

How Important Is Human Capital? A Quantitative Theory Assessment of World Income Inequality

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We build a model of heterogeneous individuals—who make investments in schooling quantity and quality—to quantify the importance of differences in human capital vs. total factor productivity (TFP) in explaining the variation in *per capita* income across countries. The production of human capital requires expenditures and time inputs; the relative importance of these inputs determines the predictions of the theory for inequality both within and across countries. We discipline our quantitative assessment with a calibration firmly grounded on US micro evidence. Since in our calibrated model economy human capital production requires a significant amount of expenditures, TFP changes affect disproportionately the benefits and costs of human capital accumulation. Our main finding is that human capital accumulation strongly amplifies TFP differences across countries: to explain a 20-fold difference in the output per worker, the model requires a 5-fold difference in the TFP of the tradable sector, vs. an 18-fold difference if human capital is fixed across countries.

1. INTRODUCTION

While economists consider human capital a crucial component of aggregate wealth, they have conflicting views on the importance of differences in human capital vs. total factor productivity (TFP) in accounting for income differences across countries. In this paper, we develop a quantitative theory of human capital investments to quantify the importance of differences in human capital vs. TFP in explaining the variation in *per capita* income across countries. Building a quantitative theory allows us to circumvent two major problems faced by growth accounting exercises. First, to date, there are no reliable cross-country measures of the quality of schooling across countries. If this quality is positively associated with the level of economic development, the residual in growth accounting exercises overstates the cross-country differences in TFP. A second problem arises because of the (unobserved) covariance of TFP

with measures of physical and human capital, which renders output variance decomposition difficult. Developing a quantitative theory, in turn, is a challenging task because of the lack of conclusive micro evidence on the parameters of the human capital technology.

In light of these difficulties, our paper provides a novel approach to studying income differences across countries: we build a model of *heterogeneous* individuals—who make investments in schooling quantity and quality—and use a broad set of micro facts to discipline the key parameters of the human capital technology. Motivated by the empirical studies of Neal and Johnson (1996) and Keane and Wolpin (1997), we focus on investments that take place “early” in the life of an individual and formulate a dynastic model of parental investments in the human capital of their children. Individuals are heterogeneous in terms of ability, schooling tastes, and parental resources. Individuals across countries face different wage rates and prices for human capital inputs. The model’s main novelty relative to previous work in the area is the inclusion of a production technology for human capital which takes expenditures and time as inputs.¹ The relative importance of these inputs determines the predictions of the theory for inequality both within and across countries.² The intuition is simple: if schooling requires only time inputs, a change in the ability of individuals or in the wage rate affects equally the benefits and the costs of human capital accumulation, leaving the optimal level of human capital unchanged. On the other hand, when schooling requires only the input of goods, an increase in ability or in the wage rate raises benefits but not the costs of schooling, thereby increasing the optimal human capital stock.

We discipline our quantitative assessment with a calibration firmly grounded on US micro evidence. We exploit the fact that the parameters governing human capital accumulation have important consequences for schooling and earnings inequality and intergenerational mobility *within* a country. Hence, we use US household data to pin down the key parameters—elasticities of human capital with respect to time and goods inputs—driving the quantitative implications of the theory across countries. Our baseline economy successfully matches a large number of calibration targets on schooling and earnings inequality in the US, such as the variances and intergenerational correlations of earnings and schooling, and the slope coefficient and R^2 in a Mincer regression. The model economy is also consistent with several dimensions of heterogeneity in the data that were not targeted in the calibration: schooling distribution, evidence on the relationship between schooling attainment of children and resources/background of their parents, and results in the micro literature on the enrolment effects of college tuition changes. Altogether, the paper provides an important contribution to the literature by developing a successful theory of inequality in schooling and earnings in the US economy.

We use the calibrated model economy to quantitatively assess how variations in TFP are *amplified* through human capital accumulation into large differences in output per worker across countries. We assume that countries are identical in terms of preferences and technologies and only differ in their level of TFP. Following Hsieh and Klenow (2007) and Herrendorf and Valentinyi (2009), we model sectoral productivity differences across countries. Relative to the benchmark economy (BE), we assume that a 1% reduction on the TFP of the manufacturing (tradable) sector is associated with a 0.3% reduction in the TFP of the service (non-tradable)

1. Manuelli and Seshadri (2005) and Cordoba and Ripoll (2007) follow a similar approach.

2. Bils and Klenow (2000) point out that the production of human capital is more intensive in the time input than the production of output goods. They and Klenow and Rodriguez-Clare (1997) argue that, by using a one-sector growth model, Mankiw *et al.* (1992) overstate the importance of goods input in the production of human capital and, thus, obtain results that understate TFP differences across countries. The idea that the specification of the human capital technology has important implications for inequality within a country was developed by Erosa and Koreshkova (2007) in the context of a taxation exercise.

sector. This assumption allows the model economy to match the cross-country variation on the price of services relative to manufacturing.

Our main finding is that human capital accumulation strongly amplifies TFP differences across countries: the elasticity of output per worker—at purchasing power parity (PPP) prices—with respect to TFP in the tradable sector is 1.94. This implies that a 5-fold difference in TFP explains a 20-fold difference in the output per worker, as is observed between the top 10% and bottom 10% of countries in the world income distribution. In contrast, when we solve a version of the model without human capital accumulation, an 18-fold difference in the TFP of the tradable sector is required to account for the income difference between rich and poor countries. Two main channels explain why human capital provides substantial amplification. First, our calibration implies a large share of expenditures in the human capital production function, which means that a reduction in TFP affects disproportionately the benefits and costs of human capital accumulation. Hence, while the benefit of obtaining human capital is proportional to TFP, the cost of education (relative to the price of output) is less than proportional to TFP. This mechanism accounts for the low schooling quantity and quality in poor countries. Second, human capital is an important source of income differences across countries, not only because it directly contributes to cross-country output differences, but also because a lower human capital stock discourages physical capital accumulation by lowering the marginal product of capital.

Finally, we provide several pieces of evidence that support the main predictions of the theory. First, we show that the cross-country differences in schooling implied by our theory are plausible. Second, we use our model to simulate immigrants in the US and find that some (modest) degree of selection into immigration can reconcile the quality differences in education predicted by our theory with the data on earnings of US immigrants. Third, we show that our theory is consistent with data on relative price variation across countries. Using data from the International Comparisons Program (ICP), we show that the elasticity of the price of education relative to output is quantitatively close to the elasticity implied by our simulations. The evidence supports the idea that the cost of education (relative to the price of output) does not rise proportionally with TFP, which is the main mechanism emphasized by our theory.³

The paper proceeds as follows. The next section describes in detail the economic environment. In Section 3, we consider a simple version of the model in order to illustrate the main features of our theory driving human capital investments and to motivate our calibration strategy. Section 4 lays out the calibration strategy for the BE and shows that the model economy is consistent with several dimensions of heterogeneity in the data that were not targeted in the calibration. Furthermore, the predictions of the BE are tested using results from the micro literature on the enrolment effects of college tuition changes. In Section 5, we evaluate the aggregate impact of TFP differences across countries, examine the predictions of the theory for the variation in relative prices across countries, and compare our findings to related papers in the literature. Section 6 concludes.

2. ECONOMIC ENVIRONMENT

We consider an economy populated by overlapping generations of people who are altruistic towards their descendants and invest in the human capital of their children.⁴ Investments in

3. As pointed out by one referee, the small elasticity of the price of education with respect to output is obtained despite the fact that the ICP cannot take into account unmeasured quality differences in education across countries.

4. This approach is motivated by some empirical studies of earnings inequality. Keane and Wolpin (1997) find that 90% of the variance of lifetime utility is accounted for by heterogeneity in skills of individuals at age 16, i.e. prior to labour market entry. Similarly, Neal and Johnson (1996) find that parental investments are crucial for explaining differences in skill attainments of their children.

human capital involve children's time and expenditures by parents that affect the quality of the human capital of their children. Parents cannot borrow to finance investment in human capital. Since the analysis in this paper focuses on steady states, time subscripts are omitted in the description of the model and a prime is used to indicate the next period value of a given variable.

2.1. Demographic structure

There is a large number of dynasties (mass one). Individuals live for three periods, so that the model period is set to 20 years. An individual is referred to as a child in the first period of his life (real age 6–26 years), a young parent in the second period (real age 26–46 years), and an old parent in the third period of his life (real age 46–66 years).⁵ A household is composed of three people: old parent, young parent, and a child.

2.2. Production technologies

We assume that production takes place in two sectors—manufacturing and services—with the following technologies:

$$Y_M = A_M K_M^\alpha H_M^{1-\alpha}, \quad (1)$$

$$Y_S = A_S K_S^\alpha H_S^{1-\alpha}, \quad (2)$$

where Y_M and Y_S denote the output of the manufacturing and service sectors; K_i and H_i represent the services of physical and human capital used in sector $i \in \{M, S\}$. The parameter $\alpha \in (0, 1)$ is the elasticity of output with respect to physical capital and is assumed to be equal across sectors. The parameter A_i , $i \in \{M, S\}$, represents sectoral TFP, which is allowed to vary across sectors.

Manufacturing output can be consumed (C_M) or invested in physical capital (X). Services can be either consumed (C_S) or invested in human capital (E_S). Feasibility requires

$$C_M + X = Y_M,$$

$$C_S + E = Y_S.$$

Physical capital is accumulated according to $K' = (1 - \delta)K + X$, where investment goods X are produced in the manufacturing sector.

We model human capital investments as taking place “early” in the life of an individual and including schooling as well as investments outside of formal schooling. Consistent with the view of Becker and Tomes (1986), Haveman and Wolfe (1995), Neal and Johnson (1996), Mulligan (1997), Keane and Wolpin (1997), and Keane and Wolpin (2001), among many others, we think that households invest a lot of resources in their children outside of school (health, food, shelter, books, recreational activities, and extracurricular educational activities). This view motivates our focus on a broad notion of human capital investments. The human capital of a child is produced with the inputs of schooling time ($s \in [0, 1]$) and expenditures in human capital quality ($e > 0$) according to the following production function:

$$h_c = A_H z (s^\eta e^{1-\eta})^\xi, \quad \eta, \xi \in [0, 1]. \quad (3)$$

5. In an earlier version of the paper, we modelled a retirement period. Since it did not affect the quantitative implications of the theory, we decided to abstract from retirement in the current version of the paper.

