On the Aggregate and Distributional Implications of TFP Differences across Countries†

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Abstract

We develop a theory of human capital accumulation with heterogeneous agents to quantitatively assess the aggregate and distributional effects of TFP differences across countries. Because the aggregate impact of TFP on the economy hinges on the parametrization of the human capital technology, our approach is to restrict these parameters using the cross-sectional heterogeneity within a country. Our results indicate that factor differences in TFP of 3 are amplified through physical and human capital accumulation by a factor of almost 7. In particular, our theory implies that human capital differences across countries are 2 times larger than the differences in human capital obtained using Mincer returns to schooling. Moreover, our approach allows us to study the distributive consequences of TFP differences across countries. Economic theory suggests that TFP affects both the return and cost of investment in human capital. Therefore, whether TFP increases or decreases cross-section inequality and intergenerational mobility across countries is a quantitative question. We find that countries with lower TFP feature substantially more cross-section inequality and intergenerational persistence.

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1 Introduction

In this paper we develop a theory of human capital accumulation with heterogeneous agents to quantitatively assess the aggregate and distributive effects of TFP differences across countries. We think that there are important reasons for studying cross-country income differences in a framework with heterogeneous agents. Growth accounting exercises face the problems that there are no reliable measures of human capital stocks across countries and that there is not an obvious variance decomposition when production inputs are correlated (TFP co-varies with physical and human capital stocks). Moreover, quantitative studies using theory face the problem that there is no direct evidence on the parameters of the human capital technology, and these parameters are crucial for the quantitative implications of the theory. In light of these difficulties, our paper provides a novel approach to studying the effect of TFP differences across countries. Our approach is to build a framework with heterogeneous individuals and use the cross-sectional implications of our theory to parameterize the human capital technology. In addition, our approach allows us to study the distributive consequences of cross-country TFP differences, which are yet to be explored by researchers interested in development issues. It is an open question how variations in TFP affect cross-section income inequality and intergenerational mobility across countries.

We develop an heterogeneous-agent model of physical and human capital accumulation. We consider an economy populated by overlapping generations of people that live for 5 periods and are altruistic towards their descendants. People in our model are heterogeneous in skills, physical assets, and face idiosyncratic (uninsurable) uncertainty about the learning ability of their descendants. Investment in human capital involves a time input of children and expenditures of parents that affect the quality of human capital of their children. Parents cannot borrow to finance investment in human capital. A single good is produced every period with a constant returns to scale technology in physical and human capital.

We calibrate our benchmark economy to U.S. data. Our strategy is to restrict parameters values so that the equilibrium of the model matches a set of aggregate targets and a set of targets from cross-section heterogeneity within the U.S. economy. We show that our calibration produces other economic statistics that are consistent with the evidence for the U.S. Our results indicate that factor differences in TFP of 3 are amplified through physical and human capital accumulation by a factor of almost 7. In particular, our theory implies that human capital differences across countries are 2 times larger than the differences in human capital obtained using Mincer returns to schooling. Moreover, our approach allows us to study the distributive consequences of TFP differences across countries. Economic theory suggests that TFP affects both the return and cost of investment in human capital. Therefore, whether TFP increases or decreases cross-section inequality and intergenerational mobility across countries is a quantitative question. We find that countries with lower TFP feature substantially more cross-section inequality and intergenerational persistence.

We emphasize that in our model all differences in output per worker are generated by differences in TFP (in the output-good or investment-good producing sectors). As a result, our paper is about the magnitude of TFP differences that could generate the observed income differences in the data and not about whether differences in income are due to factor accumulation or TFP. In this sense, the policy prescriptions that can be derived by our paper are close in spirit to Parente and Presctott (1999, 2000), Klenow and Rodriguez-Clare (1997), and Hall and Jones (1999) about the importance of TFP differences in accounting for the wealth of nations. We find however that differences in TFP have a large impact in human capital accumulation (in particular unmeasured quality differences in human capital) that are the source of a substantial amplification effect of TFP on income differences across countries.

