \frac{T_b}{\sum_{j=0}^{C}\pi_{Tj}T_j}, \text{ or } \frac{K_b}{\sum_{j=0}^{C}\pi_{Kj}K_j} > s_b > \frac{T_b}{\sum_{j=0}^{C}\pi_{Tj}T}.$$

Now, dividing equation (8) by equation (9), we obtain the final equations,

(10) $$\frac{\pi_{Lc}L_c}{L_b} < \frac{s_c}{s_b} < \frac{\pi_{Tc}T_c}{T_b} \text{ or } \frac{\pi_{Kc}K_c}{K_b} < \frac{s_c}{s_b} < \frac{\pi_{Tc}T_c}{T_b}.$$

To interpret the first set of inequalities, if India is a net importer of labor and exporter of land (and conversely for the United Kingdom), then (a) the relative efficiency of land in India π_{Tc} must be *at least as high as* $(s_c/T_c)/(s_b/T_b)$, that is, their relative shares of GDP compared to land; (b) the relative efficiency of labor in India π_{Lc} *cannot exceed* $(s_c/L_c)/(s_b/L_b)$, that is, their relative shares of GDP compared to labor. Taken together, we conclude that the *efficiency of land relative to labor* in India, π_{Tc}/π_{Lc}, must be *at least as high as* $(L_c/T_c)/(L_b/T_b)$, which is simply (population/acre) in India versus the United Kingdom.

In the next section, we will apply these inequalities to estimate the relative productivity of labor and land in 1910 and 1990. Before turning to these results, it might be useful to contrast the HOV approach with the single-

9. Brecher and Choudhri (1982) also make use of the sign pattern of U.S. trade in 1947 (when it exported both labor and capital) to draw some conclusions.

sector Cobb-Douglas function used earlier in the paper. With the single sector, we were assuming that TFP varied across countries and acted as a driving force behind capital mobility. We ignored the contribution of land to total GDP in modern times. Once we introduce trade data, however, it becomes quite relevant to incorporate trade in agricultural goods, and the amount of land embodied in trade. In our calculations below, we will focus on the labor and land content of trade, while ignoring capital embodied in trade. Thus, we do not need to take any stand on the extent of capital flows between countries, and how this responds to productivity. Rather, we will simply treat the labor and land endowments as exogenous across countries, although differing in their productivities, and use their endowments combined with the factor contents of trade to infer the factor productivities.

6.7 Evidence from the Sign Pattern of Trade

To illustrate these calculations, some data on population, land area, GDP, and their ratios are shown in table 6.9 for 1910 and in table 6.10 for 1990. These are all measured relative to world totals. For example, the figure of 0.36 for GDP/population in India for 1910 indicates that India has 36 percent of the world average GDP per capita. Surprisingly, this number remained much the same in 1990 (dropping just slightly to 0.34), although this finding relies on the fact that we are using the purchasing power parity (PPP)–adjusted GDP values from the PWT. Prices are so low in India that its GDP is 3.5 times higher in the PWT for 1990 than obtained from World Bank data, which convert its nominal GDP to dollars with current exchange rates. In contrast to the roughly constant value for India, most European nations have increased their level of real GDP per capita relative to the world, in some cases nearly doubling their world share. This is consistent with the divergence in income levels described in section 6.2, of course. We also report GDP relative to crop acreage, or crop plus pasture, and these show a mixed pattern between 1910 and 1990—increasing for some European nations relative to the world, but falling for others.

To use these data to estimate the productivity of factors, we focus on India relative to some comparison countries. Choosing the United Kingdom as the initial comparison, we use the first set of inequalities in equation (10). Then their ratio of per capita GDP is shown in the column marked (1) in table 6.11, which provides an *upper bound* to the efficiency of labor in India relative to the United Kingdom. The value of 0.13 indicates that an Indian worker is *less than* 13 percent as productive as his counterpart in the United Kingdom.[10] The ratios of GDP to crop land or crop plus pasture are shown in columns (2) and (3), and provide *lower bounds* to the efficiency of land in

