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ABSTRACT

In this paper, we examine the changes in per-capita income and productivity from 1700 to modern times, and show four things: (1) that incomes per capita diverged more around the world after 1800 than before; (2) that the source of this divergence was increasing differences in the efficiency of economies; (3) that these differences in efficiency were not due to problems of poor countries in getting access to the new technologies of the Industrial Revolution; (4) that the pattern of trade from the late nineteenth century between the poor and the rich economies suggests that the problem of the poor economies was peculiarly a problem of employing labor effectively. This continues to be true today.

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1. Introduction

In the late nineteenth century at the same time as transport and communication costs were declining across the world, there occurred what has recently been dubbed by Ken Pomeranz "The Great Divergence." 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 endogenous 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 (TFP) of economies.

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 2, and these are quite consistent with the results of Pomeranz, Easterly and Levine. The third observation – that the poor countries had *access* to new technologies – is dealt with in section 3. We show that at the same time as 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 U.K., as the rich. The problem, as we demonstrate in section 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 was 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 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 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 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 8.

2. Incomes Per Capita

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 that 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 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 pre-industrial 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 1 portrays this divergence, showing income per capita in the USA, Japan, Europe, Russia and China relative to India in 1700, 1820, 1910, 1952, 1978 and 1992. Table 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 US since 1800? We argue that the overwhelmingly cause was a decline in the relative efficiency of utilization of technology in these countries relative to the more successful economies such as Britain and the USA. Conventional estimates report that about one third of the difference in incomes 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 would itself *respond to* differences in the country productivity levels.

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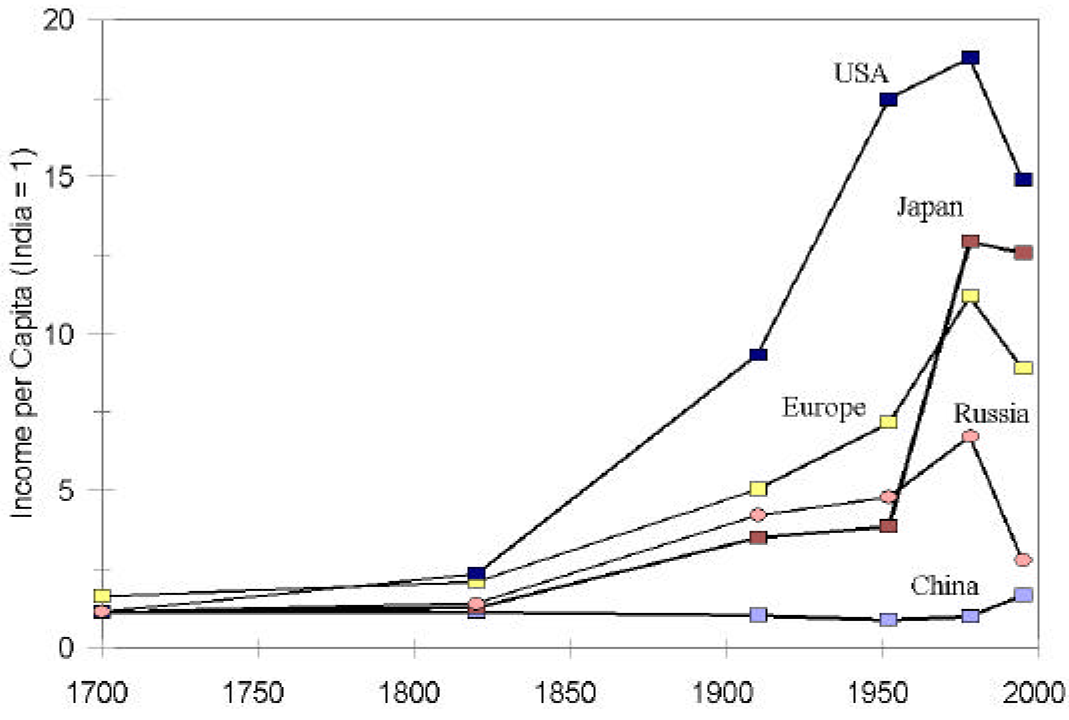
[1] These population figures for Tahiti come from the years 1800 to 1820 when there may already have been some population losses from contact with Europeans. See Oliver (1974).

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

Figure 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.

Table 1: Income per Capita, 1910 and 1990

Country	(1) GDP per capita relative to India, 1910	(2) GDP per capita relative to India, 1990	(3) Calculated Efficiency (TFP), 1910 α=0.33, γ=0.1	(4) Calculated Efficiency (TFP), 1990 α=0.33, γ=0	(5) Calculated Efficiency (TFP), 1990 α=0.50, γ=0
USA	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	-	-
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)

