Technology-Skill Complementarity and International TFP Differences*

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Abstract

What determines whether a country is better at using some technologies than others? A widely held view is that a country's ability to absorb and implement technologies is tied to its human capital. In this paper, we construct a novel specification of technology that incorporates this idea. Countries are comprised of a range of industries with heterogeneous productivities. In high human capital countries, productivity is maximized for industries with the most sophisticated technologies, while in low human capital countries, productivity is maximized for industries with less sophisticated technologies. A key result is that both aggregate total factor productivity and the industrial structure of an economy are driven by inter-industry variations in productivity which in turn is a function of human capital. We embed this specification within a standard production function framework and undertake a development accounting exercise. Our results indicate that almost half of the variation in aggregate TFP differences can be explained by the distribution of inter-industry TFP.

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1 Introduction

The standard of living in U.S. is estimated to be about 20 times higher than the standard of living in Kenya. What are the roots behind these enormous income differences across countries? As Robert Lucas eloquently put it, "Once one starts to think about [these questions], its hard to think about anything else."[1]. This key question has led to an explosion in the field of economic growth over the past two decades. Over the past decade, this body of research has increasingly shown that total factor productivity (or the "residual") differences account for most of the cross-country differences in GDP per worker.[2] While this is an important step forward, the fact remains that TFP is a proximate determinant and not a fundamental determinant of average incomes. Moreover, exercises that tend to emphasize the primacy of TFP do not always incorporate the role of human capital in shaping it.

In this paper we pay particular attention to the role of what one might call appropriate human capital. In particular, we revisit the question - are all countries equally good at using all technologies? The trivial answer to this is no. The view of a uniform technology within an economy that diffuses instantly across all industries is hardly a depiction of reality. Agriculture does not use the same technology as the software industry. Furthermore, within each industry, different technologies will have different skill requirements. Since each country has its own skill endowments, some industries will be more productive in one country than in another. The subsequent question is, what determines whether a country is better at using some technologies than others? Here, we model the idea that a country is best suited to produce some specific technologies that complement its human capital. To fix ideas, we can think of ranking countries in terms of their human capital. At the same time, we can also rank technologies in terms of their increasing sophistication. One can argue that more sophisticated technologies tend to be more productive when used with higher amounts of human capital. Less sophisticated technologies are not necessarily more productive when used with high levels of human capital. For instance, poor countries that are less abundant in human

[1] See Lucas (1988)

[2] See Hall and Jones(1999) and Klenow and Rodriguez-Clare (1997). Both papers argue that a substantial variation in GDP per worker is due to differences in TFP as opposed to factors of production (mainly physical and human capital). Subsequent research, however, has tried to reinstate the primacy of human capital. See Seshadri and Manuelli (2005).

capital are not efficient in producing the latest IT equipment and software. Conversely, these countries might be efficient in producing textiles or agricultural products that traditionally require less human capital. While these observations are in themselves not new, we implement a novel mechanism to capture these ideas, and relate them to comparisons of aggregate TFP undertaken in the literature.

We model total factor productivity as comprising three distinct components. First, there is a sector neutral national homogeneous TFP component, a common assumption in the literature. This can reflect the overall ease with which technologies can enter an economy, or other aspects of efficiency that are not necessarily technology specific. Second, we allow for variation in technology levels across industries within a country. Thus, while we adopt a product variety framework for intermediate inputs, we allow the productivity of intermediate inputs to vary. Third, and the crucial innovation in our setup, is the introduction of a human capital driven technology component. In particular, within different varieties, there are some for which productivity is highest, given the country's current human capital level relative to the remaining varieties. Thus, the third component gives some industries within a country a productivity advantage over other industries. To get an initial idea of how the last two features interact, consider Figure 1.

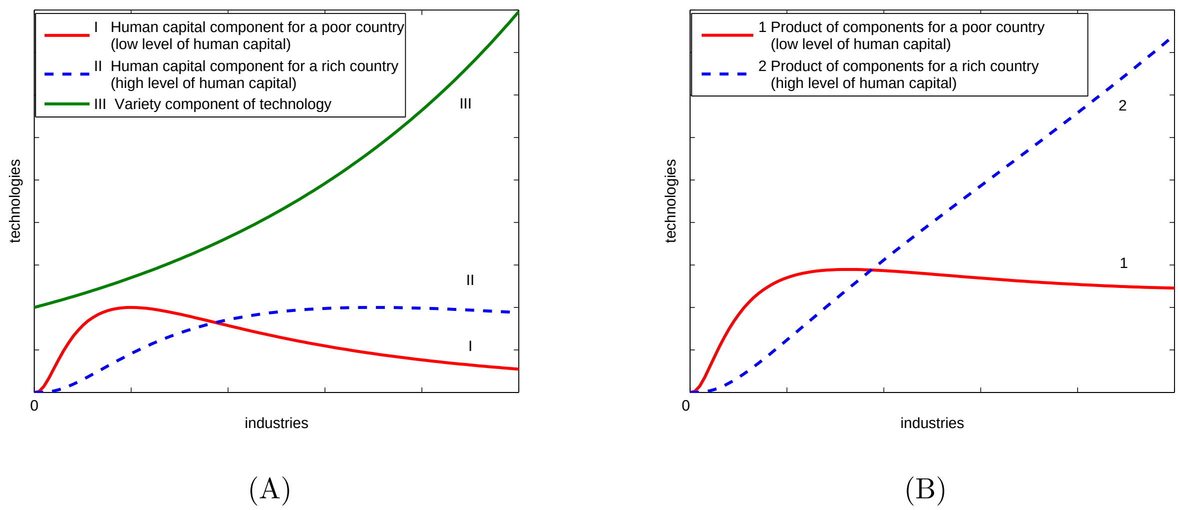


Figure 1: Distribution of the components of technology across industries

Here industries are indexed along 0 to 1, with industry 0 using the least sophisticated technology and industry 1 using the most sophisticated technology. Thus, *ex-ante*, at any point in time it is feasible for a whole range of industries to exist. In Figure 1 Panel A, this inter-industry variation in technology which is independent of human capital is depicted by line III. Now consider two countries with different levels of human capital per worker. For the country with a low level human capital (line I), the human capital specific aspect of productivity is maximized at an industry with a low degree of sophistication and for the country with high human capital level (line II), this is maximized at an industry with a higher degree of sophistication. The human capital component of productivity is then multiplied by the industry specific productivity of each country (line III). The product of the two is depicted in Figure 1 Panel B. In our benchmark model, this distribution of industry specific TFP becomes a component of aggregate TFP. Finally, though not depicted, for each of the countries, this is further multiplied by the national homogeneous TFP level.

A few important inferences can be made right away. First, note that the manner in which lines I and II are drawn suggest that poor countries are really disadvantaged in producing sophisticated goods. However, rich countries are not as disadvantaged in producing less sophisticated goods. This asymmetry does appeal to one's intuition. A relatively uneducated worker in a poor country will not have the capabilities to operate hi-tech equipment which requires substantial investments of time and costs in human capital. On the other hand it is conceivable that a highly educated worker, with some training, can start working in an industry that does not require much human capital.[3] Secondly, note that for some industries (the less sophisticated ones), the poor country shown by line 1 in Figure 1 Panel B is actually more productive than the rich country. However, we still need to multiply these with the homogeneous TFP component and if the differences in the latter are large enough across countries then the first two components may be less relevant.

This quantitative question is addressed in the second part of the paper. We calibrate the equilibrium solution of the model by using a standard development accounting approach in order to back out our measure for aggregate TFP (which is a product of all three components). We undertake a variance decomposition exercise and we find that differences in aggregate TFP explain 62% of variation in GDP per worker. More importantly, we also calculate the contribution of the non-homogeneous components of TFP in the variation of aggregate TFP. We infer that the former

[3] The cliche of the "overqualified worker" comes to mind.

accounts for 41% of the variation in the latter. This is a fairly large number and it underscores the importance of what others have referred to as "technology-skill" complementarity.[4]

The rest of the paper is organized as follows: Section 2 presents the model where we emphasize the new formulation for technology and its importance in the construction of TFP. In section 3 we describe the calibration methodology and we use different measures for human capital in a variance decomposition exercise similar to Klenow and Rodriguez-Clare (1997). Section 4 concludes.