10. Rather than using total population in tables 6.9 and 6.10, we should actually use estimates of the workforce.

Table 6.9 **Data on Population, Land, and GDP, circa 1910**

Country or Area	Share of Population	Share of Crop Area	Share of Crop + Pasture	Share of GDP	GDP ÷ Population (1)	GDP ÷ Crop (2)	GDP ÷ (Crop + Pasture) (3)
India	0.169	0.114	0.044	0.061	0.36	0.54	1.40
China	0.312	0.079	0.074	0.116	0.37	1.47	1.57
United Kingdom	0.023	0.005	0.005	0.064	2.82	12.57	12.86
Rest of Europe	0.197	0.104	0.054	0.360	1.83	3.45	6.67
Austria	0.004	0.001	0.001	0.007	1.77	5.13	6.22
Belgium	0.004	0.001	0.000	0.010	2.47	14.31	23.04
Bulgaria	0.002	0.003	0.001	0.003	1.23	0.96	2.53
Denmark	0.002	0.002	0.001	0.003	2.25	1.73	4.27
Finland	0.002	0.002	0.001	0.003	1.63	1.43	3.59
France	0.022	0.015	0.009	0.056	2.56	3.63	6.26
Germany	0.036	0.010	0.005	0.089	2.46	8.91	16.56
Greece	0.001	0.003	0.002	0.002	1.30	0.75	0.85
Hungary	0.004	0.004	0.002	0.006	1.53	1.57	3.50
Ireland	0.002	0.001	0.001	0.004	1.71	4.09	3.41
Italy	0.019	0.011	0.005	0.034	1.75	2.97	6.26
The Netherlands	0.003	0.001	0.001	0.007	2.22	9.54	12.18
Norway	0.001	0.001	0.000	0.003	2.27	5.02	11.36
Portugal	0.003	0.003	0.001	0.004	1.31	1.47	4.10
Spain	0.011	0.015	0.006	0.019	1.70	1.27	3.34
Sweden	0.003	0.003	0.001	0.007	2.23	2.60	6.13
Switzerland	0.002	0.000	0.001	0.005	2.41	15.72	9.00

Source: Crop and pasture areas are from the UN Food and Agriculture Organization (1991) and apply to years around 1957.

Table 6.10 Data on Population, Land, and GDP, 1990

Country or Area	Share of Population	Share of Crop Area	Share of Crop + Pasture	Share of GDP	GDP ÷ Population (1)	GDP ÷ Crop (2)	GDP ÷ (Crop + Pasture) (3)
India	0.161	0.117	0.037	0.054	0.34	0.46	1.45
China	0.215	0.067	0.102	0.076	0.35	1.13	0.74
United Kingdom	0.011	0.005	0.004	0.38	3.52	8.30	10.39
Rest of Europe	0.068	0.072	0.033	0.206	3.03	2.87	6.28
Austria	0.001	0.001	0.001	0.005	3.38	4.74	6.84
Belgium	0.002	0.001	0.000	0.007	3.52	11.73	21.63
Bulgaria	0.002	0.003	0.001	0.003	1.65	0.98	2.21
Denmark	0.001	0.002	0.001	0.004	3.70	2.03	6.27
Finland	0.001	0.002	0.001	0.004	3.74	2.10	6.70
France	0.011	0.013	0.006	0.040	3.70	2.98	6.29
Germany	0.012	0.005	0.002	0.046	3.89	8.81	18.67
Greece	0.002	0.003	0.002	0.003	1.80	1.27	1.82
Hungary	0.002	0.004	0.001	0.003	1.43	0.78	2.13
Ireland	0.001	0.001	0.001	0.002	2.47	2.51	1.41
Italy	0.011	0.008	0.003	0.036	3.32	4.34	10.39
The Netherlands	0.003	0.001	0.000	0.010	3.47	15.25	23.50
Norway	0.001	0.001	0.000	0.003	3.97	5.33	15.83
Portugal	0.002	0.002	0.001	0.004	1.99	1.69	4.48
Spain	0.007	0.014	0.006	0.019	2.55	1.34	2.99
Sweden	0.002	0.002	0.001	0.006	3.93	3.26	9.13
Switzerland	0.001	0.000	0.000	0.006	4.39	19.58	13.39

Sources: Crop and pasture areas are from the UN Food and Agriculture Organization (1991); GDP is from the Penn World Tables (5.6).

Table 6.11 Implied Efficiency of Labor and Land, 1910 and 1990

India Relative to Other Country	Efficiency of Labor (upper bound) (1)	Efficiency of Cropland (lower bound) (2)	Efficiency of Cropland + Pasture (lower bound) (3)	Efficiency of Cropland ÷ Labor (lower bound) (4)[a]	Efficiency of (Cropland + Pasture) ÷ Labor (lower bound) (5)[b]
Results for 1910 (using population)					
United Kingdom	0.13	0.04	0.11	0.33	0.85
Finland	0.22	0.38	0.39	1.69	1.75
Germany	0.15	0.06	0.08	0.41	0.58
Sweden	0.16	0.21	0.23	1.27	1.41
Results for 1990 (using population)					
United Kingdom	0.10	0.06	0.14	0.58	1.46
Finland	0.09	0.22	0.22	2.45	2.41
Germany	0.09	0.05	0.08	0.61	0.90
Sweden	0.09	0.14	0.16	1.66	1.85
Results for 1990 (using workers)					
United Kingdom	0.12	0.06	0.14	0.46	1.15
Finland	0.12	0.22	0.22	1.87	1.83
Germany	0.11	0.05	0.08	0.49	0.72
Sweden	0.11	0.14	0.16	1.25	1.39

Sources: Columns (1)–(3) for 1910 (using population) are computed by dividing data in the like-numbered columns for India and each comparison country, from table 6.9. Columns (1)–(3) for 1990 (using population) are computed by dividing data in the like-numbered columns for India and each comparison country, from table 6.10. Columns (1)–(3) for 1990 (using workers) are recomputed from table 6.10 but use the number of workers in each country rather than the population.