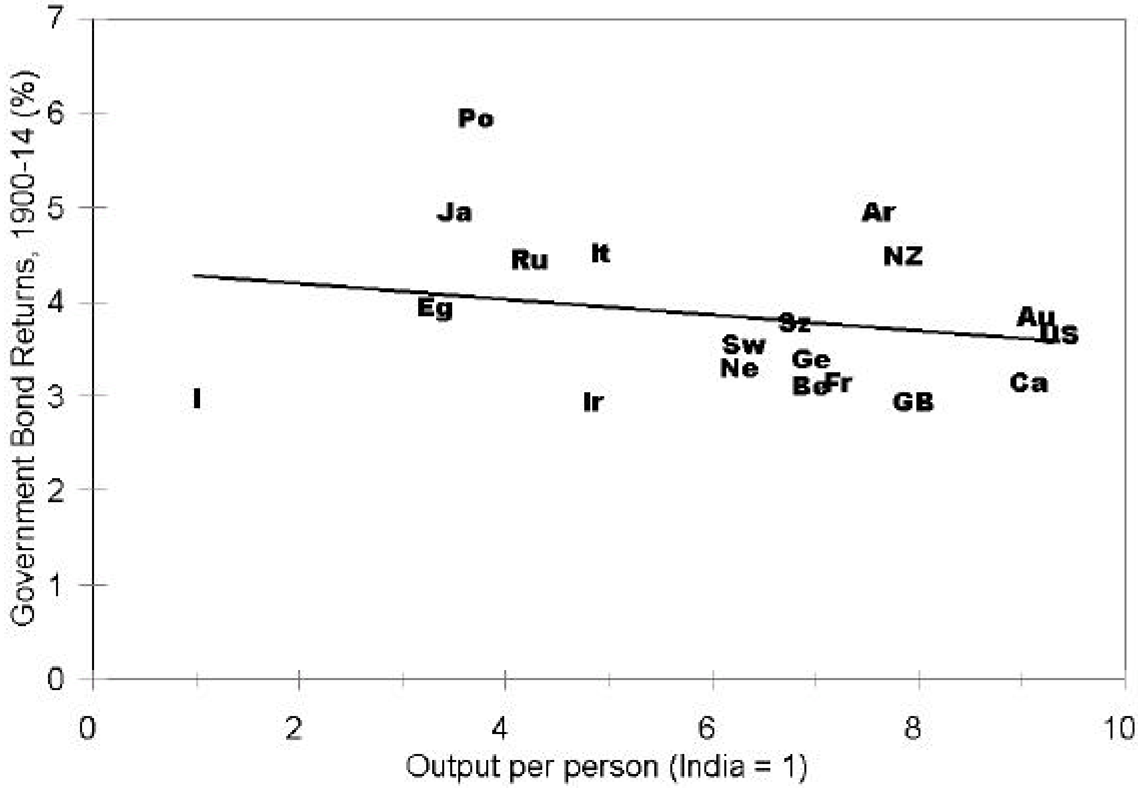
Notes: TFP in column (3) is computed assuming full capital mobility between countries, according to equation (5). TFP in columns (4) and (5) is computed from equation (1').

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 movements by the late nineteenth century. Figure 2, for example, shows rates of return on government bonds in nineteen countries at a variety of income levels in 1900-14 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 two to one. But importantly this variation had little correlation with the income level of the country. Indeed if we regress government bond rates in 1900-14 on output per capita through 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 of return it would help equalize rates of return across all assets in domestic capital markets. Table 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

Figure 2: Government Bond Returns, 1900-14



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

Sources: Table 1. Edelstein (1982) - India, New Zealand. Homer and Sylla (1996) – Britain, Ireland, USA, France, Germany, Belgium, Netherlands, Canada, Italy, Switzerland. Mauro, Sussman and Yafeh (2001) – Argentina, Egypt, Japan, Russia, Sweden, Portugal, Australia (sterling bonds in London).

Table 2: Rates of Return on Railway Debentures, 1870-1913

Country or Region	Relative Output per Capita (India = 1)	Rate of Return (%)
USA	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. Edelstein (1982), p. 125.

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 total factor productivity? Suppose as an approximation that the production function is Cobb-Douglas so that:

$$Y_i = A_i K_i^{\alpha} L_i^{\beta} T_i^{\gamma} \qquad (1)$$

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:

$$(Y_i/L_i) = A_i(K_i/L_i)^{\alpha} (T_i/L_i)^{\gamma} \qquad (2)$$

The rental on capital can be computed by differentiating (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]

$$(K_i/L_i) = A_i^{1/(1-\alpha)} (T_i/L_i)^{?/(1-\alpha)} \qquad (3)$$

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 (3) into (2), we obtain the following expression for output per capita:

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

$$(Y_i/L_i) = (A_i)^{1/(1-\alpha)} (T_i/L_i)^{\gamma/(1-\alpha)} \quad (4)$$

Notice that the right-hand side of (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 (4) that we can calculate relative efficiencies in the world economy circa 1910 as,

$$A_i = (Y_i/L_i)^{(1-\alpha)} (T_i/L_i)^{-\gamma} \quad (5)$$

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, ?, has become very small in recent years (4) suggests that the sole significant cause of differences in income per capita between India and the USA and other advanced economies is differences in TFP.

Evidence from 1910

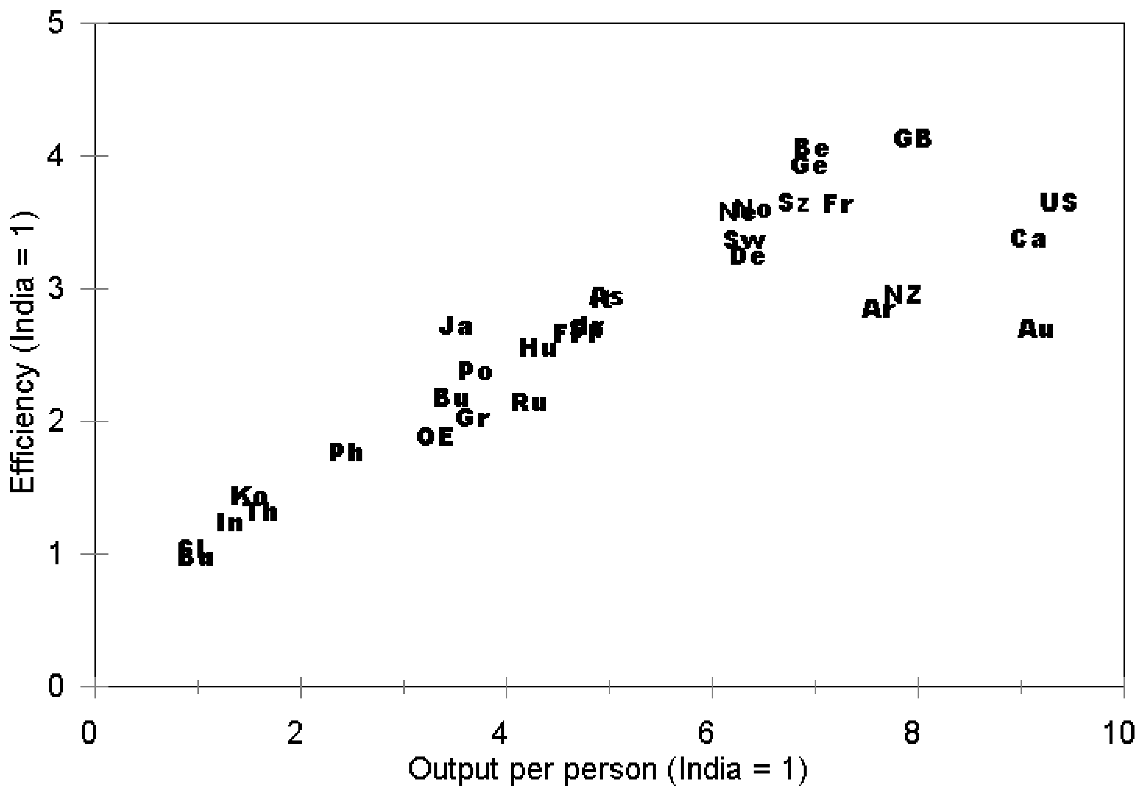
Even without reliable data on capital stocks across countries, we can calculate TFP from (5) if there is mobile capital. Column (3) of Table 1 and Figure 3 shows the implied TFP of the various countries in the world in 1910 for which we have data, relative to India, assuming the share of capital in national 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% 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 US, Canadian or Australian economies was really below that of Great Britain in 1910. What we also see 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 GDP might be regarded as unreasonable for 1910, and that poorer economies would systematically show up as having smaller levels of investment 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 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.