Our paper is closely related to Manuelli and Seshadri (2005) who measure human capital differences across countries using life-cycle human capital theory. Our paper differs from Manuelli and Seshadri (2005) in two important respects. First, we restrict the parameters in the human capital technology using cross-section heterogeneity in the U.S. while Manuelli and Seshadri use life-cycle data for the U.S. We view the two approaches as complementary in providing measures of human capital differences. An advantage of using cross-section heterogeneity to restrict the human capital technology is that our estimated parameters are not subject to time, cohort, and age effects of life-cycle data that are difficult to control for empirically. Moreover, relative to the aggregate data, the cross-sectional data is rich in information about investments in human capital and their returns. For instance, the variation in schooling and earnings across individuals provides valuable information about the schooling elasticity of earnings. However, by focusing on the life-cycle, Manuelli and Seshadri offer a more comprehensive measure of human capital that ours, one that includes in addition to formal schooling, early development and on-the-job human capital accumulation. Second, our paper also focuses on the distributional impact of TFP differences across countries with incomplete markets for investment in human capital. While this feature of our model is not crucial for the aggregate implications of the theory, it is essential in our calibration strategy of the human capital technology.

The paper proceeds as follows. In the next section we describe a simple human capital accumulation problem to illustrate the importance of the main features of our theory. Section 3 describes in detail the economic environment of our benchmark economy. In section 4 we calibrate the benchmark economy to U.S. data. Section 5 discusses the main characteristics of the benchmark economy and section 6 computes experiments where economies differ by the TFP parameter. We emphasize in this section the aggregate and distributional impact of TFP differences across countries. We present a sensitivity analysis in section 7 and conclude in section 8.

2 Simple Illustration

In this section we consider a simple accumulation problem of human capital in order to illustrate how the quantitative aggregate implications of TFP differences across countries hinge on the specification of the human capital technology. We also use this simple framework to motivate our approach of using cross-section heterogeneity within a country to restrict the human capital technology. Imagine an economy populated by an infinitely-lived representative household with standard preferences over consumption. The household is endowed with one unit of productive time each period and a positive level of human capital at date 0. At each date, output is produced with a linear technology in human capital. Assume that human capital accumulation requires time and expenditures in education as inputs.

Moreover, we assume that a fixed fraction μ of expenditures corresponds to time purchased in the market (differently from own time) and a fraction $(1-\mu)$ corresponds to purchases of goods. In order to obtain analytical results, we also assume that human capital depreciates fully during the period.

Given this description, a planner then solves the following problem:

$$\max_{\{c_t, e_t, s_t, h_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t u(c_t),$$

s.t.

$$c_t + (1-\mu)e_t = A\left[h_t - h_t s_t - \mu e_t\right], \qquad t = 0, 1, ...$$

$$h_{t+1} = \left(s_t^{\eta} e_t^{1-\eta}\right)^{\xi}, \quad t = 0, 1, ...$$

$$c_t, e_t \geq 0, \quad s_t \in [0,1], \quad t = 0, 1, ...$$

with ξ and $\eta \in (0,1)$ and $h_0 > 0$ given. Note in the resource constraint that the cost of time purchases is affected by A while the costs of goods is not. The steady-state solution to this problem has a simple form and is given by:

$$h_s = \left\{\left[\frac{A(1-\eta)}{\eta\left(\mu A + 1 - \mu\right)}\right]^{(1-\eta)\xi} \frac{\beta\eta\xi}{1+\beta\eta\xi}\right\}^{\frac{1}{1-(1-\eta)\xi}}.$$

Notice that the steady-state level of human capital depends positively on the TFP parameter A as long as the share of expenditures in goods in the human capital accumulation technology is positive, which requires a time share η less than 1 and μ positive. Intuitively, when human capital accumulation only requires time inputs (that is, no expenditures in goods) the level of TFP affects equally the return and cost of human capital and, as a result, it does not affect human capital accumulation.

Cross-country Implications In order to make comparisons across countries, we need to make some assumptions regarding the parameters of the model. If we assume that ξ, η, μ, δ, β and z are equal across countries, then relative output per worker between any two countries i and j is given by:

$$\frac{y_i}{y_j} = \left(\frac{A_i}{A_j}\right)\left[\frac{A_i}{A_j}\left(\frac{\mu A_j + 1 - \mu}{\mu A_i + 1 - \mu}\right)\right]^{\frac{(1-\eta)\xi}{1-(1-\eta)\xi}}.$$