Notes: The bounds shown in columns (4) and (5) are valid only if the comparison country is a net importer of land and a net exporter of labor (as embodied in goods). The countries listed above satisfy this for 1910 and 1990, with the exception being the United Kingdom, which is an importer of both land and labor.

[a]Column (2)/column (1).

[b]Columns (3)/column (1).

India relative to the United Kingdom. They give a value of 0.04 or 0.11, implying that a hectare of land in India is *at least* 4 percent as productive (11 percent for crop land) as that in the United Kingdom. Putting together these estimates for labor and land, we obtain the final columns in table 6.11, which show that the efficiency of crop land relative to labor is *at least* 0.33 in India relative to the United Kingdom (or 0.85 for crop plus pasture). Because these values are less than unity, we do not find evidence of factor-specific productivity differences. That is, the trade patterns for India and the United Kingdom, as measured by signs of their factor-content of trade, are consistent with *generalized inefficiency* within India.

One explanation for this finding is the extremely small size of the British Isles, so that when measured relative to population, the United Kingdom is scarce in land compared to India. Another explanation, though, is that the United Kingdom may not have the opposite sign pattern of trade as India, in which case the inequalities in equation (10) do not apply. In fact, using the data of Estevadeordal and Taylor (2001, 2002) circa 1910 and Trefler (1993, 1995) for 1983, it turns out that the United Kingdom is a net importer of *both* land and labor, whereas we presume that India is a net exporter of land and importer of labor. So it makes sense to work with some other European countries that have the opposite sign pattern of trade from India.

Using Estevadeordal and Taylor's (2002a, b) data, we find that there are only three countries that have the opposite sign pattern of trade as India in 1910, being net importers of land (measured by renewable resources) and net exporters of labor: Finland, Germany, and Sweden. These three countries were still net importers of crop land and net exporters of (nonagricultural) labor in 1983, according to the data from Trefler (1993, 1995). Trefler does not report the factor-content of trade for India, but he does include Pakistan, which is a net exporter of crop land and importer of (nonagricultural) labor; we presume that the same sign patterns holds for India. Accordingly, we report results for these three comparison countries in the rest of table 6.11.

Using Finland as the comparison country, we see that the implied efficiency of crop land relative to labor is at least 1.69 in 1910, and that this lower bound has risen to 2.45 in 1990. In this case, there is evidence of *biased technological change,* with land in India becoming increasingly productive relative to labor. To understand where this result is coming from, we note that the ratio of population to crop land in India, relative to the world, has changed little in the century, falling from 1.5 in 1910 to 1.4 in 1990.[11] In contrast, Finland has experienced a larger fall in this ratio, from 0.9 in 1910 to 0.6 in 1990. With fewer persons per acre in Finland, the fact that it re-

11. These ratios can be computed by dividing the population and cropland columns within tables 6.9 and 6.10.

mains a *net importer* of land indicates that the productivity of its workers relative to land must be enhanced over time; conversely, the productivity of Indian workers must be falling relative to land.

The results of comparing India to Sweden are similar to those for Finland and indicate that land is more productive than labor in India, and that this differential has been increasing over time. Again, this result can be understood by noting that the ratio of population to crop land in Sweden, relative to the world, has fallen from 1.2 in 1910 to 0.8 in 1990. Despite this, Sweden has remained a net importer of land and net exporter of labor, with the opposite trade pattern in India, so the productivity of Indian workers must be falling relative to land. When using Germany as a comparison country, however, we do not obtain bounds that are tight enough to indicate any factor-specific technological differences with India.

Unfortunately, there are no other countries we can use that have the opposite trade pattern from India. However, to check the robustness of our results, there is one other calculation we can do, at least for 1990: Namely, we can use the number of *workers* in each country, rather than total population, to measure the labor endowment. This is done at the bottom of table 6.11, which can be compared to the results immediately above it.

We can see that using workers rather than population generally reduces our lower-bound estimates of the efficiency of land relative to labor, in columns (4) and (5) of table 6.11. The reason for this is that only about 40 percent of the population in India is economically active workers, whereas this percentage varies around 50 percent for Finland, Germany, Sweden, and other European countries. Recalling that columns (4) and (5) are computed as labor relative to land area, in India compared to each country, we expect these ratios to fall when workers rather than population are used. Nevertheless, it remains true that land is more productive than labor in India relative to either Finland or Sweden. This supports our hypothesis that the unusual trade pattern of India and Pakistan, whereby they are net exporters of land-intensive products both historically and today, is explained by a lower efficiency of labor relative to land in those countries.