1.1 Related Literature

Our approach constructs a link between two strands of the literature. First, we take into account the recent findings of the vast literature of appropriate technology and skill biased technological differences. The idea of a country being better at using technologies specific to its capital-labor ratios dates back to Atkinson and Stiglitz (1969). Basu and Weil (1996) further build upon this concept of "appropriate technology" in a learning-by-doing model where improvements in technology are localized and tied to capital-labor ratios. While our current version of the paper is a static one, it is easy to see that the distribution of technologies across inputs could ultimately be a function of localized learning by doing albeit based on human capital rather than capital-labor ratios.

Closest to our paper, however are Caselli and Coleman (2006) and Acemoglu and Zilibotti (2001). Using a model of endogenous technological choice, Caselli and Coleman show that technologies chosen by different countries are not identical because of the existence of technological skill bias: poor countries choose technologies that complement unskilled labor, while rich countries (skilled labor abundant) favor the use of technologies that complement skilled labor. However, the structure in our paper is more general in the sense that since technologies themselves are partly endogenous to human capital, it provides a theory for where technological differences come from without having to estimate production possibility frontiers. Further, since we allow for a continuum of goods, the model can provide some theoretical implications regarding the diversification in the structure of production. Finally, in principle, the model can allow for a joint endogenous evolution of human capital and technological change- something we explore in a separate paper. Nevertheless, the two papers should be viewed as complementary.

Acemoglu and Zilibotti (2001) point out that some technologies might be inappropriate for

[4]See Goldkin and Katz (1998).

poorer, less skill abundant countries, since the new technologies from rich countries are meant to be used by skilled workers. They find that income disparity arises because of "technology-skill mismatch" where skill scarce countries are forced to adopt some skill biased technologies ultimately leading to lower productivity. However ex-ante this is quite different from our paper since we do not have any such skill mismatch and skill-scarce countries choose to focus on less sophisticated technologies in equilibrium. Nevertheless, it is easy to see that one could get the same outcome if we introduced distortions in our model which would lead to an inefficient production structure. Again, this is obviously something that is true in reality (whether one thinks of urban bias or agricultural protection) and is a future extension that we plan to work on.

Finally, we connect the above conclusions to the findings of the emerging literature of inter-sectoral linkages. The view is that sectoral composition and the ties between sectors create a multiplier effect reflected in TFP differences.[5] Jones (2008) builds a model of linkages across intermediate goods starting from the premise that intermediate goods enter the final good production in a complementary fashion. The idea is that weak links, i.e., industries with low productivity will cause even lower productivities in subsequent industries. Hsieh and Klenow (2007) stress that missallocation of inputs at the firm level highly affects TFP. By using micro data they quantify this impact by constructing a measure for within industry TFP for manufacturing sectors in China, India and United States.

2 Model

We consider a discrete-time model with a representative infinitely lived consumer who maximize utility over a final homogenous good. In addition to the final good, there is a continuum of intermediate inputs which in conjunction with capital produce the final good. The intermediate inputs are produced using skilled labor and unskilled labor. The key innovation is, of course, the

[5] Chanda and Dalgaard (2007) also show that the allocation of inputs between agricultural and non-agricultural sector has a significant impact on TFP levels and provide evidence that the resulting relative efficiency between sectors accounts for 85% of international variation of TFP. They indicate that structural differences are as important as technological differences in explaining TFP disparity. Caselli (2005) notes that without sectorial differences, income disparity would be reduced to one third of its actual level and as long as these sectorial differences matter, it might be wiser to focus on barriers to mobility of inputs across industries rather than barriers to technology adoption.

construction of the technology for each of these varieties which we shall discuss in detail later. In this section we solve for equilibrium GDP which in turn depends upon the equilibrium allocation of endowments across industries. Using this equilibrium allocation, we derive expressions for aggregate TFP, and its inter-industry component.

2.1 Production

2.1.1 Final good sector

Perfectly competitive firms produce a homogeneous final good by combining capital and a continuum of differentiated intermediate inputs using a Cobb-Douglas production function,

$$Y_t = K_{Y_t}^{1-\alpha} \int_0^1 X_{it}^{\alpha} di, \qquad 0 < \alpha < 1, \tag{1}$$

where K_{Yt} is the capital used in the production of final goods at time t, X_{it} is the amount of intermediate good i used in final good production at time t and α is the share of intermediate good i in total output. From here on, we eliminate the time subscripts unless otherwise noted.

Final good producers maximize their profits:

$$\pi = P_Y Y - (r + d) K_Y - \int_0^1 p_i X_i di,$$

where r is the interest rate and d is the depreciation rate. To simplify matters, we assume that from now on the depreciation rate is 1. Further, we set the final good as the numeraire good, with $P_Y = 1$. First order conditions imply that the conditional demand for intermediate input, X_i, and capital, K_Y are:

$$X_i = \left[\frac{p_i}{\alpha}\right]^{\frac{1}{\alpha-1}} K_Y \tag{2}$$

$$1 + r = (1-\alpha)\frac{Y}{K_Y} \tag{3}$$

2.1.2 Intermediate goods sector

The intermediate goods sector consists of a continuum of differentiated varieties i that are indexed from 0 to 1.The composite intermediate good is obtained by aggregating all varieties $i \in (0, 1)$:

$$X = \int_0^1 X_i di \tag{4}$$

Monopolistic competition characterizes the market setting of each variety i. Before entering the market, a potential entrant needs to make an up-front investment to acquire the appropriate technology $A(i,h)$ for variety i. Each variety i is produced by a single firm according to the following production function:

$$X_i = A(i,h) L_i^{\delta} H_i^{1-\delta}, \tag{5}$$

where L_i and H_i represent the amount of unskilled and skilled labor used in the production of variety i and δ is the share of unskilled labor.

We assume that each country faces the following resource constraints:

$$\int_0^1 H_i di = H \qquad \int_0^1 L_i di = L \tag{6}$$

where L and H represent the fixed supply of total unskilled and skilled labor in the economy.

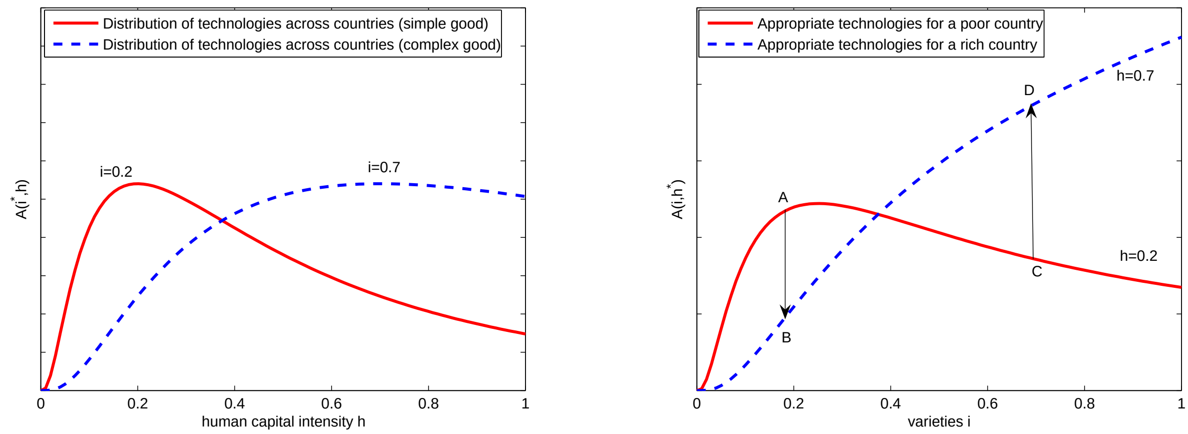
Technology

We assume that technology is country specific, variety specific, and human capital specific. All of these can be captured using the following functional form,

$$A(i,h) = B\ e^{\mu i}\ e^{-\frac{1}{2}\left(\ln \frac{h}{i}\right)^2}, \tag{7}$$

- B is the country-specific productivity index at time t (sector neutral homogeneous component) that grows at an exogenous rate ϕ.
- $e^{\mu i}$ is the variety specific component of technology that reflects the sophistication of each variety (i.e. productivities are increasing exponentially at a rate μ).
- $e^{-\frac{1}{2}(\ln \frac{h}{i})^2}$ is the human capital specific component of technology, where the appropriate human capital $h = \frac{H}{H+L}$ describes the country-specific human capital intensity.