Therefore, TFP differences across countries have a direct impact on output per worker and an indirect impact through human capital accumulation. The elasticity of TFP on human capital depends on the parameter μ determining the share of time-purchases in total expenditures in human capital and on the expenditure elasticity of human capital accumulation as determined by $(1-\eta)\xi$. Notice that when all expenditures consists of purchases of time ($\mu = 1$), TFP does not affect human capital accumulation. In this case, the ratio of output per worker across countries is given by:

$$\frac{y_i}{y_j} = \frac{A_i}{A_j},$$

so that there is no amplification through human capital accumulation of TFP differences across countries. When all expenditures are in goods ($\mu = 0$), TFP differences across countries are amplified by human capital accumulation according to

$$\frac{y_i}{y_j} = \left(\frac{A_i}{A_j}\right)\left(\frac{A_i}{A_j}\right)^{\frac{(1-\eta)\xi}{1-(1-\eta)\xi}} = \left(\frac{A_i}{A_j}\right)^{\frac{1}{1-(1-\eta)\xi}}.$$

In this case, the elasticities of TFP on human capital and output are $\frac{(1-\eta)\xi}{1-(1-\eta)\xi}$ and $\frac{1}{1-(1-\eta)\xi}$. These elasticities are determined by the share of expenditures in the human capital production technology. To emphasize the quantitative importance of the expenditure-share $(1-\eta)\xi$ notice that in order for the model to produce a factor difference in output per worker of 20 between any two countries, a factor difference in TFP of 3.3 between these countries would be needed if $(1-\eta)\xi = 0.6$ (an output elasticity of 2.5), while a factor difference in TFP of only 1.35 is needed if $(1-\eta)\xi = 0.9$ (an output elasticity of 10). Also, notice that if human capital accumulation only requires time inputs ($\eta = 1$) the TFP differences across countries are not amplified through human capital accumulation. Therefore, the quantitative implications of TFP in our model hinge on the expenditure elasticity of human capital investments and on the share of goods in total expenditures in human capital.

Cross-section Heterogeneity We have shown that the share of goods in total expenditures and the expenditure elasticity of human capital determine the quantitative effects of TFP on output and human capital accumulation. In our quantitative exercise in Section 5, we use estimates from Kendrick (1976) and the U.S. Department of Education (1996) to restrict the share of goods in total expenditures in education. Unfortunately, there is no conclusive micro evidence on the parameters determining the expenditure elasticity of human capital (η and ξ).[1] In light of these difficulties, and following Erosa and Koreshkova (2004), we build a framework with heterogeneous agents and use the cross-sectional implications of our theory in order to parameterize the human capital technology. To motivate this approach, notice that in a competitive decentralization of the above planner's problem, log-earnings of a person with human capital h would be given by

$$\log(Ah) = b_0 + \frac{1}{1-(1-\eta)\xi}\log(s),$$

where $b_0 = \log(A) + \frac{(1-\eta)\xi}{1-(1-\eta)\xi}\log\left(\frac{A(1-\eta)}{\eta(\mu A+1-\mu)}\right)$ is a constant and $\frac{1}{1-(1-\eta)\xi}$ represents the schooling elasticity of income. The theory thus implies that the parameters determining the amplification effect of cross-country TFP differences also determine the schooling elasticity of income. This is important because following the influential work of Mincer (1974) there is a vast amount of empirical studies estimating how schooling affects income. In the representative agent framework that we have presented, schooling s and human capital do not vary across agents. The task is then to build a quantitative theory with rich heterogeneity in schooling and income that can be matched to the data. Then, the cross-sectional implications of the theory can be compared to the U.S. data. In particular, we could compare the schooling elasticity of earnings in our theory with the findings in empirical studies of the U.S. economy.[2]

[1]The survey in Browning, Hansen, and Heckman (1999) suggests a wide range of estimates from micro evidence for $\eta+\xi$, between 0.5 and almost 1. Similarly, there is wide variation in estimates for the individual shares of time and goods.

[2]Notice that in this simple framework, the Mincer return −which is the change of log wages on years of schooling− can be calculated using the Chain Rule as the derivative of log wages on log schooling times the derivative of log schooling on schooling. As a result, the Mincer return is given by $\frac{1}{(1-(1-\eta)\xi)}\frac{1}{s}$. More importantly, this return does not depend on the share of goods in the total cost of human capital accumulation.

We end this section by noting that the intercept term b_0 in the log-earnings/schooling relationship in this simple model depends on the TFP parameter A. Thus, ignoring this intercept term in measuring human capital stocks across countries (i.e. using only Mincer returns to estimate human capital across countries) can produce misleading results. Since differences in the intercept term can be broadly interpreted as capturing differences in quality of education across countries, measures of human capital using Mincer returns do not capture all differences in human capital across countries. We use our quantitative framework to evaluate the importance of this omission in estimates of human capital stocks across countries using estimates from Mincer regressions. In the next section we present our benchmark economy with heterogeneous agents and human capital accumulation that builds on the basic insights from this section.