6.8 Conclusions

We have shown above that the fundamental cause of the divergence of income per capita experienced since the Industrial Revolution is a difference in the ability of countries to employ the same technology at equal levels of efficiency. Improvements in the mobility of goods and capital fall into relative unimportance when compared to the effects of differences in TFP, both in historical periods and today.

The source of these differences in TFP remains mysterious. In this paper we explore potential methods of testing whether these were generalized efficiency differences, such as would be caused by a lack of knowledge, or managerial ability in poor countries, or whether they were more specifically linked to problems with the efficiency of labor in poor economies. The data we have assembled so far support the hypothesis that labor in India has a lower efficiency than land, with each measured relative to countries with the opposite sign pattern of trade. By comparing countries with opposite trade patterns, both in 1910 and 1990, we ended up with a very small sample: India or Pakistan relative to Finland, Germany, and Sweden. There are two directions our research could go to enlarge this sample and gain more confidence in the results.

First, we could obtain further evidence on relative productivities by using the *magnitude* of trade, rather than just its sign pattern. For modern times these data are available from Trefler (1993, 1995). Indeed, we have utilized the factor-efficiency reported by Trefler to compare Pakistan to a wider range of other countries and to confirm the results reported in table 6.11: For most comparison European countries, Pakistan has a lower efficiency of labor relative to land. This exercise is incomplete, however, without the equivalent comparison for historical periods, and here the data are much harder to obtain. Estevadeordal and Taylor (2002a, b) do not include India (or any other developing country) in their data circa 1910, and in addition, their units of resource endowments are incommensurate with their units for resources embodied in trade. Thus, we have not been able to utilize data on the *magnitude* of trade to estimate factor productivities for historical periods.

A second direction for research is to extend the HOV model we have outlined to incorporate nonhomothetic tastes (some progress along these lines is made by Trefler 1995). The fact that India is a net exporter of land is all the more surprising when we consider that this factor is needed to grow food, which figures so prominently in the budgets of its poorest citizens. In other words, the effective endowment of land is lower than it appears once we subtract that amount that is essential for its large population to survive. This observation can be formalized in the context of the HOV model, to obtain effective endowments of land (and other factors) that adjust for nonhomothetic tastes. We expect that the implied factor productivities that would come out of the resulting HOV equations would show an even *lower* efficiency of labor in India than we have obtained. This would reinforce our conclusion that it is the inefficiency of technology in its use, rather than in its availability, that appears to limit the prospects of poorer countries.

References

Acemoglu, Daron, Simon Johnson, and James A. Robinson. 2001. Reversal of fortune: Geography and institution in the making of the modern world income distribution. MIT, Sloan School of Management, Department of Economics, and University of California–Berkeley, Department of Political Science. Mimeograph.

Boag, George L. 1912. *Manual of railway statistics.* London: Railway Gazette.

Brecher, Richard A., and Ehsan U. Choudhri. 1982. The Leontief paradox, continued. *Journal of Political Economy* 90 (4): 820–23.

Bruland, Kristine. 1989. *British technology and European industrialization: The Norwegian textile industry in the mid-nineteenth century.* Cambridge: Cambridge University Press.

Bureau of Railway Economics. 1915. *Comparative railway statistics: United States and foreign countries, 1912.* Washington, D.C.: Bureau of Railway Economics.

Clark, Gregory. 1987. Why isn't the whole world developed? Lessons from the cotton mills. *Journal of Economic History* 47 (March): 141–73.

De Long, J. Bradford, and Lawrence H. Summers. 1991. Equipment investment and economic growth. *Quarterly Journal of Economics* 106:445–502.

Easterly, William, and Ross Levine. 2000. What have we learned from a decade of empirical research on growth? It's not factor accumulation: Stylized facts and growth models. *World Bank Economic Review* 15:177–219.

Edelstein, Michael. 1982. *Overseas investment in the age of high imperialism: The United Kingdom, 1850–1914.* New York: Columbia University Press.

Estevadeordal, Antoni and Alan M. Taylor. 2002a. A century of missing trade? *American Economic Review,* 92 (1): 383–93.

———. 2002b. Testing trade theory in Ohlin's time. In *Bertil Ohlin: A centennial celebration, 1899–1999,* ed. R. Findlay, L. Jonung, and M. Lundahl. Cambridge: MIT Press, 463–93.

Headrick, Daniel. 1988. *The tentacles of progress: Technology transfer in the age of imperialism, 1850–1940.* Oxford: Oxford University Press.