The human capital component captures the distribution of technologies across countries and across industries. On one hand, by holding i constant ($i = i^*$), $A(i,h)$ as a function of h describes the *log normal distribution of technologies across countries within industry* i^* (see Figure 2 Panel A). Thus, skill intensity h shapes the appropriate technology $A(i,h)$ for a given industry i^*. Moreover, the highest technology for i^* is developed by the country that satisfies $h = i^*$. For $h < i^*$, $A(i^*,h)$ is increasing in h suggesting that technologies and skills are complements. This relationship is



(A) (B)

Figure 2: Distribution of technologies. Panel (A): across countries; Panel (B): across industries

switched if $h > i^*$, in the sense that technology and skill endowments are substitutes ($A(i^*, h)$ is decreasing in h).

On the other hand, by holding h constant ($h = h^*$), and letting $A(i, h)$ vary with respect to i only, we get the *distribution of technologies across industries* $i \in [0, 1]$ *within a country* (see Figure 2 Panel B). In other words, each industry has its own appropriate technology based on the country specific human capital intensity. The substitutability/complementarity between technology and skills can be seen once again in Figure 2 Panel B: the same increase in h has different effects on $A(i, h)$ depending on the location of i within the range: for a simple variety ($i \to 0$), the A(i,h) will decline (movement from A to B) suggesting that $A(i, h)$ and h are substitutes, while for a complex variety($i \to 1$) the $A(i, h)$ will rise (movement from C to D) i.e., $A(i, h)$ and h are complements.

The decision to enter industry i is made in two stages:

Stage 1: Free-entry condition

The up-front investment in $A(i, h)$ represents a setup cost F_i to each potential entrant. Thus, F_i as a barrier to entry characterizes each industry i. In period t the potential entrant makes the investment in $A(i, h)$ and enter the market if the present value (as of t) of future monopoly profits exceeds the entry costs. Let $V_t = \frac{\pi_{t+1}}{1+r}$ be the present discounted value of future profits as of time

t. If $V_t > F_{it}$ then the firm enters the market for i. In equilibrium, the free-entry condition has to be met:

$$\frac{\pi_{t+1}}{1+r} = F_{it} \tag{8}$$

Stage 2: In period $t+1$, the firm makes all pricing and output decisions that maximize its monopolistic profits.
Given (5), the cost function of the producer of variety i is:

$$C(w_{L_i}, w_{H_i}, X_i) = \frac{1}{A(i,h)} \frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}}\ w_{L_i}^{\delta} w_{H_i}^{1-\delta} X_i$$

Each monopolist maximizes its profits each period:

$$max \quad \pi(i) = p_i X_i - C(w_{L_i}, w_{H_i}, X_i)$$

The first order conditions give the optimal price charged by the monopolist, which represents a standard markup of $\frac{1}{\alpha}$ over the marginal cost of manufacturing intermediate goods:

$$p_i = \frac{1}{\alpha} \frac{1}{A(i,h)} \frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}}\ w_{L_i}^{\delta} w_{H_i}^{1-\delta} \tag{9}$$

as well as the nominal wages w_{L_i} and w_{H_i}:

$$w_{L_i} = \delta\alpha^2 K_Y^{1-\alpha} Y\ A(i,h)^{\alpha}\ L_i{}^{\alpha\delta-1}\ H_i{}^{(1-\delta)\alpha} \tag{10}$$

$$w_{H_i} = (1-\delta)\alpha^2 K_Y^{1-\alpha}\ A(i,h)^{\alpha}\ L_i{}^{\alpha\delta}\ H_i{}^{(1-\delta)\alpha-1} \tag{11}$$

Therefore, all pricing and output decisions of the firm are influenced by $A(i,h)$. Equations (2) and (9) yield the explicit demand X_i:

$$X_i = \left[\frac{1}{\alpha^2} \frac{1}{A(i,h)} \frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}} w_{L_i}^{\delta} w_{H_i}^{1-\delta}\right]^{\frac{1}{\alpha-1}} K_Y \tag{12}$$

Next, using equations (9) and (12) we solve for profits π_i in order to back out F_i from the free-entry condition (8). Thus,

$$F_i = \frac{\pi_{t+1}(i)}{1+r} = \frac{1}{1+r}\,(1-\alpha)\,\alpha^{\frac{1+\alpha}{1-\alpha}}\ A(i,h)^{\ \frac{\alpha}{1-\alpha}} \left[\frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}} w_{L_i}^{\delta} w_{H_i}^{1-\delta}\right]^{\frac{\alpha}{\alpha-1}} K_Y \tag{13}$$

Equation (13) implies that the entry costs F_i are an increasing function of the appropriate technology $A(i,h)$. Summing up the setup costs from all industries $i \in [0,1]$, we get total investments in appropriate technologies:

$$K_X = \int_0^1 F_i di = \frac{1}{1+r} (1-\alpha)\, \alpha^{\frac{1+\alpha}{1-\alpha}} \left[\frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}} w_{L_i}^{\delta} w_{H_i}^{1-\delta} \right]^{\frac{\alpha}{\alpha-1}} \int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di\, K_Y \tag{14}$$

2.2 Consumers

The economy has a large number (N) of infinitely lived consumers and zero population growth. At each moment t consumers maximize the present discounted value of their lifetime CES utility function:

$$max \sum_{t=0}^{\infty} \beta^t u(C_t)\,, \qquad u(C_t) = \frac{C_t^{1-\sigma} - 1}{1-\sigma} \tag{15}$$

where $\beta > 0$ is the discount rate, $\sigma > 0$ is the inverse of intertemporal elasticity of substitution and $u(C_t)$ is the objective function.

Consumers' budget constraint is given by:

$$D_{t+1} = C_t + w_H H_t + w_L L_t + (1+r) D_t,$$

where D_t represents total asset holdings at time t, $w_H H + w_L L$ is the wage income, and r is the interest rate. C_t is consumption of the final good which is the choice variable, while D_{t+1} is the state variable-a stock variable that reflects assets inherited from the past.

The solution of the Bellman equation from below gives the optimal path for consumption and investment:

$$V(D_t) = [u(C_t) + V(D_{t+1})]\,,$$

where $V(D_t)$ describes the value function that represents the objective function $u(C_t)$ maximized with respect to C_t and D_{t+1} from time t onwards. The Euler equation is given by;

$$\beta \frac{U'(C_{t+1})}{U'(C_t)} = \frac{1}{1+r} \tag{16}$$

In other words $\left[\frac{C_{t+1}}{C_t}\right]^{-\sigma} = \frac{1}{\beta(1+r)}$. Thus the growth rate of C_t is

$$g_C = \frac{C_{t+1} - C_t}{C_t} = [\beta(1+r)]^{\frac{1}{\sigma}} - 1 \tag{17}$$

2.3 General equilibrium

We present a decentralized equilibrium solution of the model in which firms are maximizing their profits, consumers are maximizing their utility and inputs and output markets clear. Equilibrium is defined by the following conditions:

1. $Y = C + I$
2. $\overline{K} = K_Y + K_X$
3. $L = \int_0^1 L_i di$ and $H = \int_0^1 H_i di$

The second condition explains that investments in the final goods sector, K_Y, and investments in appropriate technologies made in the intermediate goods sector, K_X, sum up to total capital in the economy $\overline{K}$. Each period $\overline{K}$ fully depreciates, thus $\overline{K}_{t+1} = I_t = Y_t - C_t$, where I_t is total amount of investments and C_t is consumption at time t. The third condition reflects labor market equilibrium implying that the labor employed by all industries add up to the total labor supply.