Evidence from 1990

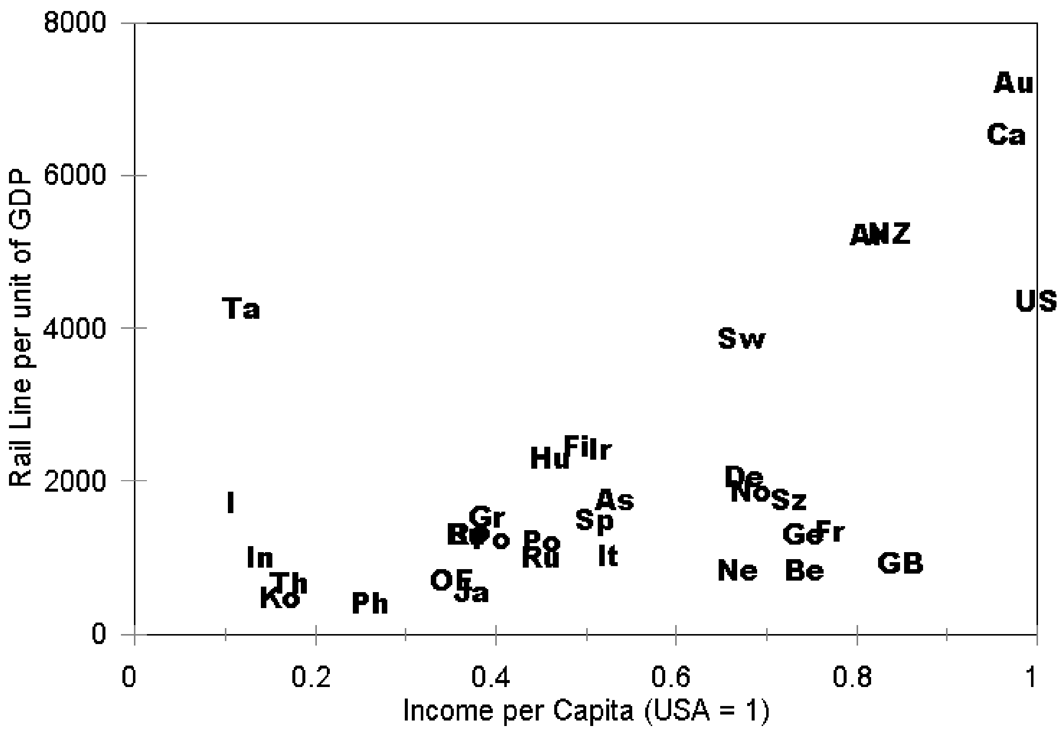
The assumption here that capital will be proportional to output finds support in the international economy of the 1990s. Using a sample of countries including those in Table 1 for 1990, Figure 5 shows capita per worker versus GDP per worker, with both measured relative to India. Recall from (3) and (4) these should be equal with full capital mobility, and from Figure 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 PWT for which capital is available for 1990, we find:

Figure 3: Calculated Differences in Efficiency (TFP) circa 1910



Note: 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 A, Austria, Au, Australia, Ar, Argentina, Be, Belgium, Bu, Burma, Ca, Canada, Cy, Cyprus, De, Denmark, Fi, Finland, Fr, France, Ge, Germany, GB, Great Britain, Gr, Greece, Hu, Hungary, In, Indonesia, Ir, Ireland, It, Italy, Ja, Japan, Ko, Korea, Ne, Netherlands, NZ, New Zealand, OE, Ottoman Empire, Ph, Phillippines, Po, Portugal, Ru, Russia, SL, Shri Lanka, Sp, Spain, Sw, Sweden, Sz, Switzerland, Th, Thailand, US, United States of America.

Figure 4: Railway Line per unit of GDP, 1910



Note: Country symbols as in figure 3.

$$\text{Ln(Capital/worker)} = \underset{(0.11)}{-0.01} + \underset{(0.07)}{1.32}\ \text{ln(GDP/worker)}, \qquad N=60,\ R^2=0.85.$$

The coefficient on ln(GDP/worker) is somewhat higher that 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 Penn World Tables does not provide us with data on the share of national income received by labor and capital, in order to estimate α, we rewrite (1) as $\ln(Y_i/L_i) = \ln A_i + \alpha \ln(K_i/L_i)^{\alpha}$, and regress real GDP per worker on real capital stock per workers. Running this regressions over all countries and years for which data is available in Penn World Tables, 1965-1990, and including fixed effects for countries, we obtain $\alpha=0.50$ (s.e.=0.01). Performing the same regression in first-differences, which still including 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 1 we report the calculation of total factor productivity (TFP) using these values of α, and the formula:

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

where all variables are measured relative to those in India.