A unit of schooling time (quantity of schooling) is produced with one unit of a child's time and \bar{l} units of market human capital services. In other words, schooling requires own time and human capital purchased in the market.⁶ Educational expenditures in quality are assumed to be in terms of services.⁷

To model heterogeneity across individuals, we follow the micro literature in allowing individuals to differ in terms of their ability z and their taste for schooling θ . We assume that the shocks to z and θ are idiosyncratic to each dynasty and that they are observed at the beginning of the period, that is, before human capital investments take place. The ability z is transmitted across generations according to a discrete Markov transition matrix $Q(z, z')$, where $q_{i,j} = Pr(z' = z_i | z = z_j)$. The taste shock θ is *iid* across individuals and, possibly, correlated with the current realization of the ability shock z . The distribution of the taste shock is thus described by a discrete matrix $Q_\theta(z, \theta)$. The parameter A_H in the human capital production function (3) is common across all individuals in the economy and is normalized to 1 in our baseline economy.⁸

2.3. Preferences

The per-period utility function of the household is

$$\frac{1}{1 - \sigma} ((C_M)^\gamma (C_S)^{1-\gamma})^{1-\sigma} + v(s, \theta),$$

where C_M represents consumption of manufacturing goods and C_S consumption of services. The term $v(s, \theta)$ represents utility of schooling, where θ is a taste shock that varies across individuals. Thus, consistent with the micro literature on schooling (see, for instance, Keane and Wolpin (2001) and Card (2001)), in our model heterogeneity in schooling decisions is driven by variation not only in parental wealth and labour market returns (ability) but also in schooling tastes. We model many sources of schooling variation across individuals because our calibration will target the variance in schooling in the US economy. Had we assumed that individuals only differ in ability, our calibration would have exaggerated the elasticity of schooling decisions to variation in ability. In this case, our results would have likely overestimated the response of human capital investments to TFP, since in our theory differences in ability across individuals operate similarly to differences in TFP across countries.

2.4. Market structure and relative prices

We assume competitive markets for factor inputs and outputs. Profit maximization in the manufacturing and services sectors imply $P_S = \frac{A_M}{A_S}$, where we have set the price of manufacturing goods to 1 (numeraire).

The optimal allocation of total expenditure C between consumption of manufacturing goods C_M and services C_S solves the static problem

$$c(C) \equiv \max_{C_M, C_S} (C_M)^{\gamma_j} (C_S)^{1-\gamma_j}$$

$$s.t. \quad C = P_S C_S + C_M.$$

6. Schooling s is a Leontief function of own time t and market human capital services h_s : $s = \min\{t, \frac{h_s}{\bar{l}}\}$.

7. In Erosa *et al.* (2009), we allow for educational expenditures to be a composite of manufacturing goods and services.

8. In Erosa *et al.* (2009), we consider cross-country variation in the efficiency of the human capital technology by allowing the parameter A_H to vary across economies (Klenow and Rodriguez-Clare (1997) allow for the possibility that countries differ in the productivity of the education sector).

Optimal behaviour implies that total consumption expenditures $C = \frac{(P_S)^{1-\gamma_j}}{\gamma_j^{1-\gamma_j}} c = P_c c$, where $P_c \equiv \frac{(P_S)^{1-\gamma_j}}{\gamma_j^{1-\gamma_j}}$ is the price of a composite consumption good c .

2.5. *Public education*

Since our calibration strategy is to use cross-sectional heterogeneity within a country to restrict the parameters governing human capital accumulation, we cannot abstract from the effects of public education on education and labour market outcomes. We model public education by assuming that education expenditures are subsidized at the rate p per unit of schooling time. These expenditures are financed with a proportional tax τ on households' income. Public and private expenditures are perfect substitutes in the production of human capital.

2.6. *Decision problem of the household*

All decisions of the household are made by the young parent. The state of a young parent is given by a quadruple (q, h_p, z, θ) : resources (disposable income and assets) of the old parent q , human capital of the young parent h_p , child's ability z , and child's taste for schooling θ . Households face uncertainty over the realization in future periods of ability, school taste, and market luck, and hence they maximize the expected discounted lifetime utility of all generations in the dynasty. Young parents choose consumption c , assets a' , time spent in school by their children s (where $1 - s$ is the working time of the children), and resources spent on the quality of education of their children e . A parent who provides his child with s years of schooling and a quality of education e incurs expenditures $P_S e + (w\bar{l} - p)s$, where $w\bar{l}$ is the cost of market human capital services per year of education and p denotes public education expenditures (or subsidies) per year of education.

The decision problem of a young household can be written using the language of dynamic programming as follows:

$$V(q, h_p, z, \theta) = \max_{c, e, s, h', a} \left\{ U(c) + v(s, \theta) + \beta \sum_{z', \theta', \mu'} \Xi(z, \theta, z', \theta', \mu') V(q', \mu' h_c, z', \theta') \right\}, \quad (4)$$

subject to

$$\begin{aligned} P_c c + P_S e + (w\bar{l} - p)s + a &= (1 - \tau)w [\psi_2 h_p + \psi_1 h_c (1 - s)] + q, \\ h_c &= A_H z (s^\eta e^{1-\eta})^\xi, \\ q' &= (1 - \tau) [w\psi_3 h_p + ra] + a, \\ a &\geq 0, \quad s \in [0, 1], \end{aligned}$$

where $U(c) = \frac{c^{1-\sigma}}{1-\sigma}$, $\Xi(z, \theta, z', \theta', \mu') \equiv Q_z(z, z')Q_\theta(z', \theta')Q_\mu(\mu')$ and (ψ_1, ψ_2, ψ_3) are life-cycle productivity parameters. The first two terms in the objective function are current period utility and the third term is expected discounted future utility. The expectations of the next period's value function is taken over the market luck of the current child μ' and over the ability z' and school taste θ' of the child born in the next period. The first constraint is the household budget constraint, where the right-hand side is given by the sum of the earnings of the young parent and the child upon finishing school $(1 - \tau)w[\psi_2 h_p + \psi_1 h_c (1 - s)]$ and the resources q

(after tax earnings and gross asset return) brought to the current household by the old parent. The third constraint defines the parental wealth q' of the next household in the dynasty line.

We emphasize that when young parents make education decisions for their children, they know the ability z and the taste for schooling θ . However, they face uncertainty regarding the market luck of their children μ' , which is realized in the adult stage of the individual's life cycle. The human capital h_c of an individual at the end of the first period of life evolves stochastically, according to a realization of a market luck shock μ' : $h_p = \mu' h_c$, where μ' is *iid* across individuals and time according to a density $Q_\mu(\mu)$ with a mean equal to 1. For tractability reasons and motivated by the empirical cross-country evidence,⁹ our theory abstracts from on-the-job human capital accumulation. We assume that markets are imperfect in that households cannot perfectly insure against labour market risk and the human capital shocks affecting their descendants. Moreover, individuals cannot borrow.

3. HUMAN CAPITAL INVESTMENTS IN A COMPLETE MARKETS ENVIRONMENT

This section provides some analytical results that shed light on how the parameters of the human capital technology determine the quantitative implications of the theory. To study a simplified version of the model economy, we assume complete markets and abstract from tastes for schooling. As a result, human capital investment decisions are independent of consumption decisions and maximize lifetime income. We show that the quantitative implications of the theory for income inequality—within and across countries—depend crucially on the expenditure elasticity of human capital. We also study how cross-country differences in sectoral productivities generate heterogeneity in relative prices and human capital investments.

3.1. Human capital investments across individuals and countries

Consider a world with a large number of countries. Each country is populated by measure 1 of dynasties and is characterized by a vector of prices (w, P_S) that varies across countries. Capital markets are assumed to be perfect so that in equilibrium individuals make efficient investments in human capital. Attention is confined to a steady-state analysis. The equilibrium interest rate is given by individuals' rate of time preference ρ . Although the theory makes no predictions for the distribution of income, consumption, and wealth, it does have important implications for the variation of schooling and earnings across individuals and countries.

3.1.1. The decision problem. We analyse how variation in wages and variation in ability (z) lead to heterogeneous human capital investments across countries (derive macro elasticities) and across individuals (derive micro elasticities). The goal is to isolate the effects of the parameters of the human capital technology on micro and macro elasticities in our model.

Consider the decision problem of an individual with ability z in a country with a wage rate w and a price of education services P_S , where these prices are expressed in terms of the manufactured good. The human capital investment decision can be formulated as choosing schooling time (s) and expenditures (e) to maximize the present value of the lifetime earnings

9. Using the coefficients for returns to experience for each country reported by Bils and Klenow (2000), we found that the earnings of a worker with 20 years of experience relative to a worker with 10 years of experience is not systematically related to the level of *per capita* income across countries. In fact, we found a small negative correlation between returns to labour market experience (wage growth) and *per capita* income across countries, which suggests that on-the-job investments in human capital are not likely to be an important source of income differences across countries.

net of the education costs:

$$\max_{e,s,h} \left\{ w(1-s)h\psi_1 + wh\Psi - P_S e - w\bar{l}s \right\} \tag{5}$$

$$s.t. \quad h = A_H z (s^\eta e^{1-\eta})^\xi, \tag{6}$$

where $\Psi = \sum_{i=2}^3 \beta^{i-1} \psi_i$ with ψ_i representing the life-cycle productivity parameters described in the previous section, and $\beta = \frac{1}{1+r}$ provided $r = \rho$. The cost of schooling includes expenditures in human capital quality (e), time-purchases on the market (tuition costs) per unit of schooling time ($w\bar{l}$), and foregone earnings in the first period of life ($sw h \psi_1$).

Assuming an interior solution, the first-order conditions can be expressed as

$$A_H z (s^\eta e^{1-\eta})^\xi \left\{ -\psi_1 + \frac{\eta\xi}{s} [(1-s)\psi_1 + \Psi] \right\} = \bar{l}, \tag{7}$$

$$e = \left\{ \frac{w}{P_S} A_H z (1-\eta)^\xi [(1-s)\psi_1 + \Psi] s^{\eta\xi} \right\}^{\frac{1}{1-(1-\eta)\xi}}. \tag{8}$$

In the absence of tuition costs ($\bar{l} = 0$), it is easy to solve for s from equation (7) and verify that the optimal quantity of schooling does not vary across individuals with different values of z . Intuitively, when there are no tuition costs of schooling ($\bar{l} = 0$), a change in z raises proportionally the benefits and costs of schooling and has no effect on the optimal choice of years of schooling. Moreover, when $\bar{l} = 0$, there is no variation in schooling across countries (w, P_S). We thus maintain $\bar{l} > 0$. Similarly, in the absence of education expenditures ($\eta = 1$), the quality of schooling does not vary across individuals and countries. On the contrary, when $0 < \eta < 1$, equations (7) and (8) imply that both quantity and quality of schooling vary across individuals (z) and countries (w, P_S).