In equilibrium, nominal wages are equalized such that $w_{L_i} = w_L$ and $w_{H_i} = w_H$ for $i \in (0, 1)$. Using (10) and (11) the variety specific demands for unskilled labor L_i and human capital H_i are expressed as functions of nominal wages and appropriate technologies:

$$L_i = \alpha^{\frac{2}{1-\alpha}} \delta^{\frac{1-\alpha(1-\delta)}{1-\alpha}} (1-\delta)^{\frac{\alpha(1-\delta)}{1-\alpha}} K_Y \, w_L^{\frac{\alpha(1-\delta)-1}{1-\alpha}} \, w_H^{\frac{-\alpha(1-\delta)}{1-\alpha}} \, A(i,h)^{\frac{\alpha}{1-\alpha}}$$

$$H_i = \alpha^{\frac{2}{1-\alpha}} \delta^{\frac{\alpha\delta}{1-\alpha}} (1-\delta)^{\frac{-\alpha\delta+1}{1-\alpha}} K_Y \, w_L^{\frac{-\alpha\delta}{1-\alpha}} \, w_H^{\frac{\alpha\delta-1}{1-\alpha}} \, A(i,h)^{\frac{\alpha}{1-\alpha}}$$

In order to derive w_L and w_H as functions of skill endowments and technologies, we substitute the above equations into the labor market equilibrium conditions. Thus equilibrium nominal wages are given by:

$$w_L = \alpha^2 \delta \; K_Y^{1-\alpha} \, L^{\alpha\delta - 1} \, H^{\alpha(1-\delta)} \left[\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di \right]^{1-\alpha} \tag{18}$$

$$w_H = \alpha^2 (1-\delta) \, K_Y^{1-\alpha} \, L^{\alpha\delta} \, H^{\alpha(1-\delta)-1} \left[\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di \right]^{1-\alpha} \tag{19}$$

Next, we substitute the equilibrium nominal wages from (18) and (19) into the explicit demand of X_i given by (12). We can now substitute the explicit demand for intermediates X_i into the production function of the aggregate output from (1). Thus in equilibrium, aggregate income is:

$$Y = K_Y^{1-\alpha}\, L^{\alpha\delta}\, H^{\alpha(1-\delta)} \int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} \left[\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di\right]^{-\alpha} di \tag{20}$$

Equation (20) already suggests the causes of income disparities: part of Y is determined by factors of accumulation, while the other part is governed by appropriate technologies. According to the previous literature, this other part represents TFP.

In order to get a cleaner expression for TFP, denote $g(i) = A(i,h)^{\frac{\alpha}{1-\alpha}}$. The focus is on simplifying $\int_0^1 g(i) \left[\int_0^1 g(i)di\right]^{-\alpha} di$. Since $\int_0^1 g(i) \equiv G$ is constant, we can rewrite

$$\int_0^1 g(i) \left[\int_0^1 g(i)di\right]^{-\alpha} di = \int_0^1 g(i) G^{-\alpha} di = G^{1-\alpha} = \left[\int_0^1 g(i)di\right]^{1-\alpha}$$

Thus, aggregate income can now be expressed as:

$$Y = K_Y^{1-\alpha}\, L^{\alpha\delta}\, H^{\alpha(1-\delta)} \left[\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di\right]^{1-\alpha} \tag{21}$$

Next, we substitute the formula for $A(i,h)$ given by (7) into (21). Notice that:

$$\left[\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di\right]^{1-\alpha} = B_t^{\alpha} \left[\int_0^1 \left[e^{\mu i} e^{\frac{-1}{2}(\ln\frac{h}{i})^2}\right]^{\frac{\alpha}{1-\alpha}} di\right]^{1-\alpha}$$

Let $Z \equiv \int_0^1 \left[e^{\mu i} e^{\frac{-1}{2}(\ln\frac{h}{i})^2}\right]^{\frac{\alpha}{1-\alpha}} di$ capture *inter-industry TFP*. Then aggregate income from (21) becomes :

$$Y = K_Y^{1-\alpha}\, L^{\alpha\delta}\, H^{\alpha(1-\delta)} B_t^{\alpha} Z^{1-\alpha} \tag{22}$$

Next, we solve for K_X. In a similar fashion as for solving for Y, we substitute the nominal wage from (10) and (11) into the expression of K_X given by (14):

$$K_X = \frac{1}{1+r}\, \alpha\,(1-\alpha)\, K_Y^{1-\alpha} L^{\alpha\delta} H^{\alpha(1-\delta)} \left[\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di\right]^{1-\alpha}. \tag{23}$$

After substituting the interest rate from (25) into the above equation, we get $K_X = \alpha K_Y$ which implies that $K_Y = \frac{1}{1+\alpha}\overline{K}$.

Finally, we close the model by solving for the endogenous interest rate r. Along BGP, all variables grow at constant rates (i.e., $g_{\overline{K}}$, g_Y, and g_C are constant). Therefore, the growth rate of capital-output ratio is zero on BGP, which implies that $g_{\overline{K}} = g_Y$. Since total capital is given by $\overline{K} = K_X(\frac{1+\alpha}{\alpha})$, we use (23) to solve for $g_{\overline{K}} = \frac{\overline{K}_{t+1}-\overline{K}_t}{\overline{K}_t}$:

$$g_{\overline{K}} = \frac{\overline{K}_{t+1}}{\overline{K}_t} - 1 = \frac{K_{Y_{t+1}}\left[\int_0^1 A_{t+1}(i,h)^{\frac{\alpha}{1-\alpha}} di\right]^{1-\alpha}}{K_{Y_t}\left[\int_0^1 A_t(i,h)^{\frac{\alpha}{1-\alpha}} di\right]^{1-\alpha}} - 1 = (1+g_K)^{1-\alpha}\frac{B_{t+1}^{\alpha}\left[\int_0^1 \left[e^{\mu i}e^{\frac{-1}{2}(\ln\frac{h}{i})^2}\right]^{\frac{\alpha}{1-\alpha}} di\right]^{1-\alpha}}{B_t^{\alpha}\left[\int_0^1 \left[e^{\mu i}e^{\frac{-1}{2}(\ln\frac{h}{i})^2}\right]^{\frac{\alpha}{1-\alpha}} di\right]^{1-\alpha}} - 1$$

$$g_K = (1+g_K)^{1-\alpha}(1+\phi)^{\alpha} - 1$$

Therefore

$$g_K = \phi \tag{24}$$

In equilibrium, $(1+g_{\overline{K}})\frac{\overline{K}_t}{Y_t} = 1 - \frac{C_t}{Y_t}$ therefore $g_{\overline{K}} = g_C$. Using (17) and (2.3) we back out the interest rate r:

$$r = \frac{(1+\phi)^{\sigma} - \beta}{\beta} \tag{25}$$

3 Empirical Assessment

The purpose of our empirical exercise is to address the following question: to what extent do differences in inter-industry TFP explain differences in aggregate TFP? If inter-industry TFP matters, then its importance should be reflected in aggregate TFP, and our goal is to quantify the contribution of the former in the variation of the latter. Moreover, if inter-industry TFP turns out to be important then the results would emphasize the role played by appropriate human capital in driving cross-country income differences.

But first, before answering the above question, we test the significance of our theoretical model by comparing its predictions to the standard results of Hall and Jones (1999). We carry out a variance decomposition exercise for output per worker similar to the one presented in Klenow and Rodriguez-Clare (1997).