Homer, Sidney, and Richard Sylla. 1996. *A history of interest rates.* New Brunswick, N.J.: Rutgers University Press.

Investor's India Yearbook. Various years. Calcutta: Siddons and Gough.

Jones, Charles I. 1994. Economic growth and the relative price of capital. *Journal of Monetary Economics* 34 (3): 359–82.

Jones, Charles I., and Robert E. Hall. 1999. Why do some countries produce so much more output per worker than others? *Quarterly Journal of Economics* 116 (1): 83–116.

Lancashire Records Office. Platt Records, DDPSL/1/42/7-25.

Maddison, Angus. 1989. *The world economy in the twentieth century.* Paris: Organization for Economic Cooperation and Development.

Mauro, Paolo, Nathan Sussman, and Y. Yafeh. 2001. Emerging market spreads: Then versus now. Working Paper, Hebrew University.

Morris, Morris David, and Clyde B. Dudley. 1975. Selected railway statistics for the Indian subcontinent (India, Pakistan, and Bangladesh), 1853–1946/7. *Artha Vijnana* 17 (3).

Oliver, Douglas L. 1974. *Ancient Tahitian society.* Vol. 1, *Ethnography.* Honolulu: University Press of Hawaii.

Pamuk, Sevket. 1987. *The Ottoman Empire and European capitalism, 1820–1913: Trade, investment, and production.* Cambridge: Cambridge University Press.

Pomeranz, Kenneth. 2000. *The great divergence: Europe, China, and the making of the modern world economy.* Princeton, N.J.: Princeton University Press.

Prados de la Escosura, Leandro. 2000. International comparisons of real product, 1820–1990: An alternative data set. *Explorations in Economic History* 37 (1): 1–41.

Sachs, Jeffrey D. 2001. Tropical underdevelopment. NBER Working Paper no. 8119. Cambridge, Mass.: National Bureau of Economic Research.

Trefler, Daniel. 1993. International factor price differences: Leontief was right! *Journal of Political Economy* 101 (6): 961–87.
———. 1995. The case of the missing trade and other mysteries. *American Economic Review* 85 (5): 1029–46.
United Nations, Food and Agriculture Organization. 1991. *Production yearbook.* Rome: UN Food and Agriculture Organization.
U.S. Department of Commerce, Bureau of Foreign and Domestic Commerce. 1915. *Special consular reports, no. 72: British India.* Washington, D.C.: GPO.
U.S. House of Representatives. 1912. *Report of the tariff board: Cotton manufactures.* Washington, D.C.: GPO.
Wolcott, Susan, and Gregory Clark. 1999. Why nations fail: Managerial decisions and performance in Indian cotton textiles, 1890–1938. *Journal of Economic History* 59 (2): 397–423.

Comment Joel Mokyr

The sixty-four-thousand-dollar question is why the West grew rich and the countries that were somehow not like the West did not. Clark and Feenstra document that much of this divergence occurred after 1800. Not enough is known about incomes to be sure if *all* of it occurred after 1800, although in other papers Gregory Clark (2001) has suggested that income in Great Britain at least was already quite high in 1800 and rose little until 1860, which suggests that he may not quite subscribe to the "California School" led by Pomeranz (2000) and Goldstone (2001). These scholars maintain that the great divergence between West and "rest" was a fairly recent phenomenon and that by 1800 incomes were still comparable, at least between western Europe and the Yang-Zi delta. In any case, Clark and Feenstra attribute the difference between Europeans and non-Europeans to differences in productivity, and specifically labor productivity.

This paper is thus yet another installment in the Clarkian search for the Holy Grail of productivity differences. Clark's interpretation of the history of productivity as he has delineated it in a string of brilliant and provocative papers (starting with Clark 1987) is that advanced countries and poor countries faced basically the same kind of technology and had access to the same equipment and capital goods, and that institutions and culture mattered not one whit. And yet, for some reason, labor productivity in these poor countries was only a fraction of what it was in the richer countries. The difference is this mysterious substance that I shall call in his honor "factor C," the nature of which has never been specified. Clark has insisted that the data indicate that there are deep and fundamental differences in TFP be-

Joel Mokyr is Robert H. Strotz Professor of Arts and Sciences and professor of economics and history at Northwestern University, and a member of the board of directors of the National Bureau of Economic Research.

tween different economies, but he refuses even to speculate what the deeper causes might be.

Meanwhile, here is what the paper does: Clark and Feenstra demonstrate, using an array of techniques and data sources, that the poor countries of today were already poor and backward in 1910. Yet, they argue, they were not poor because their capital-labor ratios were lower than they should have been. In fact, the paper assumes that capital markets were efficient enough to roughly equalize rates of return between different countries. Whether that assumption actually holds up or not (their own data seem to cast some doubt on it), I think there is probably good reason to think that capital scarcity was not the *main* reason that the underdeveloped countries of 1910 were poor.