Proposition 1. *The theory requires $\bar{l} > 0$ and $0 < \eta < 1$ in order to generate differences in the quantity and quality of schooling across individuals (z) and countries (w, P_S).*

3.1.2. Micro elasticities. To gain insights with simple algebra, it is convenient to set $\psi_1 = 0$. Combining equations (7) and (8), taking logs, and differentiating with respect to $\ln z$, gives an expression for the individual (ability) elasticity of schooling:

$$E_{sz} \equiv \frac{\partial \ln(s)}{\partial \ln z} = \frac{1}{1-\xi}. \tag{9}$$

The elasticity of expenditures with respect to ability is obtained by differentiating equation (8) with respect to $\ln z$:

$$E_{ez} \equiv \frac{\partial \ln(e)}{\partial \ln z} = \frac{1}{1-(1-\eta)\xi} \left(1 + \eta\xi \frac{\partial \ln(s)}{\partial \ln z} \right) = \frac{1}{1-\xi}, \tag{10}$$

where the last equality used equation (9). The elasticity of human capital with respect to the ability is obtained by log-differentiating equation (6) with respect to $\ln z$ and by using equations (9) and (10):

$$E_{hz} \equiv \frac{1}{1-\xi}.$$

Taking stock of the above findings, we note that the elasticities of schooling and human capital with respect to ability are all the same. The magnitude of this elasticity is determined by

the returns to scale in the human capital accumulation technology (parameter ξ). For a given distribution of z in the population, variation in both schooling and human capital increase with the returns-to-scale parameter ξ . Hence this parameter is important for the predictions of the theory on the cross-sectional inequality in schooling and earnings.

3.1.3. Macro elasticities. Combining equations (7) and (8), taking logs, and differentiating with respect to $\ln w$, we obtain the cross-country (wage) elasticity of schooling:

$$E_{sw} \equiv \frac{\partial \ln(s)}{\partial \ln w} = \frac{(1 - \eta)\xi}{1 - \xi}. \tag{11}$$

Using equation (11), the variation in the schooling quality across countries (w) satisfies

$$E_{cw} \equiv \frac{\partial \ln(e)}{\partial \ln w} = \frac{1}{1 - (1 - \eta)\xi} \left(1 + \eta\xi \frac{(1 - \eta)\xi}{1 - \xi} \right). \tag{12}$$

Log-differentiating equation (6) with respect to $\ln w$, together with equations (11) and (12), gives

$$E_{hw} \equiv \frac{(1 - \eta)\xi}{1 - \xi}. \tag{13}$$

Since E_{hw} does not vary across individuals, aggregation is trivial: if two countries differ in TFP by a ratio A_R , then their ratio of aggregate human capital is: $H_R = \int (W_R)^{E_{hA}} dG_z = (W_R)^{E_{hA}}$, where G_z is a c.d.f of z . We conclude that $E_{Hw} = E_{hw} = \frac{(1-\eta)\xi}{1-\xi}$. Table 1 summarizes the mapping from the model parameters into the micro and macro elasticities.

We are now ready to explore the sensitivity of the wage elasticity of human capital to the parameters of the human capital technology. Since E_{hw} increases with the returns-to-scale parameter ξ and decreases with the time-share parameter η , E_{hw} increases with the expenditure elasticity of human capital and is maximized when $\eta = 0$ and $\xi = 1$. As the time-share parameter η decreases from 1 to 0, E_{Hw} takes values in the interval $[0, \frac{\xi}{1-\xi}]$. For instance, when $\xi = 0.9$, E_{Hw} takes values between 0 and 9, depending on the time-share parameter. In other words, a wage ratio of 3 can generate differences in human capital per worker anywhere from a factor of 0 to 20 000.¹⁰

Proposition 2. *The amplification effect of human capital, given by equation (13), depends crucially on the expenditure elasticity of human capital $(1 - \eta)\xi$. In particular, if the expenditure share is zero ($\eta = 1$), then human capital does not amplify TFP differences across countries, no matter how close ξ is to 1.*

Countries differ not only with respect to the wage rate but also with respect to the relative price of education services (P_S). Inspection of the individual’s optimization conditions (7) and (8) implies that the elasticities of the variable $x \in \{s, e, h\}$ with respect to P_S are $E_{x,P_S} = -E_{x,w}$ and $E_{x,w/P_S} = E_{x,w}$. Note that human capital investment decisions are determined by the ratio of the wage rate to the price of education services.

10. While E_{hw} is determined by both η and ξ , note that the expenditure elasticity alone provides a lower bound to the amplification effect. This is because $\eta \geq 0$ implies $(1 - \eta)\xi \leq \xi$, which together with equation (13) and $\xi < 1$ implies that $E_{hw} \in \left[\frac{(1-\eta)\xi}{1-(1-\eta)\xi}, \infty \right)$. On the other hand, the parameter ξ implies an upper bound for E_{hw} since E_{hw} varies from 0 to $\frac{\xi}{1-\xi}$ for all feasible values of η .

TABLE 1
Elasticities in the deterministic model

Macro	Micro
$E_{Hw} = E_{hw} = E_{sw} = \frac{(1-\eta)\xi}{1-\xi}$	$E_{sz} = E_{hz} = E_{ez} = \frac{1}{1-\xi}$
$E_{ew} = \frac{1}{1-(1-\eta)\xi} \left(1 + \frac{\xi^2\eta(1-\eta)}{1-\xi} \right)$	
for $x \in \{s, e, h\}$	
$E_{x,Ps} = -E_{x,w}$	
$E_{x,w/Ps} = E_{x,w}$	

3.2. *Amplification with cross-country variation in sectoral productivities*

We have shown that cross-country differences in relative prices (w, p_s) generate cross-country variation in human capital investments. The next step is to analyse how cross-country differences in sectoral productivities generate heterogeneity in prices across countries and, hence, in human capital investments. To make progress, assume that

$$A_S^j = (A_M^j)^\epsilon,$$

for all countries j , with $A_S^{US} = A_M^{US} = 1$ and $\epsilon < 1$. This assumption implies that a 1% change in the TFP of the manufacturing sector is associated with an ϵ -percentage change in the TFP of the service. Note that the case $\epsilon = 1$ corresponds to the standard one-sector growth model with no variation in relative prices across countries. Using $P_S = \frac{A_M}{A_S}$, it follows that

$$P_S^j = (A_M^j)^{1-\epsilon} \tag{14}$$

so that $\epsilon < 1$ implies that services are cheaper, in terms of manufacturing goods, in poor countries than in rich countries. The findings by Hsieh and Klenow (2007) suggest that $\epsilon = 1/3$ gives a reasonably good approximation of the cross-country data on relative prices.

The firms' first-order conditions in the service sector imply

$$w^j = P_S^j (1 - \alpha) A_S^j \left(\frac{K_S^j}{H_S^j} \right)^\alpha, \tag{15}$$

$$R^j = \rho + \delta = P_S^j \alpha A_S^j \left(\frac{K_S^j}{H_S^j} \right)^{\alpha-1}. \tag{16}$$

Solving for the capital–labour ratio in the service sector gives

$$\frac{K_S^j}{H_S^j} = \left\{ \frac{P_S^j \alpha A_S^j}{\rho + \delta} \right\}^{\frac{1}{1-\alpha}}. \tag{17}$$

Combine equations (14), (15), and (17) to obtain

$$w^j = c_w (A_M^j)^{\frac{1}{1-\alpha}}, \tag{18}$$

where $c_w = (1 - \alpha) \left(\frac{\alpha}{R} \right)^{\frac{\alpha}{1-\alpha}}$ does not depend on j . The real wage rate, measured in terms of manufacturing goods, increases with the TFP of the manufacturing sector.

We are now ready to focus our attention on the price ratio $\frac{w^j}{P_S^j}$, which drives the variation in human capital investments across countries. Using equations (14) and (18) gives the following expression:

$$\frac{w^j}{P_S^j} = c_{wp} \left(A_M^j \right)^{1/(1-\alpha)-(1-\varepsilon)},$$

where c_{wp} is constant across countries. Hence, the A_M -elasticity of $\frac{w}{P_S}$ is

$$E_{w/P_S, A_M} = \frac{1}{1-\alpha} - (1-\varepsilon).$$

In a one-sector growth model ($\varepsilon = 1$), this elasticity is equal to $\frac{1}{1-\alpha}$. When $\varepsilon < 1$, the cross-country variation in the relative price $\frac{w^j}{P_S^j}$ is lower than in the one-sector growth model ($\varepsilon = 1$). This is quite intuitive: when $\varepsilon < 1$, poor countries are very inefficient in producing manufacturing goods, but they are not so inefficient in producing services. Services are cheap in poor countries because these countries have a high TFP in this sector relative to manufacturing. The real wage—expressed in terms of education services—does not increase with *per capita* income across countries as much as in the one-sector growth model. It is also intuitive that the elasticity $E_{w/P_S, A_M}$ decreases with ε . That is, the elasticity is lower the higher the comparative advantage of poor countries is in producing education services.

The amplifier effect of TFP differences in the manufacturing sector on human capital differences across countries is given by

$$E_{hA_M} = E_{h,w/P_S} E_{w/P_S, A_M} = \frac{(1-\eta)\xi}{1-\xi} \left(\frac{1}{1-\alpha} - (1-\varepsilon) \right).$$

The fact that human capital production requires services (rather than goods) makes human capital less sensitive to a reduction of TFP in the manufacturing sector.

In a similar manner, we obtain

$$E_{sA_M} = E_{s,w/P_S} E_{w/P_S, A_M} = \frac{(1-\eta)\xi}{1-\xi} \left(\frac{1}{1-\alpha} - (1-\varepsilon) \right)$$

and

$$E_{eA_M} = E_{e,w/P_S} E_{w/P_S, A_M} = \frac{1}{1-(1-\eta)\xi} \left(1 + \eta\xi \frac{(1-\eta)\xi}{1-\xi} \right) \left(\frac{1}{1-\alpha} - (1-\varepsilon) \right).$$

Proposition 3. *Assume that countries differ in their relative productivities across sectors (for all j : $A_S^j = (A_M^j)^\varepsilon$ with $\varepsilon < 1$). The amplification effect of human capital accumulation is driven by the expenditure elasticity of human capital as in the one-sector growth model. The quantitative response to a change in the TFP in the manufacturing sector diminishes with the extent of a comparative advantage in producing services (decreases with ε).*

4. CALIBRATION

4.1. Parameters and targets

We calibrate our BE to data for the US. We normalize the units in which output is measured so that $A_S = A_M = 1$. The calibration of the baseline economy does not require taking an explicit