In order to do so, we express GDP per worker in Hall and Jones (1999)'s style. Therefore, equation (22) becomes:

$$y \equiv \frac{Y}{N} = \left[\frac{K_Y}{Y}\right]^{\frac{1-\alpha}{\alpha}} \left[\frac{h}{1-h}\right]^{-\delta} \frac{H}{N}\, BZ^{\frac{1-\alpha}{\alpha}} \tag{26}$$

Equation (26) is the key equation for our calibration exercise. Notice that

$$TFP = BZ^{\frac{1-\alpha}{\alpha}} \tag{27}$$

where $Z^{\frac{1-\alpha}{\alpha}}$ represents the inter-industry component in per worker terms. Equation (26) captures the double role played by h: the appropriate human capital has a direct effect on income per worker (as a factor of production), and an indirect effect through TFP.

3.1 Data

Data for GDP per worker (y), investment shares and population are extracted from Penn World Tables 6.2 that use 2000 as the base year. Capital stocks ($\overline{K}$) are calculated by using the perpetual inventory approach.

The construction of human capital is the essential piece of our empirical exercise. In this sense, we use two sources of data. First, Barro and Lee (2001) provide data for educational attainment for population aged 15 and over. They break each country's labor force into seven categories of educational attainment: no schooling, some primary, primary completed, some secondary, secondary completed, some higher, and higher completed. Second, Caselli and Coleman (2006) report the durations of primary and secondary education as well as the private returns from schooling for each country considered. Based on these datasets, we construct different measures for human capital by using the Mincerian approach. The standard Mincerian wage regression states that there is a linear relationship between the log of wage and the returns from schooling. Specifically, $\log w_i = \beta_0 + \beta_1 \lambda_i + \epsilon_i$, where λ_i represents average years of schooling for individual i. The coefficient β_1 captures the Mincerian private returns to schooling and reflects a 100 β_1% increase in wage coming from an additional year of schooling.

We construct the stocks of unskilled labor and skilled labor (human capital) for each country:

$$L = N\frac{S_1 e^{\beta\lambda_1} + ... + S_i e^{\beta\lambda_i}}{e^{\beta\lambda_1}}$$

$$H = N\frac{S_{i+1} e^{\beta\lambda_{i+1}} + ... + S_7 e^{\beta\lambda_7}}{e^{\beta\lambda_{i+1}}},$$

where S_1,S_2,...,S_7 are the fractions of labor force N that have no schooling, some primary education, ...,completed higher education. β is the country-specific private return to education and λ_1,...,λ_7

are the durations in years of each educational level for a given country.[6] Since there is a disparity across countries in terms of duration of educational levels, we rescale L and H based on the fact that in our set of countries, the shortest length of primary education is four years and six years for secondary education. Therefore, we multiply H by $e^{\beta(\lambda_3+\lambda_5-10)}$.

The next question that arises is where to place the threshold i, i.e, what constitutes unskilled labor and what human capital? We choose the secondary completed level of attainment as the boundary between unskilled and skilled labor. Then, considering the workers who completed secondary education as the reference group, we express H in "secondary completed equivalents", while L is expressed in "no schooling equivalents"(Caselli and Coleman (2006)). Alternatively, we consider the scenario where human capital consists of workers who have completed some higher education and above.

To calibrate the model we use empirical estimates for parameters α, δ, and μ. For the share of capital in aggregate output we set $(1-\alpha) = \frac{1}{3}$ (see Gollin (2002)). Following Basu (1996), the monopolist's mark-up over marginal cost is estimated to be 10%. Accordingly, we set δ - the share of unskilled labor in the composite intermediate good equal to 0.5. The sophistication of each variety - μ captures the idea that productivities are increasing exponentially with complexity (Jones (2008)). For each country, we initially set $\mu = 1$ which implies that the inter-industry TFP of the 90^{th} percentile relative to the inder-industry TFP of the 10^{th} percentile is 2.2. Later on, we undertake a sensitivity analysis and set $\mu = 0.5$ and $\mu = 1.5$ which imply a 90/10 ratio of inter-industry TFP of 1.5 and 3.3, respectively.

3.2 Calibration

We calibrate the equilibrium solution of the model given by (26) using a cross-section of 51 countries for the year 2000.

Table 1 presents the summary statistics of the data. GDP per worker (y), capital output ratio ($\frac{K}{Y}$), and human capital intensity ($h = \frac{H}{H+L}$) are calculated as ratios to the U.S. values. The data reflect huge income dispersion across countries: Kenya, the country with the lowest standard of

[6] From Caselli and Coleman (2006) we have country specific durations of primary and secondary education. For subgroups that did not complete the respective levels of study (some primary, some secondary, some higher), we use, as they did, half of the duration of that level.

living from our sample of countries, has 4.9% of U.S.' GDP per worker. Output per worker in the richest country (Singapore) is around 24 times higher than in the least developed country. The two poorest countries (Kenya and Ghana) have also the lowest levels of human capital per worker (about 5% of the U.S.' level), which implies a 20-fold difference. Also, the group of four countries with highest levels of human capital per worker $\frac{H}{N}$ (U.S., Canada, Sweden, South Korea) are also the most intensive in appropriate human capital h.

Table 1: **Summary Statistics of the Data**

Variable	Mean	Std.Dev	Min	Max
y	0.371	0.272	0.048	1.158
$\frac{K}{Y}$	0.886	0.348	0.347	1.819
h	0.409	0.244	0.035	1.036

We explore the relationship between our measure of human capital and Hall and Jones' estimates for human capital per worker. Human capital per worker ($\frac{H}{N}$) has a correlation of 0.84 (not shown here) with Hall and Jones' values that are based on a 1985 dataset.Also, Figure 3 suggests a strong positive correlation between our measure for appropriate human capital h and Hall and Jones' estimates for human capital per worker.

To calculate inter-industry TFP (Z in our calibration equation), we approximate numerically the definite integral under Z by using the quadratic interpolation method (Simpson rule). After taking logs of the levels, we back out $\ln B$, the homogeneous sector neutral component of TFP:

$$\ln B = \ln y - \frac{1-\alpha}{\alpha} \ln \frac{K_Y}{Y} + \delta \ln \frac{h}{1-h} - \ln \frac{H}{N} - \frac{1-\alpha}{\alpha} \ln Z \tag{28}$$

By substituting (28) into $\ln(TFP) = \ln B + \frac{1-\alpha}{\alpha} \ln Z$ we construct aggregate TFP. Figure 5 in Appendix indicate a strong linear relationship between our values for aggregate TFP and Hall and Jones' estimates. We find a correlation of 0.92 between the values predicted by our model and Hall and Jones' values.

To decompose this 24-fold difference in income per worker between the richest and the poorest country we carry out a levels accounting exercise by decomposing the variance of GDP per worker. Equation (26) implies that $y = \left[\frac{K_Y}{Y}\right]^{\frac{1-\alpha}{\alpha}} \left[\frac{h}{1-h}\right]^{-\delta} \frac{H}{N} \ TFP$. The methodology is based on the idea that the variance of y is divided up between the variance of factors of accumulation and the

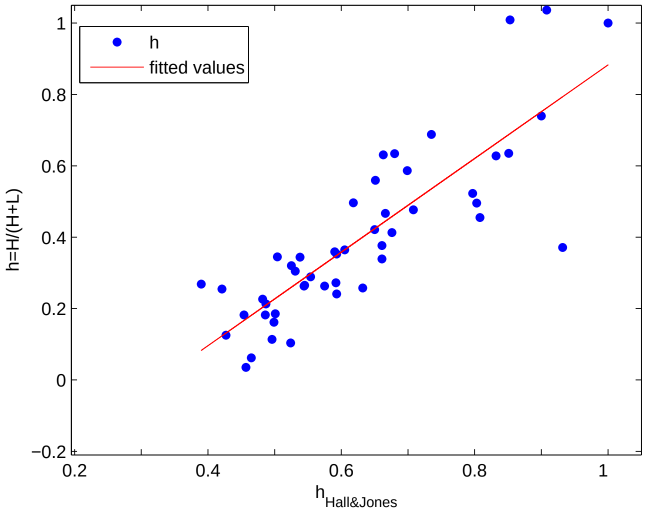


Figure 3: Comparison of appropriate human capital values with Hall and Jones (1999)' estimates for human capital per worker

variance of aggregate TFP:

$$\texttt{var}\left[\ln\left(y\right)\right]=\texttt{var}\left[\ln\left(factors\right)\right]+\texttt{var}\left[\ln\left(TFP\right)\right]+2\texttt{cov}\left[\ln\left(factors\right),\ \ln\left(TFP\right)\right]$$