In Figure 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:

$$\underset{}{\text{Ln(GDP per capita)}} = \underset{(0.04)}{-0.02} + \underset{(0.07)}{1.06}\ \ln(\text{TFP}) + \underset{(0.03)}{0.43}\ \ln(\text{Capital/Worker}),\quad N=60,\ R^2=0.96$$

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:

$$\text{Var(GDP per capita)} = 1.06^2\ \text{Var(TFP)} + 0.43^2\ \text{Var(Capital/Worker)} + 0.91\ \text{Cov} + \text{Var(error)}\ ,$$

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, capital/worker explains one-third of this variation, but the *covariance* between TFP and capital/worker explains nearly 40% of this variation! This reinforces our argument that capital/worker should be regarded as an endogenous variable, itself be *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 (γ=0). Running this regression for 1990, we obtain:

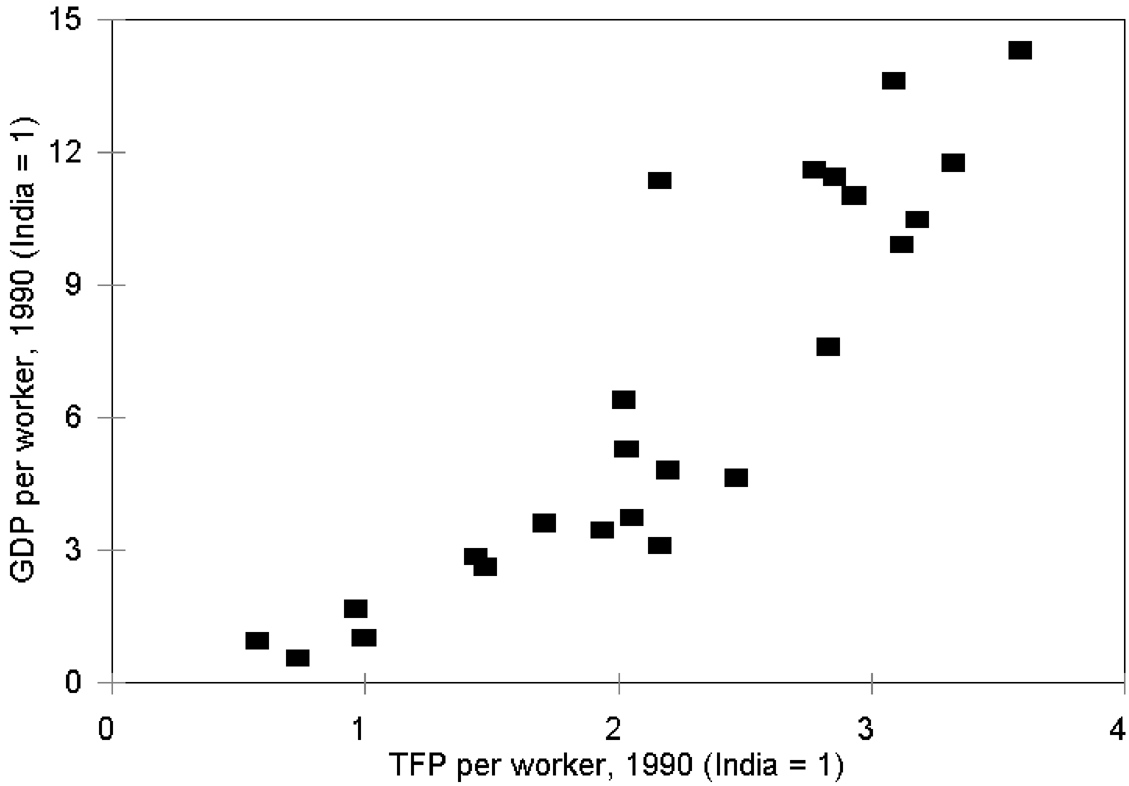
$$\text{Ln(Capital/worker)} = \underset{(0.21)}{0.55} + \underset{(0.27)}{1.86}\ \ln(\text{TFP}),\qquad N=60,\ R^2=0.46\quad .$$

The implied capital share is α=1/1.86=0.54, which is not too far away from the value α=0.4 used

Figure 5: Capital per Worker versus GDP per worker, 1990

Source: Penn World Tables (5.6).

Figure 6: GDP per capita versus TFP, 1990



Source: Penn World Tables (5.6).

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.

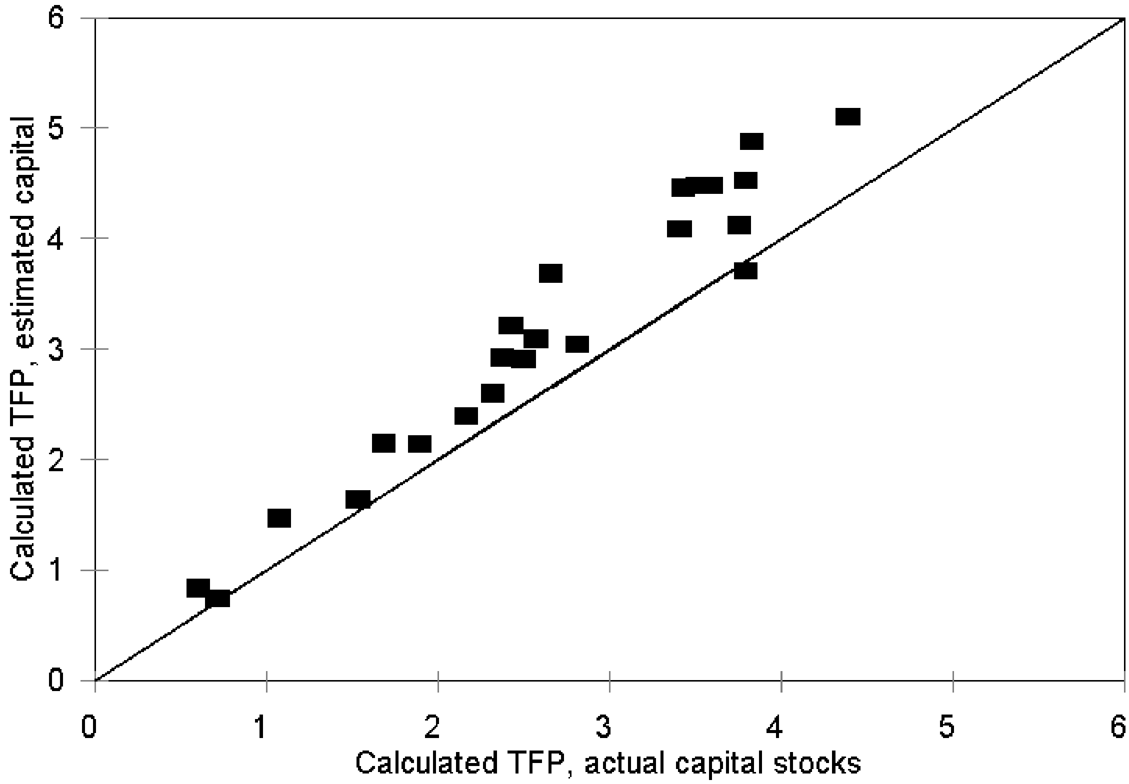
If capital is indeed mobile, then we should really take the regression above, explaining capital/worker, and substitute this into the previous regression, explaining GDP per capital. In other words, let us treat TFP as the only underlying determinant of income, and use this to obtain:

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

According to these estimates, total factor productivity 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 7, we find a very close correlation between TFP calculated using the capital stock information, and TFP calculated assuming capital per worker is proportional to GDP per worker. The observations mostly lie above the 45° 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.

Figure 7: TFP Calculated with and without Capital Stock Information, 1990



Note: TFP calculated using $\alpha = 0.33$.

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 modifies our analysis, again compute the rental on capital by differentiating (1). Allowing this to differ across countries, and expressing all variables in country i relative to India, we obtain:[4]

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

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

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

Comparing (3') and (4'), we see that capital/worker and output/worker differ by exactly the rental term, so that $(K_i/L_i) = (Y_i/L_i)/R_i$. Countries with lower rentals will attract more capital. In this case, relative efficiencies should be calculated as,

$$A_i = [(Y_i/L_i)/R_i]^{(1-\alpha)} (T_i/L_i)^{-\gamma} \quad . \qquad (5')$$

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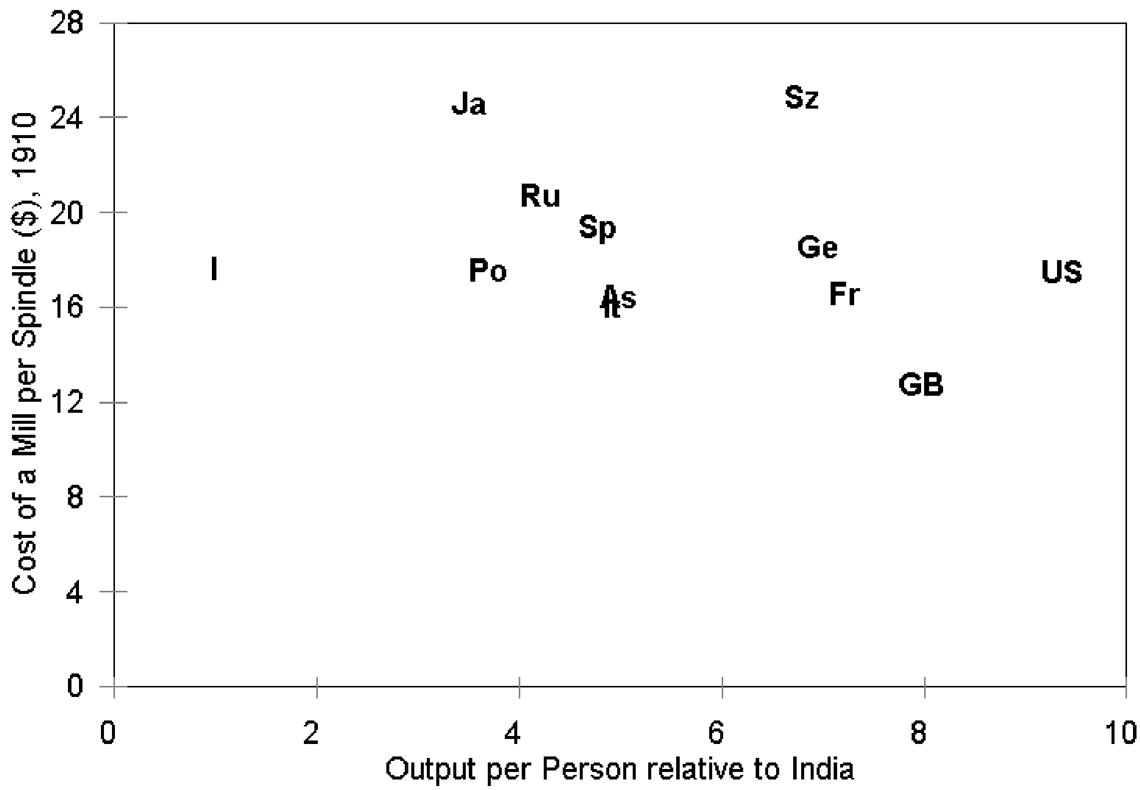
[4] From note 3, the rental on capital is $R_i = \alpha A_i (K_i/L_i)^{(1-\alpha)} (T_i/L_i)^{\gamma}$. Now divide this by the same equation for India, and express all variables relative to India, to obtain, $R_i = A_i (K_i/L_i)^{(1-\alpha)} (T_i/L_i)^{\gamma}$. Then (3') follows directly.

The rental of capital is, of course, the product of the rate of return on capital in each country, times 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 since cotton mills generally embodied imported machinery and power plants combined with local construction of the buildings. We also saw above little sign 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 8 shows these measures of capital costs relative to output per person in 1910. There is no strong sign in the pre-WWI 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 too much.