TABLE 2
Parameters and data targets

Parameter		Value	Target	US	BE
<i>Consumption preferences</i>					
CRRA	σ	2	Empirical literature	—	—
Discount factor	$\beta^{1/20}$.9646	Interest rate, %	5	5
<i>Goods/services technologies</i>					
Capital share	α	.33	Capital income share	.33	.33
Annual depreciation	δ	0.0745	Investment–output ratio	0.2	.2
<i>Human capital technology</i>					
Schooling cost*	\bar{l}	0.0327	Educ. inst. salaries, % GDP	5	5
H.C. RTS	ξ	1.00	Variance of fixed effects	0.67	0.67
H.C. time share	η	0.6	Correlation of schooling	0.46	0.48
<i>Tastes for schooling*</i>					
Low	θ_L	0.3132	Mean years of schooling	12.6	12.6
High	θ_H	5.3662	R^2 in Mincer regression	0.22	0.21
Ability-taste interact.	b	1.09	Mincer return	0.1	0.1
Ability std	σ_z	0.23	Variance of schooling	8.5	8.3
Ability correlation	ρ_z	0.78	Correlation of earnings	0.5	0.49
Market luck std	σ_μ	0.375	Variance of earnings	0.36	0.38
Tax rate on income	τ	0.043	Public educ. exp., % GDP	3.9	3.9

*Value for a non-unit-free parameter is reported for the case $A = A_h = 1$.

stand on the shares of manufactured goods in consumption expenditures (γ). In particular, we calibrate a one-sector economy with no manufacturing sector ($\gamma = 0$). It is easy to show that, for any fixed $\gamma \in (0, 1)$, the two-sector model economy delivers, after an appropriate normalization of the distribution of ability and of the distribution of taste for schooling, the same equilibrium statistics as the calibrated one-sector model economy. The parameter γ will affect the cross-country experiments in the next section of the paper, and its value will be determined later.¹¹

The mapping between model parameters and targeted data moments is multidimensional, and we thus solve for parameter values jointly. The discussion of the calibration is divided into two parts: first, we discuss parameters that relate to preferences, demographics, and the production of goods, and second, parameters that relate to human capital accumulation. A summary of parameter values and data targets is provided in Table 2.

4.1.1. Preferences, demographics, and production of goods. We set the relative-risk-aversion parameter σ to 2. There is no direct empirical counterpart for this parameter in the empirical literature since our model period is 20 years, and there is an infinite intertemporal substitution of consumption within a period. However, we consider a value of σ that is in the range of values considered in quantitative studies with heterogeneous agents. The discount factor β is set to target an annual interest rate of 5%, which is roughly the return on capital in the US economy as measured by the average return on non-financial corporate capital net

11. Letting c_1 and e_1 denote expenditures in consumption and human capital in a one-sector model, an equivalent two-sector growth model can be constructed as follows: define the quantity of consumption c_2 and human capital (composite) input e_2 so that $c_1 = P_c c_2$ and $e_1 = P_S e_2$, for $P_c = \gamma^{-\gamma}(1-\gamma)^{\gamma-1}$ and $P_S = 1$. Then, normalize the distribution of ability and the taste shock in the two-sector model as follows: $z_2 = z_1(P_S)^{(1-\eta)\varepsilon}$ and $\theta_2 = \theta_1/(P_c)^{1-\sigma}$. This ensures that all the equilibrium statistics are identical across the one-sector and two-sector model economies.

of taxes in 1990–1996 (Poterba, 1997). The capital-share parameter is set to 0.33, consistent with the capital–income share in the US economy from the National Income and Products Accounts. The depreciation rate δ is selected to match an investment-to-output ratio of 20% as documented by US Congress, Joint Economics Committee (2004).¹²

4.1.2. Human capital accumulation. Recall that the human capital technology is given by $h_c = z (s^\eta e^{1-\eta})^\xi$, where s denotes schooling time and e denotes educational expenditures. Thus, we need to specify two elasticity parameters, ξ and η . Ability follows an AR(1) process (in logs):

$$\ln(z') = \rho_z \ln(z) + \epsilon_z, \quad \epsilon_z \sim N(0, \sigma_z^2).$$

In our computations, we approximate this stochastic process with a discrete first-order Markov chain that takes seven possible values for ability z , using the procedure in the work by Tauchen (1986) to compute transition probabilities. Market luck μ is *iid* according to $\ln(\mu) \sim N(0, \sigma_\mu^2)$, approximated over five values similar to z .

On the cost side, human capital accumulation is affected by the schooling cost \bar{l} and the public education subsidy p . The latter is determined by the tax rate on income τ in equilibrium. On the preferences side, human capital investments depend on tastes for schooling. The functional form $v(s, \theta)$ specified for the utility of schooling allows for a diminishing marginal utility from schooling and a bounded marginal utility from schooling at zero level of schooling:

$$v(s, \theta) = \theta [1 - \exp\{-s\}],$$

where $\theta \in \{\theta_L, \theta_H\}$. To allow for tastes for schooling to be correlated with ability, we let the probability of the high-taste shock to increase with ability: $Prob(\theta_H | \ln(z)) = \min\{.5 + b \ln z, 1\}$.¹³ Note that $b > 0$ implies that taste for schooling and ability are positively correlated. Thus, three parameters need to be specified for the tastes of schooling: two values for schooling tastes $\{\theta_L, \theta_H\}$ and parameter b , governing the correlation of the abilities and schooling tastes.

To sum up, there are ten parameters determining human capital accumulation:

$$\{\xi, \eta, \rho_z, \sigma_z, \sigma_\mu, \bar{l}, \tau, \theta_L, \theta_H, b\}.$$

These parameters are calibrated so that in equilibrium the model economy matches the following ten targets from the US data:

1. Intergenerational correlation of log-earnings of 0.5 (Mulligan, 1997).
2. Variance of log of permanent earnings of 0.36 (Mulligan, 1997).
3. Average years of schooling of 12.63, computed from Current Population Survey (CPS) data for 1990.
4. Variance of schooling of 8.47, computed from CPS data for 1990.
5. Public education expenditures on all levels of education as a fraction of gross domestic product (GDP) of 3.9% from the US Census Bureau (1999). In computing this statistic in the data, we treat as public expenditures all state and federal expenditures. We view local public expenditures as private because they are closely tied to property values and, therefore, to the incomes of parents.

12. A similar target is obtained using the average of the investment-to-output ratio in the Penn World Tables (PWT) 6.1 for the period 1990–1996 (Heston *et al.*, 2002).

13. Ability is drawn first, and then the schooling taste is determined.

TABLE 3
Mincer regression results, NLSY

Age group	Constant	Mincer return	R^2	Num. obs.
30–35	5.68	0.08	0.16	1857
35–40	5.56	0.10	0.21	1307
40–45	5.38	0.12	0.26	427

6. The variance of individual fixed effects accounts for 2/3 of the variance of log-earnings (Zimmerman, 1992). In our model, fixed effects are due to heterogeneity in parental resources, abilities, and tastes for schooling. The rest of the variation in earnings is due to market luck. Thus, the variance of fixed effects relative to the variance of earnings (in logs) is given by $1 - \frac{\sigma_\mu^2}{\text{var}(\ln(h_c))}$.
7. A Mincer return to schooling of 10%. Since our theory is about lifetime inequality, we estimate Mincer returns using the National Longitudinal Survey of Youth (NLSY) data for 1979–2004 to proxy lifetime earnings with 6-year averages of the earnings of males aged 30–45.¹⁴ We obtained Mincer returns in the range 0.09 to 0.11, depending on the age group considered (see Table 3). In our model, we measure returns to education by regressing individual log-wages, wh_p , on years of education, given by the model period times s :

$$\ln(wh_{p,i}) = b_0 + b_1 (20s_i) + u_i,$$

where b_1 gives the Mincer returns to schooling.

8. R^2 in the Mincer regression of 0.22. We find that the R^2 tends to increase with the age group considered, taking values between 0.16 and 0.26 (Table 3). Because the average value of R^2 over the life cycle is about 0.22, we set this value as a calibration target.
9. Teacher and staff compensation share in GDP of 0.05. According to the U.S. Department of Education (2007), (public and private) institutional costs for all levels of education amounted to 7% of GDP in 1990–1995. Seventy-two per cent of these expenditures were on teacher and staff compensation (OECD, 2007). In the model, this expenditure corresponds to the $w\bar{l}s$ cost of schooling aggregated across households.
10. Intergenerational correlation of schooling of 0.46 as obtained by regressing children's years of schooling on parental education, where the latter is defined as the average years of schooling among mothers and fathers (see Hertz *et al.*, 2007).

The calibration solves a rather complicated multidimensional mapping. Nonetheless, it is useful to discuss how model parameters affect some specific targets. Given the mean years of schooling, the cost of teachers \bar{l} and the income tax rate τ to finance public education expenditures are almost directly pinned down by the share of teacher and staff salaries on GDP and by the share of public education expenditures in GDP (that is, the distribution of schooling matters little). The variance of market luck σ_μ^2 is set to match the variance of earnings. The parameter ξ —determining returns to scale in the human capital technology—targets the variance of individual fixed effects. In our theory, the earnings of parents and children are correlated in part due to differences in parental resources (the poor invest less), and in part due to an exogenous correlation of parental and children's abilities. Thus, the correlation of ability ρ_z targets the intergenerational correlation of earnings.

14. Each 6-year age group includes all males who worked full time for at least 3 out of 6 years, with observed wages and hours.

Given the parameters just discussed, the five remaining parameters—variance of ability (σ_z), mean and variance of schooling tastes (controlled by θ_H and θ_L), correlation of ability and schooling taste (controlled by b), and the time share (η)—jointly determine the mean and variance of schooling, the R^2 and schooling coefficient in a Mincer regression, and the intergenerational correlation of schooling. The mean value for schooling taste $0.5(\theta_L + \theta_H)$ can be targeted to mean years of schooling, as the utility of schooling increases the benefits of schooling time. However, this parameter has important consequences for other targets as well. To develop this point, note that the return to schooling is affected by tastes and ability, where the former determines the utility of schooling and the latter the labour market returns to schooling. By making utility of schooling more prominent in schooling decisions, an increase in the mean of schooling tastes reduces the explanatory power of schooling on earnings. On the other hand, an increase in the variance of ability raises the importance of labour market returns in schooling decisions, thereby raising the R^2 and the schooling coefficient in a Mincer regression. Moreover, while Mincer return and the R^2 tend to move together in response to these parameter changes, the relative magnitudes of these responses depend on the parameter being changed.¹⁵ The variance of schooling increases with a rise in the heterogeneity in the returns to schooling, which can be attained with an increase in both the variance of schooling tastes and ability or with a decrease in the time share (η). Furthermore, these alternative ways of increasing the variance of schooling have different implications for a Mincer regression: while the explanatory power of schooling in a Mincer regression decreases with the time-share parameter, it increases with the variance of both schooling tastes and ability. Moreover, it also increases with the parameter b —which controls the correlation of schooling and ability—by making ability more important than taste shocks as a source of schooling variance. Nonetheless, the parameter b has a distinct effect: while the intergenerational correlation of schooling increases with the parameter b , by making schooling tastes correlated across generations in a dynasty, this target is unaffected by the variance of ability or decreases with the variance of schooling tastes. Altogether, in spite of the high interdependence of the targeted moments, the parameters have distinctive quantitative effects on those moments.