Specifically, we calculate the contribution of each of these elements to the cross-country income dispersion. Following Klenow and Rodriguez-Clare (1997), we allocate half of the covariance term to TFP and the other half to factors of accumulation. Thus, the contribution of aggregate TFP is given by:

$$\frac{\texttt{var}\left[\ln\left(TFP\right)\right]+\texttt{cov}\left[\ln\left(factors\right),\ \ln\left(TFP\right)\right]}{\texttt{var}\quad\left[\ln\left(y\right)\right]} \tag{29}$$

The covariance matrix shown in Table 2 presents the results of this decomposition exercise. In accordance with the previous literature, aggregate TFP accounts for 62% in cross-country income variation, while factors of accumulation (including human capital) explain only 39%. We conclude that the direct effect of appropriate human capital on income differences is weaker than its indirect effect through TFP. Further, we quantify this indirect effect to see what is the impact of appropriate human capital on TFP differences and implicitly, on income dispersion.

Table A-2 in Appendix reports the values of TFP and its components relative to U.S. values. After ranking countries with respect to aggregate TFP, we notice that the average of the values of

Table 2: **Variance Decomposition of GDP/worker**

Variable	$\ln(y)$	$\ln(factors)$	$\ln(TFP)$
$\ln(y)$	0.632		
$\ln(factors)$	0.235	0.177	
$\ln(TFP)$	0.387	0.071	0.321

top five countries (Singapore, Hong Kong, U.S., Italy, and Canada) is about 6 times higher than the average TFP of the lowest five countries (Kenya, Ecuador, Peru, Honduras, Jamaica). Ghana has an aggregate TFP equal to only 28% of aggregate TFP in U.S.; moreover, Ghana's inter-industry TFP is just 4% of U.S.' inter-industry TFP. Not surprinsingly, human capital intensity in U.S. is about 16 times higher than in Ghana. The correlation between h and Z (not shown here) is 0.97 suggesting that inter-industry productivity is driven by human capital.

By undertaking the second decomposition exercise we try to deepen these explanations. Starting from equation (27), we decompose the variance of TFP in order to quantify the role played by inter-industry TFP in explaining international TFP differences. The contribution of inter-industry TFP is calculated based on the formula:

$$\texttt{var}\left[\ln(TFP)\right] = \texttt{var}\left[\ln(B)\right] + \texttt{var}\left[\ln(Z^{\frac{1-\alpha}{\alpha}})\right] + 2\texttt{cov}\left[\ln(B),\ \ln(Z^{\frac{1-\alpha}{\alpha}})\right]$$

Table (3) summarizes our findings by reporting the covariance matrix. The variance of inter-

Table 3: **Variance Decomposition of TFP***

Variable	$\ln(TFP)$	$\ln(B)$	$\ln(Z^{\frac{1-\alpha}{\alpha}})$
$\ln(TFP)$	0.321		
$\ln(B)$	0.187	0.233	
$\ln(Z^{\frac{1-\alpha}{\alpha}})$	0.133	-0.004	0.180

* 90/10 ratio of inter-industry TFP is 2.2 ($\mu = 1$). H consists of secondary completed education and above.

industry TFP represents 41% of the total variance in TFP and the covariance between the homogenous part of TFP and inter-industry TFP is very low. Thus, inter-industry TFP has a major impact on total TFP. Since h directly determines Z (the correlation between them is 0.97), we infer that appropriate human capital drives the differences in inter-industry TFP, and indirectly the differences in aggregate TFP. Moreover, we find a very weak correlation of -0.14 between skill intensity h and the residual B, the homogeneous component of aggregate TFP, suggesting that (without being necessarily a proof) some other factors, but not the appropriate human capital, determine the exogeneous component of TFP. This idea is reinforced by a weak correlation of -0.22 between inter-industry TFP and the residual B.

For sensitivity purposes, we carry out the same exercise for $\mu = 0.5$, which implies a lower productivity gap between the most and the least complex industries within each country (the ratio of inter-industry TFP between the 90^{th} percentile and the 10^{th} percentile is 1.5). The results shown

Table 4: **Variance Decomposition of TFP for $\mu = 0.5$ ***

Variable	$\ln(TFP)$	$\ln(B)$	$\ln(Z^{\frac{1-\alpha}{\alpha}})$
$\ln(TFP)$	0.321		
$\ln(B)$	0.213	0.226	
$\ln(Z^{\frac{1-\alpha}{\alpha}})$	0.108	-0.001	0.121

* 90/10 ratio of inter-industry TFP is 1.5. H consists of secondary completed education and above

in Table 4 suggest that in this case inter-industry TFP, captured by $Z^{\frac{1-\alpha}{\alpha}}$, still accounts for a big fraction of 33% in total variation in TFP. Table 5 reports the results for $\mu = 1.5$ (i.e, the 90/10 ratio of inter-industry TFP is 3.3); in this case almost half of the variation of aggregate TFP (49%) originates from inter-industry TFP and implicitly from appropriate human capital. Therefore, the

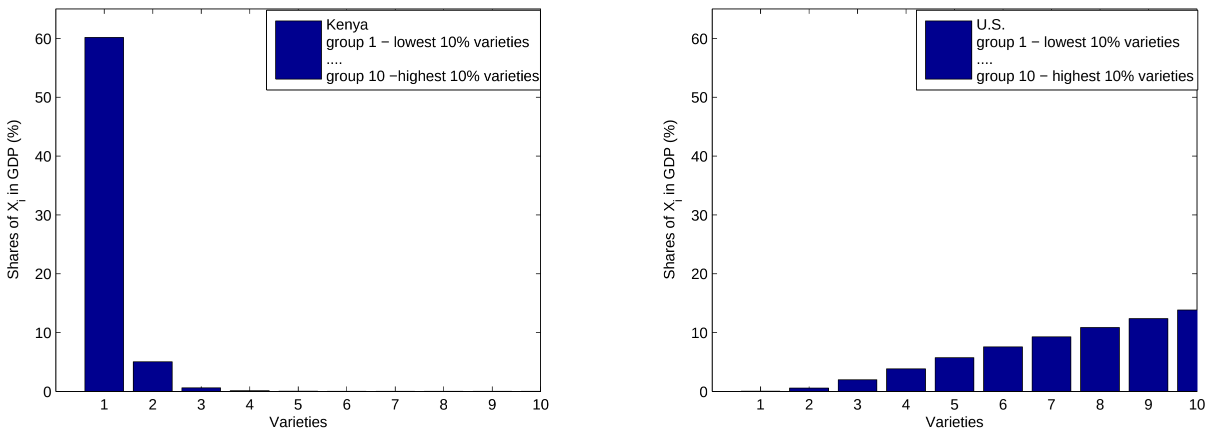
Table 5: **Variance Decomposition of TFP for $\mu = 1.5$ ***

Variable	$\ln(TFP)$	$\ln(B)$	$\ln(Z^{\frac{1-\alpha}{\alpha}})$
$\ln(TFP)$	0.321		
$\ln(B)$	0.161	0.256	
$\ln(Z^{\frac{1-\alpha}{\alpha}})$	0.160	-0.009	0.255

* The 90/10 ratio of inter-industry TFP is 3.3. H consists of secondary completed education and above

higher the discrepancy between the most productive and the least productive industries within a country, the more important is the contribution of inter-industry TFP in the variance of aggregate TFP. Since this discrepancy tends to be higher in less developed countries, the role of inter-industry TFP is even more critical to them. In other words, there is more room for less skill intensive countries to improve inter-industry TFP by increasing their stocks of human capital. Thus, policies that stimulate skill intensity and inter-industry TFP would lower cross-country differences in total factor productivity.