Clark and Feenstra estimate a set of Cobb-Douglas aggregate production functions in which they calculate TFP in a world in which equalized rates of return on capital are imposed as a constraint. In that case the *amount* of capital employed would depend entirely on the efficiency of the economy (since the rate of return is exogenous), and hence differences in capital-labor ratios between poor and rich countries are not a *cause* of poverty but its effect. What this means, of course, is that TFP is the sole determinant of differences in income per capita. In fact, the story as they see it is that capital is proportional to output. Low-productivity countries get punished twice: They get lower labor productivity *and* lower capital-labor ratios. The paradigmatic industry Clark and Feenstra have in mind for their observations in 1910 is railroads, on which they spend quite a bit of time. Measuring capital in terms of railway line per GDP in 1910, they find an approximate proportionality, as they do for more encompassing measures in 1990.

The differences in TFP, the authors argue, are not due to differences in *access to* technology either. It is easier to copy technology and to employ it than to develop it de novo, and they find it hard to believe that lack of access to it could block productivity from increasing. The use of fertilizers, the exploitation of railroads, or the spinning of coarse cotton were all techniques that required little knowledge to be applied, apart from investment in them, and thus could be readily deployed anywhere in the world. The well-documented globalization of the pre-1914 world was instrumental in making this technology more accessible. While Europe and the United States protected themselves by tariffs, the poorer parts were dominated by free-trade-minded imperialist governments and had no such choice. Clark and Feenstra document in some detail the improvement in transportation and communication, and this material is well known and uncontroversial.

Where the paper gets really interesting is where Clark and Feenstra try to measure "efficiency in the *use* of technology." It is not entirely clear what is meant by that, but in some sense it is the mother of all residuals: Once you have accounted for all factors of production *and* for differences in access to technology, this difference in TFP is what is left to explain. For 1910, their test case is the efficiency of railroad transport, presumably a technology that was wholly shared among poor and developed nations. Table 6.5 gives us railroad operating efficiency, an interesting variable, measured as railroad output per worker, per track mile and "overall efficiency" (presumably a weighted average of the two). By the logic of this table, however, not only India had a problem: Austria and Switzerland, hardly third world countries even in 1910, are only half as efficient as the United States and barely better than Japan, and in terms of overall efficiency China actually beats Sweden.

More perplexing, Clark and Feenstra point out that in India, whose railroads are the doormat of this efficiency contest, railroads were run and operated mostly by British engineers and experts. They conclude that "the problem of operating Western technology efficiently in poor countries like India was the main barrier to the spread of this technology." This variable called "operating a technology efficiently," factor C if you will, remains mysterious in nature and leaves the reader dissatisfied. Once or twice they raise the issue of whether the paradox could be caused by some greater failure of "managerial ability." But this, too, remains unresolved.

Instead, they embark on an exercise to see which of the factors of production is responsible for the lower efficiency by examining the relative factor-content of traded goods. India, they point out, is more densely populated than Europe in terms of population per cultivable land, yet it is exporting land-intensive goods. This exercise follows Dan Trefler's technique of elaborating on the Leontief paradox literature, trying to find factor-specific differences in productivity based on the factor-contents of tradables. This discussion is not very easy to follow, in part because the discussion moves somewhat quickly from a three-factor to a two-factor world (presumably because capital is assumed to be equally efficient worldwide, although I wonder why this assumption does not get tested here) and in part because of the need to examine countries that have opposite trade patterns (in terms of their factor-content) from India. These countries both turn out to be Scandinavian. Clark and Feenstra find that Indian land is more productive than Indian labor relative to these countries, and that this gap got worse over the twentieth century. This is, in some sense, a demonstration of comparative advantage, but it also raises the classical Leontief issue of why countries export goods intensive in factors in which they are ostensibly poorly endowed. Clark and Feenstra argue that India had lots of labor, and its labor force was cheap. But that labor force lacked sadly in factor C, which made it so unproductive as to actually make India look like a country relatively rich in land. The source of the differences in TFP, which is to blame for everything, as the authors say, "remains mysterious." It seems fair to say that they obviously spent more ingenuity in posing the issue than in giving us a clue as to how it may be resolved.

I should say from the outset that I do not know the answer either, and that the best one can do is to suggest to the authors where to look a bit more closely. Despite the careful research in compiling and analyzing their data, the paper conveys the impression that the authors decided to ignore the literature on virtually every one of the subtopics they deal with, and just start with a fresh mind. Such a strategy, in some cases, makes sense and I am sure that there are examples in the history of science in which a major breakthrough was attained by a sharp and unbiased mind who did not let the existing literature that was denying the very possibility of the discovery confuse him. Ignoring what has been done before does, of course, mean that there is a certain danger of reinventing a few wheels and providing an audience with a sense of dèja vu, as well as a danger of missing clues that others have noticed.