4.2. *The benchmark economy*

The BE matches all the calibration targets quite closely (see Table 2). We now show that the model is also consistent with several dimensions of heterogeneity in the data that were not targeted in the calibration: schooling distribution, evidence on the relationship between schooling attainment of children and the resources/background of their parents, and results in the micro literature on the enrolment effects of college tuition changes. Overall, our paper makes an important contribution by developing a successful theory of inequality in schooling and earnings in the US economy.

4.2.1. Schooling distribution. While the calibration only targeted the mean and variance of schooling, the model economy accounts surprisingly well for the distribution of schooling.¹⁶ Table 4 reports maximum attained school years by population percentiles obtained from

15. For instance, changes in schooling tastes (mean and variance) tend to have a strong impact on the R^2 , and changes in the standard deviation of ability tend to have a strong impact on the schooling coefficient of the Mincer regression.

16. We note, however, that time in school is a continuous variable in our model, making its comparison with the data non-trivial. In particular, the distribution of schooling in the data has clear spikes at levels of education where an educational degree is completed.

TABLE 4
Schooling distribution—model vs. data

Percentile	Distribution of schooling years						
	5	10	25	50	75	90	95
Data (CPS 1990)	8	9	12	12	14.1	16	18
Model	10	10.2	10.6	11.2	14.1	17.2	19.4

CPS 1990 data and those generated by our model. The model slightly over-predicts educational attainments at the bottom of the distribution and under-predicts them at the top of the distribution.

4.2.2. Schooling and parental background. Although the calibration targeted the inter-generational correlation of schooling, the BE is consistent with other statistics relating parental background to an offspring's schooling. According to the statistics reported by Keane and Wolpin (2001), the probability that a child attains schooling less than or equal to 12 years conditional on his highest educated parent having less than or equal to 12 years of schooling is 0.71 in the data. This probability is 0.72 in the model. Similarly, the probability that a child attains more than 12 years of schooling conditional on his highest educated parent having more than 12 years of schooling is 0.60 in the data. This probability is 0.67 in the model economy.

In reviewing the literature on children's educational attainment, Haveman and Wolfe (1995) report that the elasticity of children's educational attainments with respect to family economic resources varies in the range of 0.02–0.20. In many of the studies cited in their survey, family income is recorded only in a single year and hence measures permanent income with an error. Haveman and Wolfe (1995) argue that when income is measured over a long period of time, the estimated impact of income is far greater. Our model economy produces an elasticity of 0.16, which is well within the range of values in the empirical literature.

4.2.3. Expenditures on education. In a well-known study, Haveman and Wolfe (1995) estimated the annual investment in children in the US economy in the year 1992. Their calculations distinguish the investments made by public institutions from those made by parents, as well as between direct and indirect private costs. They report that direct non-institutional private costs of education of children aged 0–18 accounted for 8% of GDP.¹⁷ Private and public institutional costs for all levels of education add 7.5% of GDP (US Census Bureau). The total direct cost of education in the US is thus 15.5% of GDP. In our model, the calibration did not target the aggregate amount of expenditures in education. Computed as the sum of $(P_{Se} + w\bar{l}s)$ over all students, the total cost of education accounts for 14.3% of GDP, a value slightly below the estimate of Haveman and Wolfe (1995).

4.2.4. Experiment: effects of tuition on college enrolment. There is a large literature on enrolment effects of college tuition changes to which the predictions of the model can be compared. This literature is surveyed by Leslie and Brinkman (1987) and discussed by Keane and Wolpin (2001). Typically, the effects of college costs on enrolment are identified from time-series and cross-state variations in tuition rates and grant levels. To compare results

17. Direct non-institutional costs of education include housing, food, transportation, recreation, health care, and clothing.

across studies, it has become standard to use the percentage change in the overall enrolment rate of 18- to 24-year-olds in response to a tuition increase of \$100 per year, expressed in dollars for the academic year 1982–1983. In a survey covering 25 empirical studies, Leslie and Brinkman conclude that, for national studies including the full range of public and private institutions, estimates of the effects of a \$100 increase in 1982–1983 dollars tend to tightly pack in the range of a 1.8–2.4% decline in the enrolment rate of 18- to 24-year-olds.

To evaluate the response of college enrolment to a price change in the model economy, we simulate a one-period unanticipated increase in college tuition of \$1000 in 1982–1983 dollars. This experiment is done in partial equilibrium so that factor prices are kept fixed. We find that college attendance declines by 1.5% per 100 dollars increase in college tuition, which is close to the consensus estimates in the empirical literature review by Leslie and Brinkman and to the recent estimates by Keane and Wolpin (2001).¹⁸ In a schooling model structurally estimated with NLSY data on white young males, the authors found a decline in the college enrolment rate of 1.2% per \$100 tuition increase in 1982–1983 dollars. Using estimates from Kane (1994), Keane and Wolpin report that a \$1000 tuition increase in 1982–1983 dollars leads to declines in the enrolment rate of 34.0, 20.0, 12.3, and 3.0%, respectively, for white males whose parents are in the first through fourth income quartiles. In comparison, our model economy predicts declines of 23.6, 21.9, 18.0, and 9.8% for individuals with parents in the first through fourth income quartiles. The model is thus consistent with the evidence that tuition effects are much stronger among individuals born in families with a low parental income, although tuition effects decline with parental income more steeply in the data than in the model. Altogether, the model is consistent with the micro evidence on the enrolment effects of college tuition changes.

5. QUANTITATIVE RESULTS

This section uses the theory developed to quantitatively assess the consequences of TFP differences across countries. We assume that countries are identical in terms of preferences and technologies but differ only in their level of TFP. We asked the following questions: what cross-country differences in TFP are required for the model economy in order to account for a 20-fold income ratio between rich and poor countries? Does human capital play an important role in amplifying income differences across countries?

5.1. *The experiment*

To assess the magnitude of the TFP differences needed to account for the observed disparity in *per capita* income across countries, we first need to take a stand on the values of two key parameters (ε, γ). The first parameter, ε , determines the elasticity of the TFP in the service sector to a change of the TFP in the manufacturing sector. The other parameter, γ , pins down the share of manufacturing goods in consumption. Intuitively, ε determines the importance of cross-country heterogeneity in relative prices, while γ affects how the variation in relative prices impact on investment decisions and output per worker across countries.

The quantitative experiments below assume that the data counterpart to the service and manufacturing sectors in the model economy are the non-tradable and tradable sectors in the data analysed by Hsieh and Klenow (2007). In a cross-country study, these authors find that a

18. More precisely, we found that a \$1000 increase in tuition increases the enrolment rate by 15%. Following the literature, we divide by 10 to obtain the response to a change in tuition of 100 dollars. We obtained quite similar results when we simulated an increase in tuition of 500 dollars. In this case, the decrease in tuition was 7.3% which implies a decline of 1.45% in enrolment per \$100 increase in tuition.

1% variation in the TFP of the tradable sector is associated with a 0.3% variation in the TFP of the non-tradable sector in 1996, and that this elasticity was about 0.4 in 1985 (see Table 7 on page 581).¹⁹ We thus consider experiments with $\varepsilon = 0.3$ and 0.4. To evaluate the sensitivity of the results, we also consider a “low” and a “high” value for the parameter ε by setting $\varepsilon = 0.1$ and 1.

Recall that the parameter γ —determining the share of manufacturing goods in consumption—does not affect equilibrium statistics in the BE. With no loss of generality, we can then set $\gamma = 0.27$ in the BE so that this economy is consistent with the share of services in consumption expenditures in the US.²⁰ Note that in the data the share of services in aggregate consumption expenditures increases with *per capita* income across countries, suggesting that the parameter γ varies with the level of economic development. To match the variation in the share of services in consumption expenditures across countries, the experiments below assume that the parameter γ varies with TFP in the manufacturing sector with a constant elasticity. For each of the values of ε considered, we calibrate the value of this elasticity so that the theory is consistent with the fact that the elasticity of the share of tradables in consumption expenditures with PPP output is -0.13 .

5.2. Measurement

Before proceeding to the results, we emphasize that the valuation of output across countries in a model with schooling is far from trivial. Because this problem has not been addressed in the literature, it is important to discuss the source of this difficulty and how we deal with it. To measure GDP at PPP prices, a set of “international prices” needs to be chosen in a manner consistent with the methodology in the PWT (Heston *et al.*, 2002). The set of “international prices” in the PWT is constructed by averaging prices among all countries, according to the procedures established by the ICP of the United Nations. In order to calculate the average price for a product across countries, each with its own currency, the prices in the individual countries are converted into a common numeraire currency using PPP exchange rates. The average price for good i is defined as

$$P_i = \sum_j \frac{p_i^j}{E^j} \frac{q_i^j}{\sum_j q_i^j} \quad (19)$$

for $i = 1, \dots, n$, where p_i^j and q_i^j represent the price and quantity of product i in country j . Each national price is converted into a common numeraire currency by dividing by the country’s PPP exchange rate E^j , and then averaged across all countries. The resulting price P_i is a weighted arithmetic average of the converted national price using the quantity shares as weights. Thus, P_i is the total value of the world transactions for good i , expressed in terms of PPP exchange rates, divided by the total quantity of the good.

19. Hsieh and Klenow (2007) report that the elasticity of TFP with respect to PPP output is about one-third lower in the non-tradable sector than in the tradable sector in the year 1996 (see Table 7 on page 581). This ratio is 0.5 in 1980 and 0.4 in 1985.

20. Note that in the data the education services provided by private non-profit institutions and government are included in the final consumption of households at their cost (see the Handbook of the International Comparison Program). To be consistent, we define total consumption in our model as the sum of household consumption c and expenditures in education e . Hence, in the baseline economy the parameter γ determining the share of tradable in aggregate consumption is set so that $\frac{\gamma c}{c+e} = 0.23$ (authors’ estimate using PWT data), which implies $\gamma = 0.27 > 0.23$.

Note that the set of international prices and the PPP exchange rates in the PWT are jointly determined as the solution to a system of equations involving prices for all goods and PPP exchange rates for all countries. Solving such a system of equations in our model economy is a very demanding task as it involves simulating a set of model economies. The simulated model economies should mimic the world distribution of countries in terms of their population sizes and income distribution. In this way, the distribution of quantities transacted across countries for various commodities can be aggregated as in the PWT data. To circumvent this difficult problem, researchers typically calibrate the baseline economy to the US and set international prices equal to the prices in the baseline economy. This approach is motivated by the fact that, because the PWT use aggregate quantities to aggregate country prices, rich-country prices are weighted more than poor-country prices (see the discussion in Hsieh and Klenow). Below, we argue that this approach has some serious drawbacks when applied to a model of schooling, such as the one in this paper.