Overall, the results indicate a significant role for inter-industry TFP in the international variation of TFP. Since human capital is driving the productivities of different industries within a country, we expect human capital to be concentrated in the industries where technologies complement skills. We categorize industries in ten groups based on their sophistication in order to calculate each group's share in total GDP (see Appendix 1A). The representation of industries within an economy is shaped by the existent human capital intensity in the country: in a poor country, production is clustered in less skill intensive industries, while in a rich country (human capital abundant), skill intensive industries are better represented in GDP. Figure 4 captures exactly this trend: in Kenya's case (Figure 4 Panel A), almost 60% of GDP can be attributed to the lowest 10% of varieties, 5% of GDP is accounted by the next group and from here on, as we move up on the sophistication scale, the shares of more complex varieties in GDP become smaller and smaller and almost inexistent.



(A) Kenya (B) U.S.

Figure 4: Shares of industries in GDP (%).

One can observe exactly the opposite pattern in U.S (Figure 4 Panel B), where the shares of varieties in GDP are increasing in sophistication. The group of highest 10% of varieties accounts for 14% of GDP, followed by the second highest 10% group that produces 12% of GDP, while the least intensive human capital industries that fall in the lowest 10% group comprise only 0.02% of GDP.

Finally, as a sensitivity analysis, we carry out the same decomposition exercise of the variance of TFP for a higher threshold of human capital. We measure human capital as consisting of workers who have attained some higher education and above and we keep the 90/10 ratio of inter-industry TFP at 2.2.

Table 6: **Variance Decomposition of TFP for $\mu = 1$.***

Variable	$\ln(TFP)$	$\ln(B)$	$\ln(Z^{\frac{1-\alpha}{\alpha}})$
$\ln(TFP)$	0.304		
$\ln(B)$	0.214	0.4	
$\ln(Z^{\frac{1-\alpha}{\alpha}})$	0.089	-0.185	0.274

* The 90/10 ratio of inter-industry TFP is 2.2. H consists of partial higher education and above.

Table 6 reports a decrease of the variance of inter-industry TFP falls to 29% of total variance of TFP while the covariance term increases significantly. These results suggest that the new threshold for skilled labor is set too high and the new measure of human capital is too exclusive.

4 Conclusions

Cross-country income differences have been pinned down to TFP differences, which are captured by differences in technologies. Nonetheless, technologies differ not only across countries, but also across industries within a country. Countries are not similarly equipped to adopt technologies, therefore they are not equally efficient in using them. This heterogeneity arises from the relative role given to human capital by each country. A rich country, abundant in human capital, favors more sophisticated industries that use human capital intensively. However, the same industries are poorly represented in a less developed economy that lacks the necessary skills to use complex technologies. Thus, each country's human capital intensity is *appropriate* for an industry with a particular level of sophistication, where technologies complement skills.

We capture this role of appropriate human capital in shaping each country's map of industries. Specifically, we develop a theoretical endogenous model with a novel formulation of the industry-level technology as a function of appropriate human capital. This new specification allows us to decompose aggregate TFP into inter-industry TFP (the non-homogeneous component of TFP driven by human capital) and an exogenous productivity residual. In accordance with previous studies, aggregate TFP explains 62% of the variance of output per worker. Moreover, after undertaking a variance decomposition exercise, we find that inter-industry TFP accounts for 41% of the variation of aggregate TFP, suggesting that appropriate human capital explains indirectly, through inter-industry TFP, a substantial part of income differences.

Finally, appropriate human capital models the distribution of shares of industries into GDP. The results of our levels accounting exercise show that in rich countries where technologies complement skills, a higher fraction of GDP is attributed to complex industries, while the opposite holds for poor countries where GDP consists mainly of unsophisticated industries.

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Appendix

1A. Share of industry i in GDP:

From (1) and (2) we calculate the share of variety i in GDP:

$$\frac{p_i X_i}{Y} = \alpha \frac{p_i X_i}{\int_0^1 p_i X_i di} = \alpha \frac{X_i^{\alpha}}{\int_0^1 X_i^{\alpha} di} \tag{30}$$

X_i is given by the first order condition from the intermediate goods sector:

$$X_i = \left[\frac{1}{\alpha^2} \frac{1}{A(i,h)} \frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}} w_{L_i}^{\delta} w_{H_i}^{1-\delta} \right]^{\frac{1}{\alpha-1}} K_Y$$

.

After substituting for $\frac{\delta^{-\delta}}{(1-\delta)^{1-\delta}} w_{L_i}^{\delta} w_{H_i}^{1-\delta}$, we get:

$$X_i^{\alpha} = L^{\alpha\delta} H^{\alpha(1-\delta)} A(i,h)^{\frac{\alpha}{1-\alpha}} \left[\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di \right]^{-\alpha} = L^{\alpha\delta} H^{\alpha(1-\delta)} \left[\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di \right]^{1-\alpha} \tag{31}$$

Substituting (31) into (30), we have:

$$\alpha \frac{p_i X_i}{\int_0^1 p_i X_i di} = \alpha \frac{A(i,h)^{\frac{\alpha}{1-\alpha}}}{\int_0^1 A(i,h)^{\frac{\alpha}{1-\alpha}} di} \tag{32}$$

$$= \alpha \frac{A(i,h)^{\frac{\alpha}{1-\alpha}}}{B^{\frac{\alpha}{1-\alpha}} Z} = \alpha \frac{B^{\frac{\alpha}{1-\alpha}} \left[e^{\mu i} e^{\frac{-1}{2}(\ln \frac{h}{i})^2} \right]^{\frac{\alpha}{1-\alpha}}}{B^{\frac{\alpha}{1-\alpha}} Z} = \alpha \frac{\left[e^{\mu i} e^{\frac{-1}{2}(\ln \frac{h}{i})^2} \right]^{\frac{\alpha}{1-\alpha}}}{Z}$$

Thus, the share of variety i in GDP is given by:

$$\frac{p_i X_i}{Y} = \alpha \frac{\left[e^{\mu i} e^{\frac{-1}{2}(\ln \frac{h}{i})^2} \right]^{\frac{\alpha}{1-\alpha}}}{Z} \tag{33}$$

Next, we calculate the share of the lowest 10% of varieties in GDP:

$$\frac{\int_0^{0.1} p_i X_i di}{Y} = \alpha \frac{\int_0^{0.1} \left[e^{\mu i} e^{\frac{-1}{2}(\ln \frac{h}{i})^2} \right]^{\frac{\alpha}{1-\alpha}} di}{\int_0^{1} \left[e^{\mu i} e^{\frac{-1}{2}(\ln \frac{h}{i})^2} \right]^{\frac{\alpha}{1-\alpha}} di}$$

.....