The PWT do report significant differences in the purchase prices of capital goods across countries in the post WWII 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 is taken from the benchmark surveys for the Penn World Tables, 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 times its purchase price. For these years we do not have information on interest rates by country. But 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.

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

Figure 8: The Estimated Purchase Price of Capital in 1910



Notes: Output per person is measured as an index with India set equal to 1. The symbols used are: As, Austria, Fr, France, Ge, Germany, GB, Great Britain, I, India, It, Italy, Ja, Japan, Po, Portugal, Ru, Russia, Sp, Spain, Sz, Switzerland, US, United States of America.

Sources: Table 1, Clark (1987).

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

$$\underset{}{\text{Ln(Capital/worker)}} = \underset{(0.11)}{0.17} + \underset{(0.08)}{1.16}\ \ln(\text{GDP/worker}) - \underset{(0.23)}{0.47}\ \ln(\text{Rental}), \qquad N=52,\ R^2=0.89$$

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 having the rental included, so that it becomes closer to unity. The rental itself has a negative coefficient, but less than unity as predicted; 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 towards zero.

Computing TFP according to (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 (4') to obtain:

$$\text{Ln(GDP per capita)} = \underset{(0.08)}{0.27} + \underset{(0.12)}{1.65}\ \ln(\text{TFP}) - \underset{(0.18)}{0.67}\ \ln(\text{Rental}), \qquad N=52,\ R^2=0.87$$

Once again, we find that total factor productivity 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, while the rental only explains 5% of this variation, with the *covariance* between TFP and the rental explaining another 16% 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/climate (Sachs, 2001), or institutions (Acemoglu, et al, 2001), or social capital (Jones and Hall, 1999) play 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 or to the use* of technologies.

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 while developing new knowledge is an arduous task, copying innovations is much easier. Also while 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 course yarn was much easier technically than spinning fine yarn. Countries such as India could thus specialize in course 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 Britain and later the USA. 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.

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 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 coats 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.

Table 3: Railway Mileage Completed

Year	Britain	USA	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

Ocean transport was similarly revolutionized in this period by the development of the steamboat. In the 1830s and 1840s while 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 trans-oceanic 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), p. 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% lighter and gave 15% 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 to produce one hp-hour, but by 1881 it 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% from 1870 to 1910. In 1906, for example, it cost 8 shillings to carry a ton of cotton goods by rail the 30 miles from Manchester to Liverpool, but only 30 shillings to ship those goods the 7,250 miles from Liverpool to Bombay. This cost of shipping cotton cloth was less than one percent of the cost of the goods. By the late nineteenth century industrial locations with good water access, which were on well established shipping routes – Bombay, Calcutta, Madras, Shanghai, Hong Kong – could get access to all the industrial inputs of Britain at costs not too much higher than many firms in Britain. In part this was because since Britain's exports were mainly manufactures with high value per unit volume there was excess shipping capacity on the leg out from 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 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% of the distance on the journey from London to Bombay and 32% of the distance on the journey from London to Shanghai. Thus while in the 1840s it took sailing ships from 5 to 8 very uncomfortable months to get to India, by the 1912 in principal the journey could be done in 15 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 then 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 Britain by a telegraph system partly over land which could transmit messages in 24 hours, and in 1866 a successful transatlantic telegraph service had been established. Thus by 1866 orders and instructions could be communicated half way 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 AD, 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 Britain. With the telegraph, rail, and steamship it was possible to send information across the world in much faster 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 the Industrial Revolution technologies to almost any country in the world thus seemed to have been completed by the last quarter of the nineteenth century.

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% of their production as early as 1845-1870, 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), pp. 5, 6, 34). These firms reduced the risks to foreign entrepreneurs by such practices as giving them machines on a trail 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 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.

Table 4: Platt Ring Frame Orders by Country, 1890-1934

Country	Sales, 1890-1914 (9 years)	Sales, 1914-1936 (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
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
USA	2	0
West Africa	0	2

Source: Platt Ring Frame Order Books, Lancashire Record Office.

Similar capital goods exporters developed in the rail sectors, and later in the U.S. in the boot and shoe industry. In the railways British construction crews completed railways in many foreign countries under the captainship of such flamboyant entrepreneurs as Lord Brassey. The reason again for the oversees exodus was in part the saturation of the rail market within Britain by the 1870s after the boom years of railway construction. By 1875 in a boom lasting just forty-five years 71% of all the railway line ever constructed in 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 Britain, and the Indian railway mileage by 1910 was significantly greater than that of Britain, as Table 3 above shows.

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

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 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 Britain to support new textile industries. Most of the Indian subcontinent and of 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 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 Britain and India. Any manufacturer who set up a cotton mill in Bombay was assured that he or she would have 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 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% 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 protected by a 5% ad valorem revenue tariff also.

4. Efficiency in the Use of Technology

Though 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 (1998)).

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×$0.285 + ton-miles×$0.0066). The quality of passenger service varied greatly, which 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-miles was multiplied by $0.023, the average revenue per passenger mile for first class. Table 5 shows the implied output per worker and output per track mile in $. On this measure output per worker in the USA in 1914 was six times output per worker in India, even though India was using an equivalent technology.

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[6] From freight revenues across countries we estimate that the cost of freight hauling a ton of freight x miles in the USA in 1914 in $(0.285+.0066z).