As discussed in the handbook of the ICP, there is very little basis for comparing education prices across countries using tuition or fees because they usually do not cover full cost and are not market prices because of heavy government subsidies. It is thus not possible to use equation (19) to determine an international schooling price that can be used to value schooling output across countries. As a result, the ICP uses an “indirect approach” which involves using data on the PPP prices of inputs to aggregate at international prices expenditures on education inputs.²¹ Since the salaries of teachers are a major schooling cost, the international salary for teachers is a crucial determinant of schooling expenditures at international prices. However, the US wage badly approximates the actual wage used in the PWT to value education costs across countries. While for most products, such as cars and airline tickets, the US and similarly rich economies account for most of the world transactions, this is not the case for schooling, for two reasons. First, the variation in average years of schooling across rich and poor countries is easily an order of magnitude smaller than the variation in the consumption of cars and airline tickets. Second, poor countries account for the bulk of the world population of school-aged individuals. Thus, equation (19) is likely to put a significant mass on the salaries of teachers in poor countries.²²

The above discussion stresses a novel point: the choice of an international wage rate to value teachers’ services across countries in a schooling model is a delicate issue. Moreover, as we have verified in our computational experiments, the results for output inequality across countries critically depend on the choice made. To circumvent these difficulties, we compute GDP at international prices net of teacher output or, equivalently, we measure national income net of the salary of teachers. The advantage of this approach is that we avoid taking a stand on how to set the international real wage for teachers. Moreover, using data from the PWT on institutional expenditures in education, we have made a similar adjustment to the GDP data in the PWT by computing GDP at international prices net of institutional expenditures. We have verified that all statistics of interest (such as the dispersion in income *per capita* and the

21. The price of education is then obtained as the ratio of education expenditures at domestic prices to expenditures at international prices.

22. While it is obviously important to aggregate all international prices in the model economy in a manner consistent with the PWT, this issue is of first-order importance when it comes to aggregating teachers’ wages. Because the cross-country variation in real wages is very large, incorrect weights can lead to an international salary for teachers in the model economy that is grossly at odds with the PWT. To deal with this problem, one approach would be to calibrate the model economy to replicate the world population distribution across rich and poor economies and use equation (19) to jointly solve for the set of international prices and countries’ PPP exchange rates. This is a daunting task. Moreover, there is no guarantee that our simulations can mimic the world distribution of years of schooling because our calibration targets only average years of schooling in the baseline economy.

TABLE 5
Amplification

ε	0.1	0.3	0.4	1
Human capital model				
<i>TFP elasticity of GDP</i>				
PPP prices	1.53	1.94	2.08	2.8
Domestic prices	1.98	2.16	2.26	2.8
A_M ratio for GDP, PPP, ratio of 20	7.1	4.7	4.0	2.9
TFP elasticity of physical capital	1.97	2.15	2.23	2.8
TFP elasticity of human capital	0.46	0.63	0.70	1.24
Exogenous human capital model				
<i>TFP elasticity of GDP</i>				
PPP prices	0.856	1.046	1.12	1.49
Domestic prices	1.49	1.49	1.49	1.49
A_M ratio for GDP, PPP, ratio of 20	33.1	17.5	14.5	7.5
TFP elasticity of physical capital	1.49	1.49	1.49	1.49

income elasticity of schooling) are not affected in a significant manner by this adjustment. To sum up, the experiments below measure GDP at international prices as follows:

$$GDP_j^* = Y_M + Y_s,$$

where the price of services is set as in the baseline economy ($P_S^* = P_S^{US} = 1$).²³

5.3. Amplification effect

Unlike the results in Section 3, the amplification effect in the BE cannot be characterized with an analytical expression. However, there is a simple way of measuring the amplification effect of TFP in the calibrated model economy. For each value of ε , we simulate the model economy for different values of A_M and run the following regression in the simulated data

$$\ln Y = a_1 + a_2 \ln A_M + u_i,$$

where Y denotes GDP. The values considered for A_M are 1.0, 0.5, 0.25, and 0.125. We run the regression for GDP measured at domestic prices and PPP prices. The fact that the R^2 in all the regressions are close to 1 implies that the estimated regressions represent a good description of how A_M and Y covary in the simulated data. The coefficient a_2 can then safely be interpreted as the elasticity of output with respect to A_M .

Table 5 reports the main results in the paper. The elasticity of GDP—at PPP prices—with respect to A_M is 1.94 when ε is 0.3 and 2.08 when ε is 0.4. To assess what the estimated elasticities imply for understanding the observed income differences across countries, we compute the TFP ratio in the manufacturing sector needed to generate a ratio of aggregate income at PPP prices of 20. This ratio is roughly the PPP-income ratio between the 10% richest countries to the 10% poorest countries in the world income distribution. The ratio of TFP in tradables needed to explain a PPP-income ratio of a factor of 20 is 4.7 when $\varepsilon = 0.3$ and 4.0 when $\varepsilon = 0.4$. These findings imply a substantial amplification of TFP differences across countries.

23. In Erosa *et al.* (2009) we evaluate how the results change when the US wage rate is used as an international price to value teachers' services in GDP. We show that this procedure has highly counterfactual implications.

The mechanism generating a large income disparity is that a low TFP leads individuals in poor countries to invest fewer resources into accumulating both physical and human capital relative to individuals in rich countries.²⁴

One way of assessing the amplification results in our paper is to compare them with the findings by Hsieh and Klenow (2007). These authors perform a development accounting exercise using a growth model with no human capital accumulation and find that a 1% rise in the TFP of the tradable sector increases output per worker by 1.04.²⁵ To show that the much larger amplification in our theory is due to human capital accumulation, we calibrate a version of the model economy with no investments in human capital.²⁶ When $\varepsilon = 0.3$ and human capital is *exogenous*, the A_M elasticity of output at PPP prices is 1.05, which is quite close to the 1.04 estimated by Hsieh and Klenow. The ratio of TFP in manufacturing to explain a PPP-income ratio of a factor of 20 is now 17.5, which is much higher than the 4.7 ratio in the economy with investments in human capital.

Human capital is an important source of amplification of income differences across countries for two reasons. First, human capital directly contributes to cross-country output differences because poor countries accumulate less human capital than rich countries. Second, a higher human capital stock stimulates more physical capital accumulation by raising the marginal product of capital. As a result, human capital accumulation amplifies the effects of TFP differences on physical capital: while the A_M elasticity of physical capital is 2.15 in the economy with human capital accumulation, it is only 1.49 in the model with no human capital investments (as documented in Table 5 for the economy with $\varepsilon = 0.3$). Note that the strength of these effects increases when sectoral productivity differences across countries are small (ε is high). The TFP elasticities of human and physical capital rise with ε as the higher the value of this parameter the lower the comparative advantage of poor countries at producing services (see Figure 1).

The results in Table 5 indicate that it is important to model sectoral productivity differences for assessing the role of human capital in amplifying income differences. When ε is set at a low value, poor countries exhibit a high relative TFP in the service sector, which, in turn, leads to a low price of services relative to rich countries. Since services are a key input in the production of human capital, cheap services in poor countries operate as a force towards reducing income inequality. Nevertheless, the amplification role of human capital is large even for implausibly low values of ε . When $\varepsilon = 0.1$, the TFP elasticity of PPP output is 1.53 in the model with human capital accumulation and 0.86 in the economy with exogenous human capital. This differential in TFP elasticities across model economies is not minor: to generate an income ratio of 20 the economy with endogenous human capital requires an A_M ratio of 7.1, while the economy with exogenous human capital requires an A_M ratio of 33.1 (see Table 5).

At a theoretical level, it is interesting to answer the following question: how does a 1% change in TFP in all sectors in the economy affect output per worker? The answer is provided by the one-sector version of the model economy ($\varepsilon = 1$), and it is startling: the amplification effect is now 2.8. In a world where TFP varies uniformly across sectors, the TFP ratio needed

24. Our baseline experiments minimize the role of human capital in amplifying income differences across countries by assuming that human capital investments only require services. Since poor countries have a comparative advantage in the production of human capital inputs (services are relatively cheap), their low aggregate productivity is not too detrimental to human capital accumulation. In Erosa *et al.* (2009), we investigate how the quantitative findings change when a fraction of educational expenses are in the form of tradable goods (such as pencils, paper, books, and computers) and when we allow countries to differ in their efficiency at producing human capital.

25. They report an elasticity of TFP in the tradable sector with respect to income *per capita* in 1996 of 0.962, which implies a TFP elasticity of income of $1/0.962 = 1.04$.

26. Labour productivity is fixed at $h = z s^{1/\varepsilon}$, where s is set at its average value in the BE.

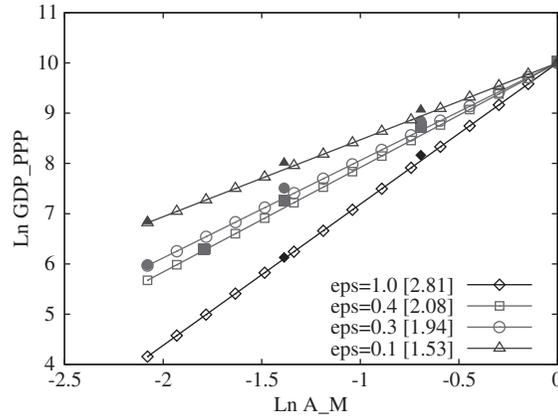


FIGURE 1

TFP amplification of output

Notes: Model PPP income is normalized by the 1990 US GDP at PPP prices. Solid points represent simulated economies; lines are linear regressions with log-TFP in manufacturing sector as an explanatory variable. TFP elasticities (regression coefficients on TFP) are indicated in square brackets.

to generate a PPP-income ratio of a factor of 20 would be only 2.9, which is about two-thirds of what is implied by the two-sector model with $\varepsilon \in [0.3, 0.4]$. Nevertheless, from a development accounting view, the relevant amplification effect is the one estimated with the two-sector model, as the evidence suggests that TFP does not vary uniformly across sectors. We conclude that it is important to model both human capital and sectoral productivity differences for assessing the cross-country variation in productivity.

5.4. Discussion on relative prices and human capital

We have shown that human capital is an important source of amplification and that the TFP elasticity of output depends critically on the parameter ε . Since ε determines the variation in relative prices across countries, it is important to examine the implications of the theory for relative prices and test them with the evidence from the PWT. Moreover, to address the concern that our quantitative theory may be exaggerating the TFP elasticity of human capital investments, we examine evidence on the variation in education prices and human capital across countries.