For instance, there are a few pages in Grossman and Helpman (1991), not cited in this paper, that deal with the issue of the international diffusion of knowledge. They point out that a country gains access to the body of knowledge that has accumulated in the outside world through trade contacts, and that this is how integration into the world economy can promote innovation and growth. They speculate that this access is a function of the *level* of trade, which would be testable given the TFPs computed by Clark and Feenstra. I am not entirely sure that I would really expect the level of trade to be a good proxy for the amount of contact that makes the use of foreign technology more effective, but it seems worth a look.

There is, of course, a large literature on the Leontief paradox. Whether the introduction of human capital into the story resolved the mystery there to his satisfaction or not, I do not know. But the words *human capital* and *skill* do not appear in this paper, which is rather odd. Perhaps education, and the kind of culture that workers get imbued with in some countries to make them work harder and be more conscientious on the job, is a complete canard in the view of the authors, but they need to dismiss it on the basis of more evidence than is supplied here.

Moreover, in the literature there is one publication much similar to this project, namely a small paper published by Bob Lucas (1990). Much like Clark, Lucas has the marvelous ability to pose a very naive and elementary-sounding question to an audience of economists, and then force them to admit that they do not know the answer even though they instinctively feel that they should. Unlike Clark, however, Lucas does have the tendency to suggest answers to these conundrums, and although they are not always convincing to everyone, they seem to be sufficiently so to account for his influence. In this paper Lucas asked a simple question, namely, “Why doesn’t capital flow from rich to poor countries?” The dilemma is posed in a similar way to Clark and Feenstra: Start from a simple C-D production function, plug in some stylized numbers, and take a step back: presto, a paradox.

Lucas figured that, given that U.S. output per worker was 15 times that of India, the rate of return to capital should be 15 to the power of the reciprocal of the elasticity of the capital-labor ratio, which comes to 58 times higher in India than it is in the United States. In other words, Lucas asked the same question as Clark and Feenstra with the exactly reversed assumption: Assume TFP is the same between the two countries, and let the entire difference be in the rates of return. If this were even remotely true, capital should flow like mad from rich to poor countries even if the rates of return do not end up being wholly equalized. In fact, Lucas pointed out that there should be no investment in rich countries at all—every penny of investment should flow to poor countries.

Of course, Lucas could have stopped right there and said, well, that's not happening, so there must be a mysterious difference in the productivity coefficient and that's it. But in fact he proceeded in that paper and elsewhere to discuss the quality of labor and human capital, not only in the sense that more educated and better trained workers are more efficient, but also in the sense of cross–labor force externalities by which more educated workers make other workers more efficient. Lucas also worried more about international capital markets than Clark and Feenstra. He pointed out that before 1945, with much of the recipients of capital controlled by imperialist powers, one might have expected the colonialists to behave more like labor-market monopsonists and therefore underinvest in poor countries to keep wages low and reap a rent. He claimed that there is no reason why such monopsonistic power disappeared after 1945, even if it switched from foreigners to locals, but that political independence may have exacerbated capital market imperfections by producing risks of repudiation. Lucas then tried to compute how much of the original gap is explained by these various modifications, and while I cannot say that his methods are less oversimplified than Clark and Feenstra's, his paper does leave less of an aftertaste of "un-resolvedness."

My point, then, is not to argue that Lucas's approach is superior to the one here, but rather that if they had gone back and compared their methodology with his, they might have nuanced and qualified some statements and perhaps left us with a few more clues as to where the resolution might lie. This is also true, mutatis mutandis, for another piece of recent scholarship, although one using a very different methodology, namely Amsden (2001). There are some ideas in that book that might suggest to the authors where some of the clues to their riddle might lie. In a chapter alliteratively entitled "Tribulations of Technology Transfer," Amsden details the many complexities in adopting Western technology, the many things that can go wrong, and why seemingly similar forces could lead to very different productivity outcomes. By pointing to the important implicit or "tacit" component of technology, she is actually suggesting a new and important role for human capital and a possible clue to what factor C may be. Here Clark and Feenstra could do worse than to read more in the work of historians of technology. One of those, Rachel Laudan (1984, 6–7), points out that technological knowledge is tacit knowledge, that rules of performance cannot be fully spelled out, and that effective transmission requires personal contact. In her view, this can go a long way toward explaining why technology transfer from inventor to follower country so often fails. To be sure, the tacit component in technology has been declining as codifiability has increased, but because many techniques have become more complex, the total amount of tacit knowledge may not have been. To understand codified knowledge, one needs a "book of codes," and even if the book of codes is explicit, one needs a higher order code to read that one, and so on (Cowan and Foray 1997).