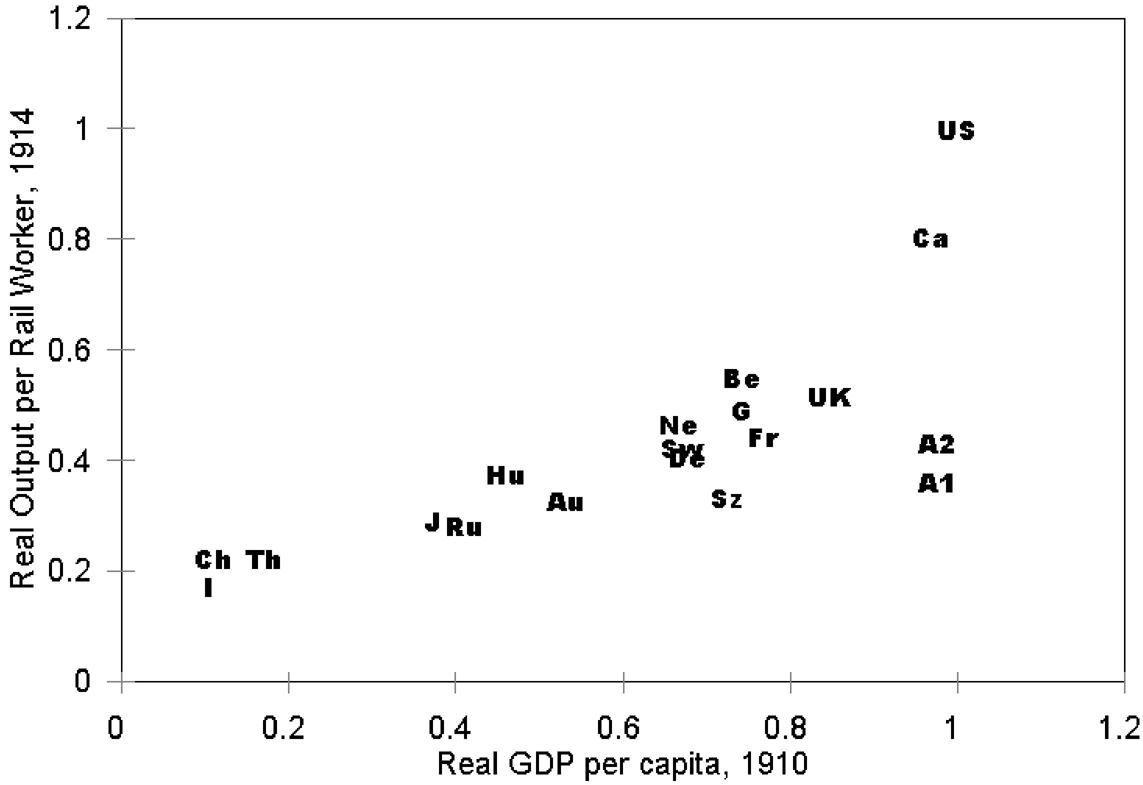
Table 5: Railroad Operating Efficiency circa 1914

Country	Year	Output per worker, $	Output per track mile, $	Efficiency (USA=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
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	-
UK	1912	898	9,457	0.72	25,854
USA	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.

Figure 7: Output per worker on railways versus GDP per capita, 1910



Note: A1 is New South Wales, A2 is South Australia. Otherwise country codes as before.

Since Indian rail equipment was mostly imported from Britain, a better comparison might be with the UK. UK output per worker was three times output per worker in India. Figure 7 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 5 shows, the overall efficiency of the rail systems of these countries also varies greatly. The efficiency of the Indian rail system was only 28% of the US system, and 39% of that in the UK. These differences in the efficiency of operation of the rail system between countries like India and the USA and UK 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 English 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.[7]

The problem of operating western technology efficiently in poor countries like India was the main barrier to the spread of this technology. Table 6, for example, shows the gross profit rates of Bombay cotton mills by quinquennia from 1905-9 to 1935-9, as well as the size of the Bombay industry and the output per worker in Bombay as an index with 1905-9 set at 100. As can be seen profits were never great, but the industry grew substantially in the era of modest

[7] Morris and Dudley (1975), pp. 202-4, Headrick (1988), p. 322.

Table 6: The Bombay Industry, 1907-1938

Year	Gross profit rate on fixed capital	Size of the Bombay Industry (m. spindle-equivalents)	Output per worker in Bombay (Index)	Output per worker in Japan (Index)
1905-9	0.06	3.09	100	100
1910-4	0.05	3.43	103	115
1915-9	0.07	3.68	99	135
1920-4	0.08	4.05	94	132
1925-9	-0.00	4.49	91	180
1930-4	0.00	4.40	104	249
1935-9	0.02	3.91	106	281

Notes: Profits and output per worker were calculable only for the mills listed in the Investor's India Yearbook.

Source: Wolcott and Clark (1999).

profits up to 1924. Thereafter, however, profits collapsed (as a result of Japanese competition) and the Bombay industry soon began to contract. The last column shows what was happening to output per worker in Japan, where using 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.

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 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, Britain, Ireland, Egypt, Nigeria, 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 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

Table 7: The Commodity Trade of British India, 1912-13

Commodity	Imports $ m.	Exports $ m.	Net Exports $ m.
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: United States, Department of Commerce (1915).

, Bureau of Foreign and Domestic Commerce, Special Consular Reports, No. 72, British India (Washington: Government Printing Office, 1915).

effectively exported its raw cotton to Britain to be manufactured there, paying for this with the export of other raw materials. The effective net raw material export of India in 1912 was about $460 million. With Indian GDP measured in US prices at about $11.5 b. this implies that exports of raw materials were about 4% 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 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 imports 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. 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 was India an exporter of land intensive goods at the turn of the century. While 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 workers in India is less productive that abroad, so the *effective* population there is smaller than otherwise.

Table 8: World Trade in Cotton Textiles, 1910

All Net Exporters:	All Cotton Goods ($ m.)	Cotton Yarn ($ m.)	Grey Cloth ($ m.)	Colored Cloth ($ m.)
U.K.	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
U.S.A.	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
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

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

Sources: United States, House of Representatives (1912), Vol. 1, Appendix A, pp. 212-218.