5.4.1. Theory and evidence on relative price variation. The valuation of education inputs as well as the comparison of education prices across countries is a difficult task for many reasons. First, private investments in education are unobserved. Second, while the PWT reports aggregate data on institutional expenditures on education, there may be unmeasured quality differences in the institutional expenditures across countries. Third, as discussed in Section 5.2, the choice of an international wage rate to value teaching services across countries is far from trivial. In light of these difficulties, we propose two proxies for the price of education: the price of services relative to the price of manufactured goods and the wage relative to the price of output, motivated by the fact that human capital production requires teacher time and expenditures on education services.

Figure 2(a) plots cross-country data on the price of services vs. *per capita* income from the PWT for the year 1996 as well as the simulated model data. Note that the elasticity of

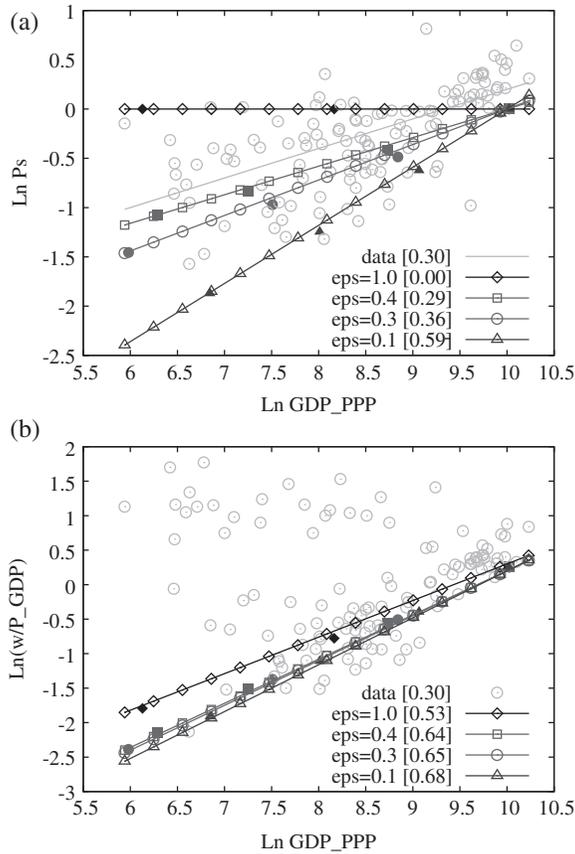


FIGURE 2

Prices and income. (a) Price of services relative to the price of manufactured goods. (b) Wage rate normalized by the price of output

Notes: Model PPP income is normalized by the 1990 US GDP at PPP prices. Solid points represent simulated economies; lines are OLS regressions with *per capita* income at PPP prices as an explanatory variable. Income elasticities (regression coefficients on GDP, PPP) are indicated in square brackets. Data on prices of non-tradables and education are from Heston *et al.* (2002).

the relative price of services with respect to PPP output is 0.30 in the PWT data, which is quite close to the 0.29 value predicted by the economy with $\epsilon = 0.4$ and to the 0.36 value obtained in the economy with $\epsilon = 0.3$. The economies with $\epsilon = 1$ and 0.1 have counterfactual predictions for the variation in the price of services across countries: the former implies no variation in relative prices across countries, while the latter grossly over-predicts the variation in the data (Figure 2(a)). We conclude that the evidence supports values of ϵ within the range [0.3, 0.4], with the best fit of the data obtained when the value of ϵ is close to 0.4.

The PWT define PPP exchange rates for education as education expenditures in national currency divided by their real value in international dollars. The education PPP exchange rates are computed with data on expenditures by *educational institutions*, for there are no cross-country data on educational expenditures at the level of the household. Figure 2(b) plots the PWT data on the price of education, normalized by the PPP price of GDP, and the PPP output *per capita*. The model counterpart is the wage rate, normalized accordingly.

Figure 2(b) documents that in the data the price of institutional expenditures in education tends to increase with income across countries albeit the relationship is not very strong (0.046) and not statistically significant at conventional levels. Moreover, when we exclude data from African countries, the estimated income elasticity of the education price becomes highly significant and equal to 0.58. This value is quantitatively close to the predictions of our theory: our simulated economies with $\varepsilon = 0.3$ and 0.4 deliver income elasticities of 0.64 and 0.65 when we measure the price of education using the real wage in terms of PPP output. Hence, if anything, the price of education inputs rises a little too fast with the level of economic development in our simulations relative to the data, suggesting that the quantitative results understate human capital differences across countries. We conclude that the evidence supports the mechanism driving the effects of TFP on human capital accumulation in our theory: while the benefit of obtaining human capital is proportional to TFP, the cost of education (relative to the price of output) is less than proportional to TFP implying that the incentives to accumulate human capital are much stronger in rich than poor countries.

5.4.2. Theory and evidence on variation in human capital. Next, we turn to the question: are the cross-country differences in human capital investments implied by the theory plausible? For each value of ε , we obtain observations for average years of schooling and output per worker by simulating economies that vary in their relative levels of TFP. In Figure 3, we plot cross-country data on schooling and income, taken from Cohen and Soto (2007) and Heston *et al.* (2002), together with the simulated data from the model economy. The figure reveals that the income semi-elasticity of schooling in the cross-country data is 2.56. All the simulated model economies generate a lower schooling-income semi-elasticity than in the data. The highest value of the semi-elasticity, 1.86, is generated by the economy with $\varepsilon = 1$. Given that our theory does not overstate schooling differences across countries, we then ask if the cross-country differences in the *quality* of schooling across similar schooling levels are reasonable.

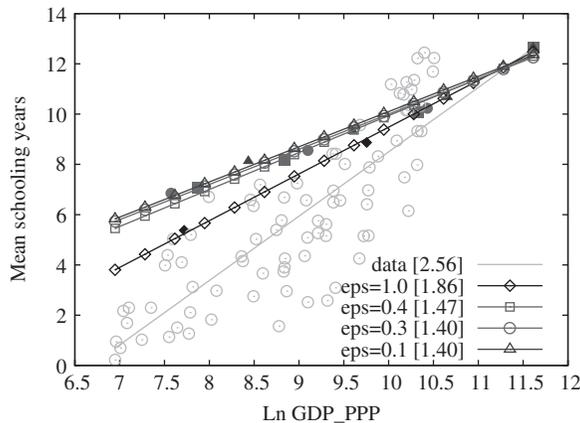


FIGURE 3

Schooling and income

Notes: Model PPP income is normalized by the 1990 US GDP at PPP prices. Solid points represent simulated economies; lines are OLS regressions with *per capita* income at PPP prices as an explanatory variable. Income semi-elasticities (regression coefficients on GDP, PPP) are indicated in square brackets. Data is from Cohen and Soto (2007).

TABLE 6
US immigrant characteristics*

GDP, PPP, percentile	20–30	30–40	40–50	50–65	MEX-PRT
Number of countries	11	10	7	5	2
Relative home GDP, PPP	24.4	33.3	44.8	58.5	45.75
Years of schooling	12.5	12.8	12.4	14.3	7.45
Relative earnings	0.97	0.92	0.94	1.07	0.93

* Authors' computation using data from Hendricks (2002, Table B1).

In an influential paper, Hendricks (2002) measures cross-country differences in schooling quality using data on relative earnings (adjusted by schooling levels) of immigrants in the US. Table 6 provides summary statistics on the data analysed by Hendricks. The population of US immigrants is divided into four groups according to the income-percentile of the country of origin relative to the US. The country groups considered are the 20-th, 30-th, 40-th, and 50-th to 65-th percentiles of the US *per capita* income. The average years of schooling among immigrants in these country groups are, respectively, 12.5, 12.8, 12.4, and 14.3, and the average earnings of these immigrants are 97, 92, 94, and 107% of the earnings of similarly educated workers in the US (see Figure 4). While Mexico and Portugal have a *per capita* income of roughly 45% of the US level, we did not include these two countries in the 40-th income percentile group because immigrants born in Mexico and Portugal have on average 7.4 years of schooling—a schooling level well below that of all other immigrants in Hendricks' sample. Nevertheless, we examine the data for Mexico and Portugal separately in a fifth country group.

We simulate immigrants from five potential source countries differing with respect to their TFP in order to generate comparable statistics from the model economy. Immigrants are selected so that they have an average level of schooling consistent with the data reported by Hendricks. We then compute the ratio of earnings between immigrants and equally schooled workers in the BE and compare these results to the evidence by Hendricks (2002).

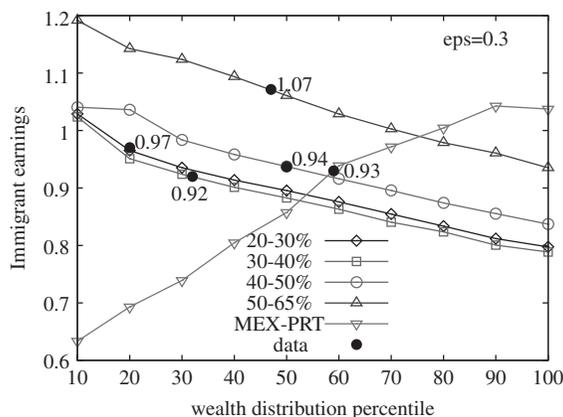


FIGURE 4

Relative earnings of immigrants

Notes: Data on relative earnings of immigrants across countries is from Hendricks (2002), adjusted by the level of schooling of the immigrant population. Each curve corresponds to an economy with a *per capita* PPP income relative to that of the US in the percentile indicated. Wealth percentiles are for populations with similar schooling.

To proceed, we need to take a stand on how immigrants are selected from the population in the source country. In our model economy, equally schooled individuals can be heterogeneous in many characteristics (taste for schooling, ability, parental human capital, and wealth) and, thus, in their earnings. As a result, selection into emigration from the distribution of these characteristics has important consequences for their average earnings. We now study in detail how different forms of selection by wealth affect the results. For each source country, we compute the wealth distribution for individuals within a given schooling bracket, and we entertain two possibilities on how immigrants are selected from these populations. First, as a benchmark, we assume that immigrants are randomly drawn from the entire wealth distribution. Second, we examine selection into emigration based on the household wealth and show that this type of selection successfully reconciles the relative earnings of immigrants predicted by the model with those obtained from the data.²⁷ Figure 4 presents results for the case $\varepsilon = 0.3$.

When immigrants are randomly drawn from the entire wealth distribution (100-th percentile on Figure 4), our model tends to over-predict the earnings gap between workers of the same schooling level in rich and poor countries. While the earnings gap for immigrants born in countries below the 50-th percentile are about 0.80 in the model, it is above 0.90 in the data. On the other hand, the model over-predicts the relative earnings for immigrants born in Mexico and Portugal, producing a ratio of 1.04 relative to 0.93 in the data. Moreover, the model cannot account for the fact that immigrants from countries in the 50-th percentile earn about 7% more than Americans, an observation suggesting that schooling quality is higher in this group of countries than in the US.