Such tacit knowledge transfers poorly from society to society, certainly more poorly than cotton-spinning equipment, railroad cars, or bags of synthetic fertilizer. Even if the British ran much of the Indian railroads, their local unskilled workers and small station managers were still obviously at an early stage of learning to decode English technology and management. Hence, perhaps, the appalling productivity performance of Indian railroads. Yet some of these firms were essentially Western enclaves managed by westerners, and thus in some sense they should have performed well. One wonders if a study of productivity by firms would yield that foreign-managed firms performed better than native-managed. In 1913, out of 162 Indian cotton factories, 30 were managed by Europeans and 132 by Indians. Did this make a difference to productivity? If not, the role of human capital is of course amplified, and the fact that an Indian worker in 1950 had 1.4 years of schooling as opposed to about 11 years for their U.K. and U.S. counterparts has a lot to account for.

I have never fully understood what schools *precisely* did that made people more productive. Lucas sighs that we "need a more refined view of human capital than one in which five day-laborers equal one engineer" or, I would add (if Clark and Feenstra are correct), in which five Indians equal one Briton. I would suggest that we distinguish between the *education,* the *training,* and the *drilling* aspect of child conditioning. It seems that insofar as schools educated people to think for themselves and to appreciate cultural matters, we may discount their importance for productivity. This kind of education, after all, leads to the creation of independent thinking, perhaps the emergence of novel ideas, but the benefits of those were soon spread to the entire world. Training was more important, since it taught people to decode technical information and thus facilitated their learning in the arena where most of the training took place, which was of course on the job. Drilling and social conditioning may have been more important than either one of those, since they directly affected the absorption of tacit knowledge. In the end, they may have had the largest impact on productivity. Even Amsden does not explicitly make this point, yet the existence of a motivated, disciplined, and punctual labor force may be one of those bridges between culture and measurable productivity that does not collapse the moment you set foot on it.

At the end of the day, the authors will ultimately have to agree that the knowledge to operate and maintain equipment does not move freely and effortlessly across boundaries, even if the capital goods themselves do. There is a deep difference between the knowledge needed to invent or design a new machine and the knowledge required to build it on a routine basis. These are in turn different from operating and maintaining it. Thus there is a very different knowledge base required to design a bicycle, to repair one, and to ride one. To actually carry out a technique, a firm needs something we might call "competence" to set it apart from the concept of "knowledge," which is used to invent or design a technique. This competence, the literature in management science tells us, is neither free nor uniformly distributed.

Clark and Feenstra do not have much time for the notion that *institutions* had an important impact on the outcome of this game. In the Clark-Feenstra world, law and order rule, property rights are enforced, contracts are honored, and governments do nothing at best. Eventually, however, economists will come around to recognizing that institutions do more than just that: They actually help determine the motivation and loyalty of workers, the honesty of managers and bureaucrats, the reliability of consultants and experts, and the willingness of the labor force to submit itself to whatever it takes to get to the productivity levels attained elsewhere. An interesting attempt in this direction was provided recently by Parente and Prescott (2000).

Without considering institutions, Clark and Feenstra's paper faces a deep problem. After all, Mexican or Indian workers migrating to high-productivity economies do not bring their factor C with them. They leave it behind at home. That suggests that it is neither cultural nor racial, but something deeply embedded in the societies whence they come. That, perhaps, is what we mean by institutions.

References

Amsden, Alice. 2001. *The rise of the "rest": Challenges to the West from late-industrializing economies.* New York: Oxford University Press.

Clark, Gregory. 1987. Why isn't the whole world developed? Lessons from the cotton mills. *Journal of Economic History* 47:141–73.

———. 2001. The secret history of the Industrial Revolution. University of California–Davis, Department of Economics. Manuscript.

Cowan, Robin, and Dominique Foray. 1997. The economics of codification and the diffusion of knowledge. *Industrial and Corporate Change* 6 (3): 595–622.

Goldstone, Jack A. 2002. Efflorescences and economic growth in world history: Rethinking the "rise of the West" and the Industrial Revolution. *Journal of World History,* 13 (2): 323–89.

Grossman, Gene, and Elhanan Helpman. 1991. *Innovation and growth in the global economy.* Cambridge: MIT Press.

Laudan, Rachel, ed. 1984. *The nature of technological knowledge: Are models of scientific change relevant?* Dordrecht, the Netherlands: D. Reidel.
Lucas, Robert E. 1990. Why doesn't capital flow from rich to poor countries? (The "new" growth theory). *American Economic Review* 92 (May): 92–97.
Parente, Stephen L., and Prescott, Edward C. 2000. *Barrier to riches.* Cambridge: MIT Press.
Pomeranz, Kenneth. 2000. *The great divergence: China, Europe, and the making of the modern world economy.* Princeton, N.J.: Princeton University Press.