The HOV model expresses trade in terms of the *factor content* of exports and imports, i.e. the amounts of labor, capital, land, etc. embodied in the goods that are traded. That is, the factor content of trade for county c is defined as $F_c \equiv AT_c$, where:

- $T_c = Y_c - D_c$ is the (Nx1) vector of net exports of goods i=1,…,N for country c, where Y_c is production and D_c is consumption;
- $A = [a_{ki}]$ is a (MxN) matrix giving the amount of primary factor k=1,..,M used to produce one unit of production in industry i=1,…,N. (This matrix should include the primary factors used both directly and indirectly).[8]

Focusing on the case where labor, capital and land are the primary factors, then $F_c = (F_{Lc}, F_{Kc}, F_{Tc})$ 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 U.K. 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 F_c using the technology of the base country, Trefler (1995) extends the HOV model to show how the factor-content of trade are 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:

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

$$F_{Lc} = \pi_{Lc}L_c - s_c \sum_{j=0}^{C} \pi_{Lj}L_j \quad (6a)$$

$$F_{Kc} = \pi_{Kc}K_c - s_c \sum_{j=0}^{C} \pi_{Kj}K_j \quad (6b)$$

$$F_{Tc} = \pi_{Tc}T_c - s_c \sum_{j=0}^{C} \pi_{Tj}T_j \quad (6c)$$

where $s_c \equiv Y_c / \sum_{j=0}^{C} Y_j$ denotes the share of country c's GDP in world GDP.[9]

To interpret these equations, (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 (6) as:

$$\pi_{Lc}L_c - s_c \sum_{j=0}^{C} \pi_{Lj}L_j < 0, \text{ or} \quad (7a)$$

$$\pi_{Kc}K_c - s_c \sum_{j=0}^{C} \pi_{Kj}K_j < 0, \text{ and} \quad (7b)$$

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

Depending whether inequality (7a) or (7b) holds, these taken together with (7c) imply that,

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[9] 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.

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

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 GDP's, will therefore allow use 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.[10] To simplify these inequalities, consider the corresponding equations for the U.K. (labeled "b"). We expect that if the full factor content calculation were done, the U.K. 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 U.K., then we also obtain the reverse inequalities as in (8),

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

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

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

[10] 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.

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

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-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, though differing in their productivities, and use their endowments combined with the factor contents of trade to infer the factor productivities.

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 9 for 1910, and in Table 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% of the world average GDP per capita. Surprisingly, this number has remained much the same in 1990 (dropping just slightly to 0.34), though this finding relies on the fact that we are using the PPP-adjusted GDP values from the Penn World Tables. Prices are so low in India that its GDP is 3.5 times higher in the Penn World Tables for 1990 than obtained from World Bank data, that converts 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 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 U.K. as the initial comparison, we use the first set of inequalities in (10). Then their ratio of per-capita GDP is shown in the column marked (1) in Table 11, which provides an *upper bound* to the efficiency of labor in India relative to the U.K. The value of 0.13 indicates that an Indian worker is *less than* 13% as productive as his counterpart in the U.K.[11] The ratios of GDP to crop land or crop plus pasture are shown in

[11] Rather than using total population in Tables 9 and 10, we should actually use estimates of the work force.

Table 9: Data on Population, Land, GDP, circa 1910

Country/Area	Share of Population	Share of Crop Area	Share of Crop + Pasture	Share of GDP	**(1) GDP/ Pop**	**(2) GDP/ Crop**	**(3) GDP/ Crop + Pasture**
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**
UK	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**
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**

Sources: Crop and pasture areas are from the U.N. Food and Agriculture Organization (1991), and apply to years around 1957.

Table 10: Data on Population, Land, GDP, 1990

Country/Area	Share of Population	Share of Crop Area	Share of Crop + Pasture	Share of GDP	**(1) GDP/ Pop.**	**(2) GDP/ Crop**	**(3) GDP/ Crop + Pasture**
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**
UK	0.011	0.005	0.004	0.038	**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**
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 U.N. Food and Agriculture Organization (1991).

GDP is from the Penn World Tables (v. 5.6) columns (2) and (3), and provide *lower bounds* to the efficiency of land in India relative to the U.K. They gives a value of 0.04 or 0.11, implying that a hectare of land in India is *at least* 4% as productive (11% for crop land) as that in the U.K. Putting together these estimates for labor and land, we obtain the final columns in Table 11, showing that the efficiency of crop land relative to labor is *at least* 0.33 in India relative to the U.K. (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 U.K., 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 U.K. is scarce in land as compared to India. Another explanation, though, is that the U.K. may not have the opposite sign pattern of trade as India, in which case the inequalities in (10) do not apply. In fact, using the data of Estevadeordal and Taylor (2000, 2001) circa 1910 and Trefler (1993,1995) for 1983, it turns out the U.K. 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 (2000, 2001) data, there are only three countries which 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 (non-agricultural) labor in 1983, using 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

Table 11: Implied Efficiency of Labor and Land, 1910 and 1990

	(1) Efficiency of Labor (upper bound)	(2) Efficiency of Crop Land (lower bound)	(3) Efficiency of Crop + Pasture (lower bound)	**(4)=(2)/(1) Efficiency of Crop Land/ Labor (lower bound)**	**(5)=(3)/(1) Efficiency of Crop + Pasture/ Labor (lower bound)**
Results for 1910 (using population)					
India relative to:					
UK	0.13	0.04	0.11	**0.33**	**0.85**
Other Europe:					
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)					
***India relative to*:**					
UK	0.10	0.06	0.14	**0.58**	**1.46**
Other Europe:					
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)					
***India relative to*:**					
UK	0.12	0.06	0.14	**0.46**	**1.15**
Other Europe:					
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**

Notes:

1. 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 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 10. Columns (1)-(3) for 1990 (using workers) are recomputed from Table 10 but using the number of workers in each country rather than the population.
2. 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 are the UK, which is an importer of both land and labor.

(non-agricultural) 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 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 increasing 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.[12] 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 remains an *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 with India. But 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 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 11. The reason for this is that only about 40% of the population in India are economically active workers, whereas this percentage varies around 50% 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, it is expected that these ratios all fall when workers rather population is 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.

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

[12] These ratios can be computed by dividing the population and crop land columns within Tables 9 and 10.

data we have assembled so far supports 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 this data is 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 confirm the results reported in Table 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 (2000, 2001) 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 enable 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 non-homothetic 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 which 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 non-homothetic 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.

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