We now show that the model can account well for these non-trivial patterns of the immigrant earnings data, provided that selection of immigrants by wealth is allowed to play a role. We assume that immigrants are randomly drawn from the bottom part of the wealth distribution for individuals in a given schooling bracket. We consider several cases by right-censoring the wealth distribution at different percentiles, starting from the bottom 10% and gradually extending it to include more households. Notice that selection is more important the more truncated the wealth distribution is. The case of no selection corresponds to the assumption that immigrants are drawn from the entire wealth distribution (i.e. no truncation). Figure 4 graphs, for $\varepsilon = 0.3$ and 0.4, how average earnings vary as immigrants are increasingly drawn from wealthier backgrounds. We find that immigrants' human capital tends to decline with parental wealth for the first four country groups. On the other hand, earnings increase with parental wealth in the fifth country group representing Mexico and Portugal.

Why does the relationship between parental wealth and immigrants' human capital switch signs across countries? The key is that, while immigrants from the first four country groups have on average more than 12 years of schooling, immigrants in the country group representing Mexico and Puerto Rico have on average only about 7 years of schooling. As a result, immigrants from the first four country groups exhibit high average years of schooling relative to their source-country population, and the opposite is true for the case of Mexico and Portugal. When immigrants are positively selected from the schooling distribution, they tend to exhibit a relatively high taste for schooling. In this case, the rate of return to schooling is a relatively less important determinant of schooling decisions. Moreover, the importance of returns to education for schooling decisions diminishes with parental wealth: wealthy individuals tend to care more about the utility of schooling as they have a low marginal utility of consumption. As a

27. Note that selection by wealth matters because wealth is correlated with ability and schooling expenditures. Alternatively, we could directly select immigrants in terms of their ability and schooling expenditures but this would not affect our main conclusion that selection can reconcile the predictions of the theory with the data. The results below shed some light on the sensitivity of Hendrick's findings to his assumption of non-random selection into emigration.

result, conditional on a level of schooling, individuals with wealthy backgrounds tend to be of a relatively low ability and to spend little on education. This accounts for the negative relationship between earnings and parental wealth among highly schooled immigrants. Our findings show that the case of Mexico and Portugal is quite different. Immigrants from these countries are relatively low-schooled and care little about the utility of schooling. The rate of return to schooling is the main driving force behind their schooling decisions. A more favourable parental background is associated with more human capital expenditures and, hence, higher human capital.

Figure 4 indicates with a dot, for each country group, the amount of selection needed to account for the immigrants' earnings data for the economy with $\varepsilon = 0.3$. The earnings data for the first three country groups can be rationalized if immigrants are drawn from the bottom 20-th, 30-th, and 50-th percent of the wealth distribution. Moreover, assuming that immigrants are drawn from the bottom 40% of the wealth distribution accounts for the observed earnings ratio of 1.07 among immigrants born in countries in the 50-th to 65-th percentile group. The average earnings ratio observed among immigrants born in Mexico and Puerto Rico can be accounted for if immigrants from these countries were drawn from the bottom 60% of the wealth distribution. A similar picture emerges for the economy with $\varepsilon = 0.4$ (shown by Erosa *et al.*, 2009). We conclude that the model can account well for the evidence in the work by Hendricks (2002).

Our paper supports Hendricks's conclusion that accounting for cross-country income differences requires a theory of TFP. Our results, however, imply a more important role for factor accumulation. Hendricks estimates that for the five poorest countries in his sample—with an output *per capita* of 5.8% of the US level—low factor accumulation reduces income *per capita* to 47% of the US level. In our paper, the reduction in output *per capita* accounted for by low factor accumulation is 25%—almost twice as big as estimated by Hendricks.²⁸ Moreover, while the cross-country differences in schooling quantity and quality are taken as given by Hendricks, in our paper they are the result of TFP differences across countries. Nevertheless, both papers imply important TFP differences across countries: to account for a 17-fold difference in incomes across countries, Hendricks estimates that an 8-fold difference in TFPs is needed, while our model requires only about a half of that difference in the TFPs of the manufacturing sector.

6. CONCLUSIONS

We build a model of heterogeneous individuals—who make investments in schooling quantity and quality—to quantify the importance of differences in human capital vs. TFP in explaining the variation in *per capita* income across countries. We use US household data to pin down the key parameters—elasticities of human capital with respect to time and goods inputs—driving the quantitative implications of the theory across countries. Our baseline economy successfully matches a wide set of calibration targets on schooling and earnings inequality in the US, such as the variances and intergenerational correlations of earnings and schooling, and the slope coefficient and R^2 in a Mincer regression. The model economy is also consistent with several dimensions of heterogeneity in the data that were not targeted in the calibration: schooling distribution, evidence on the relationship between schooling attainment of children, and the resources/background of their parents, and results in the micro literature on the enrolment effects of college tuition changes. Altogether, the paper develops a successful theory of

28. Our quantitative findings are quite close to the ones in the study of Schoellman (2009), who uses the returns to schooling of immigrants to the US as a measure of their source-country education quality.

inequality in schooling and earnings in the US economy. We also provide several pieces of evidence supporting the cross-country predictions of the theory. Our main finding is that human capital accumulation strongly amplifies TFP differences across countries: to explain a 20-fold difference in the output per worker, the model requires a 5-fold difference in the TFP of the tradable sector, vs. an 18-fold difference if human capital is fixed across countries.

We leave for future work two important extensions of our analysis. First, we plan to explore the distributional implications of cross-country differences in TFP, fiscal policies, and support for public education. Second, we would like to model heterogeneity in the marginal returns to schooling across individuals, as emphasized by a recent micro literature (see Card, 2001). In this case, the impact of any public-policy reform on schooling is driven by the marginal returns to schooling of the individuals affected by the reform and not by the average return to schooling in the population.

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REFERENCES

- BECKER, G. and TOMES, N. (1986), “Human Capital and the Rise and Fall of Families”, *Journal of Labor Economics*, **4** (3), S1–S39.
- BILS, M. and KLENOW, P. (2000), “Does Schooling Cause Growth?” *American Economic Review*, **90** (5), 1160–1183.
- CARD, D. (2001), “Estimating the Return to Schooling: Progress on Some Persistent Econometric Problems”, *Econometrica*, **69** (5), 1127–1160.
- COHEN, D. and SOTO, M. (2007), “Growth and Human Capital: Good Data, Good Results”, *Journal of Economic Growth*, **12** (1), 51–76.
- CORDOBA, J. C. and RIPOLL, M. (2007), “The Role of Education in Development” (Working Paper No. 311, University of Pittsburg).
- EROSA, A. and KORESHKOVA, T. (2007), “Progressive Taxation in a Dynastic Model of Human Capital”, *Journal of Monetary Economics*, **54**, 667–685.
- EROSA, A., KORESHKOVA, T. and RESTUCCIA, D. (2009), “How Important is Human Capital? A Quantitative Analysis of World Income Inequality”, (Working Paper No. 11, IMDEA).
- HAVEMAN, R. and WOLFE, B. (1995), “The Determinants of Children’s Attainments: A Review of Methods and Findings”, *Journal of Economic Literature*, **33**, 1829–1878.
- HENDRICKS, L. (2002), “How Important is Human Capital for Development? Evidence from Immigrants’ Earnings”, *American Economic Review*, **92** (1), 198–219.
- HERRENDORF, B. and VALENTINYI, A. (2009), “Which Sectors Make the Poor Countries So Unproductive” (Mimeo, Arizona State University).
- HERTZ, T., JAYASUNDERA, T., PIRAINO, P., SELCUK, S., SMITH, N. and VERESHCHAGINA, A. (2007), “The Inheritance of Education Inequality: International Comparisons and Fifty-Year Trends”, *The B.E. Journal of Economic Analysis and Policy*, **7** (2), Article 10.
- HESTON, A., SUMMERS, R. and ATEN, B. (2002), “Penn World Table Version 6.1” (Center for International Comparisons at the University of Pennsylvania (CICUP)).
- HSIEH, C.-T. and KLENOW, P. (2007), “Relative Prices and Relative Prosperity”, *American Economic Review*, **97** (3), 562–585.
- KANE, T. J. (1994), “College Entry by Blacks Since 1970: The Role of College Costs, Family Background, and the Returns to Education”, *Journal of Political Economy*, **102** (5), 878–911.

- KEANE, M. P. and WOLPIN, K. I. (1997), "The Career Decisions of Young Men", *Journal of Political Economy*, **105** (3), 473–522.
- KEANE, M. P. and WOLPIN, K. I. (2001), "The Effects of Parental Transfers and Borrowing Constraints on Educational Attainment", *International Economic Review*, **42** (4), 1051–1103.
- KLENOW, P. and RODRIGUEZ-CLARE, A. (1997), "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?", in Bernanke, B. S. and Rotemberg, J. J. (eds.) *NBER Macroeconomics Annual* (Cambridge, MA: MIT Press).
- LESLIE, L. L. and BRINKMAN, P. T. (1987), "Student Price Response in Higher Education: The Student Demand Studies", *The Journal of Higher Education*, **58** (2), 181–204.
- MANKIW, N. G., ROMER, D. and WEIL, D. N. (1992), "A Contribution to the Empirics of Economic Growth", *Quarterly Journal of Economics*, **107** (2), 402–437.
- MANUELLI, R. and SESHADRI, A. (2005), "Human Capital and the Wealth of Nations" (2005 Meeting Papers 56, Society of Economic Dynamics).
- MULLIGAN, C. B. (1997), *Parental Priorities and Economic Inequality* (Chicago: University of Chicago Press).
- NEAL, D. A. and JOHNSON, W. R. (1996), "The Role of Pre-market Factors in Black-White Wage Differences", *Journal of Political Economy*, **104** (5), 869–895.
- OECD (2007), *Education at a Glance* (France: OECD Publishing).
- POTERBA, J. (1997), "The Estate Tax and After-Tax Investment Returns" (Working Paper No. 6337, National Bureau of Economic Research).
- SCHOELLMAN, T. (2009), "Matching and Accounting for Cross-Country Differences in Education Quality" (Mimeo, Clemson University).
- TAUCHEN, G. (1986), "Finite State Markov Chain Approximations to Univariate and Vector Autoregressions", *Economics Letters*, **20** (2), 177–181.
- US Census Bureau (1999), *Statistical Abstract of the United States* (Washington, DC: US GPO).
- US Congress, Joint Economics Committee (2004), *Economic Report of the President* (Washington, DC: US GPO).
- US Department of Education (2007), *Digest of Education Statistics* (Washington, DC: US GPO).
- ZIMMERMAN, D. J. (1992), "Regression Toward Mediocrity in Economic Stature", *American Economic Review*, **82** (3), 409–429.