The share of the highest 10% of varieties in GDP is given by:

$$\frac{\int_{0.9}^{1} p_i X_i di}{Y} = \alpha \frac{\int_{0.9}^{1} \left[e^{\mu i} e^{\frac{-1}{2}(\ln \frac{h}{i})^2} \right]^{\frac{\alpha}{1-\alpha}} di}{\int_0^{1} \left[e^{\mu i} e^{\frac{-1}{2}(\ln \frac{h}{i})^2} \right]^{\frac{\alpha}{1-\alpha}} di}$$

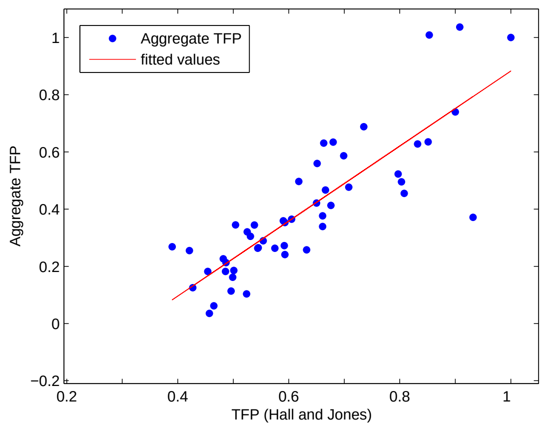

Figure 5: Comparison of TFP values with Hall and Jones (1999)' estimates

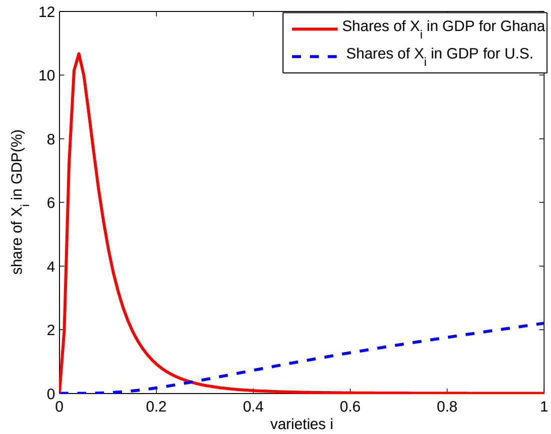

Figure 6: Shares of industries in GDP (%)for Ghana and for U.S.

Table A-1: **Data** y= GDP per worker; $\frac{K_Y}{Y}$= capital output ratio; $\frac{H}{N}$= human capital per worker; h= human capital intensity or appropriate human capital. $(1-\alpha)$= share of capital in GDP. All variables are relative to U.S.

Country	Country code	y	$\left[\frac{K_Y}{Y}\right]^{\frac{1-\alpha}{\alpha}}$	$\frac{H}{N}$	$h=\frac{H}{H+N}$
Argentina	ARG	0.352	0.950	0.438	0.413
Australia	AUS	0.715	1.100	0.580	0.740
Bolivia	BOL	0.105	0.723	0.223	0.305
Botswana	BWA	0.251	0.800	0.207	0.114
Brazil	BRA	0.228	0.966	0.218	0.226
Canada	CAN	0.736	1.118	0.768	1.037
Chile	CHL	0.349	0.865	0.396	0.377
China	CHN	0.116	0.841	0.184	0.257
Colombia	COL	0.202	0.769	0.256	0.263
Costa Rica	CRI	0.268	0.739	0.318	0.359
Cyprus	CYP	0.584	0.868	0.520	0.477
Dominican Republic	DOM	0.210	0.668	0.257	0.320
Ecuador	ECU	0.147	0.892	0.359	0.365
El Salvador	SLV	0.163	0.640	0.173	0.213
France	FRA	0.683	1.116	0.432	0.467
Germany	GER	0.657	1.129	0.453	0.559
Ghana	GHA	0.053	0.589	0.050	0.062
Greece	GRC	0.377	1.131	0.405	0.634
Guatemala	GTM	0.156	0.608	0.116	0.125
Honduras	HND	0.081	0.876	0.206	0.182
Hong Kong	HKG	0.857	1.044	0.525	0.688
Hungary	HUN	0.315	1.026	0.277	0.371
India	IND	0.086	0.703	0.127	0.182
Indonesia	IDN	0.127	0.840	0.201	0.162
Israel	ISR	0.654	1.010	0.517	0.635
Italy	ITA	0.585	1.128	0.265	0.421
Jamaica	JAM	0.145	0.981	0.247	0.104
Japan	JPN	0.626	1.349	0.440	0.522
Kenya	KEN	0.049	0.674	0.044	0.035
Malaysia	MYS	0.380	0.962	0.254	0.272
Mexico	MEX	0.262	0.996	0.405	0.344
Netherlands	NLD	0.709	1.065	0.439	0.495
Nicaragua	NIC	0.125	0.684	0.152	0.186
Pakistan	PAK	0.084	0.634	0.192	0.268
Panama	PAN	0.253	0.930	0.628	0.559
Paraguay	PRY	0.177	0.774	0.277	0.289
Peru	PER	0.143	1.056	0.405	0.497
Philippines	PHL	0.142	0.809	0.492	0.631
Portugal	PRT	0.484	1.031	0.278	0.345
South Korea	KOR	0.441	1.186	0.907	0.988
Singapore	SGP	1.158	1.216	0.309	0.265
Sri Lanka	LKA	0.122	0.703	0.190	0.241
Sweden	SWE	0.687	1.068	0.805	1.009
Switzerland	CHE	0.741	1.241	0.540	0.628
Taiwan	TWN	0.527	0.897	0.450	0.587
Thailand	THA	0.196	1.206	0.262	0.263
Tunisia	TUN	0.224	0.792	0.195	0.255
UK	GBR	0.671	0.982	0.404	0.455
Uruguay	URY	0.317	0.779	0.324	0.339
USA	USA	1.000	1.000	1.000	1.000
Venezuela	VEN	0.238	0.929	0.289	0.353

Table A-2: **TFP and its components** B=exogenous part of TFP, Z=inter-industry TFP. $(1-\alpha)$= share of capital in GDP. All variables are relative to U.S.

Country	Country code	B	$Z^{\frac{1-\alpha}{\alpha}}$	$TFP = BZ^{\frac{1-\alpha}{\alpha}}$
Argentina	ARG	0.545	0.718	0.392
Australia	AUS	0.856	0.943	0.808
Bolivia	BOL	0.424	0.588	0.249
Botswana	BWA	1.152	0.288	0.332
Brazil	BRA	0.729	0.473	0.345
Canada	CAN	0.894	1.003	0.896
Chile	CHL	0.657	0.678	0.445
China	CHN	0.497	0.520	0.258
Colombia	COL	0.680	0.529	0.359
Costa Rica	CRI	0.739	0.657	0.486
Cyprus	CYP	0.849	0.781	0.663
Dominican Republic	DOM	0.799	0.608	0.486
Ecuador	ECU	0.295	0.664	0.196
El Salvador	SLV	1.014	0.452	0.459
France	FRA	0.920	0.772	0.710
Germany	GER	0.867	0.847	0.734
Ghana	GHA	1.487	0.195	0.289
Greece	GRC	0.580	0.894	0.519
Guatemala	GTM	1.665	0.308	0.513
Honduras	HND	0.315	0.403	0.127
Hong Kong	HKG	1.150	0.922	1.059
Hungary	HUN	0.711	0.671	0.477
India	IND	0.678	0.403	0.273
Indonesia	IDN	0.537	0.369	0.198
Israel	ISR	0.887	0.895	0.794
Italy	ITA	1.253	0.727	0.911
Jamaica	JAM	0.458	0.271	0.124
Japan	JPN	0.696	0.819	0.570
Kenya	KEN	1.405	0.140	0.197
Malaysia	MYS	1.018	0.542	0.551
Mexico	MEX	0.417	0.639	0.266
Netherlands	NLD	0.996	0.797	0.794
Nicaragua	NIC	0.849	0.409	0.347
Pakistan	PAK	0.458	0.536	0.246
Panama	PAN	0.293	0.847	0.248
Paraguay	PRY	0.543	0.566	0.307
Peru	PER	0.219	0.798	0.175
Philippines	PHL	0.253	0.892	0.226
Portugal	PRT	1.082	0.639	0.692
South Korea	KOR	0.402	0.999	0.401
Singapore	SGP	2.013	0.532	1.070
Sri Lanka	LKA	0.611	0.496	0.303
Sweden	SWE	0.807	1.001	0.807
Switzerland	CHE	0.774	0.891	0.689
Taiwan	TWN	0.900	0.865	0.779
Thailand	THA	0.405	0.529	0.214
Tunisia	TUN	0.964	0.517	0.498
UK	GBR	1.098	0.761	0.835
Uruguay	URY	0.813	0.632	0.514
USA	USA	1.000	1.000	1.000
Venezuela	VEN	0.571	0.649	0.371