3 Economic Environment

We develop a quantitative heterogeneous-agent model of physical and human capital accumulation in order to study the implications of TFP differences on inequality, mobility, and output per worker across countries. We consider an economy populated by overlapping generations of individuals that are altruistic towards their descendants. Individuals are heterogeneous in skills, physical assets, and face idiosyncratic (uninsurable) uncertainty about their labor earnings. Investment in human capital involves a time input of children and expenditures of parents that affect the quality of human capital of their children. Parents can not borrow to finance investment in human capital. Since we focus on steady states, we omit time subscripts in the description of the model. We denote with a prime variables corresponding to the period following the current period.

Production Technologies We assume that output is produced with a constant returns to scale technology,

$$Y = AK^{\alpha}H^{1-\alpha}, \qquad 0 < \alpha < 1, \tag{1}$$

where Y denotes output, K represents physical capital services, H stands for aggregate human capital services, and A is total factor productivity (TFP) in the production of the output good. Output can be consumed C, invested in physical capital X, and invested in human capital E. Feasibility requires,

$$C + X + E = Y.$$

Physical capital is accumulated according to:

$$K' = (1-\delta)K + A_k X, \qquad A_k \leq 1,$$

where A_k is a parameter determining the productivity of investment in physical capital (i.e., the effectiveness with which current period output can be transformed into capital available for production in the following period). The aggregate human capital H is given by the sum of human capital across individuals in the economy. We discuss how human capital is accumulated when presenting the decision problem of the household.

Market Structure We assume that firms take factor prices as given and maximize profits by choosing the demand for factor inputs:

$$\max_{K,H>0} \left\{ AK^{\alpha}H^{1-\alpha} - wH - (r+\delta)K \right\}. \tag{2}$$

We assume that markets are imperfect since households cannot perfectly insure against labor market risk and they cannot borrow.

Demographic Structure We assume that there is a large number of dynasties (mass one). The economy is populated by overlapping generations of people that live for 5 periods and are altruistic towards their descendants. The model period is set to 16 years, which is roughly the total number of years spent on education by a person with a college degree in the data. An individual lives three periods as an adult and two periods as a child. In Panel A of Table 1 we summarize the demographic structure in our model and the mapping between age in the model and real age in the data. In the last period as an adult (retired adult) we assume an exogenous probability of survival ϕ. In our calibration we choose this probability in order to match the life expectancy at birth. A household is given by a parent-child pair in the first two stages and a retired adult in the last stage. These three stages of the life cycle of households are described in Panel B of Table 1.

Decision Problem of the Household We assume that all decisions of the household are made by the parent. The state of a young parent is given by a triple (z, h, q) representing an earnings ability shock z, human capital h, and a parental transfer q received from the

Table 1: Demographic Structure and Life-cycle Stages of Households

Panel A: Demographic Structure

Model Age	Real Age	Name
1	6-21	child
2	22-37	old child
3	38-53	young adult
4	54-69	old adult
5	70-85*	retired adult

Panel B: Life-cycle Stages of Households

Stage	Adult	Child	Adult's Age	Child's Age
1	young	child	38-53	6-21
2	old	old child	54-69	22-37
3	retired	–	70-85	–

*There is an exogenous probability of survival for retired adults so that their life expectancy at birth is lower than 85 years of age.

previous household in the dynasty line. Households maximize discounted lifetime utility of all future generations in the dynasty. Young parents choose consumption c_y, asset-savings a'_y, time spend in school by their children s (where $1-s$ is working time of the children) and the resources spent in the quality of education of their children e. We assume that a parent that provides his child with s years of schooling and a quality of education e incurs expenditures of $e+(w\bar{l}-p)s$, where $w\bar{l}$ is a per year schooling cost (which is assumed to depend on the market wage rate) and p denotes public education expenditures (or subsidies) per year of schooling. We take a broad view of human capital and interpret the quality of education e as including non-schooling expenditures (such as child rearing and health care) that enhance the future earnings power of children. Because we abstract from investment in human capital on the job, we capture the life-cycle growth in wages by assuming exogenous life-cycle productivity parameters (ψ_c, ψ_y, ψ_o) for child, young adult, and old adult individuals. The productivity of old children is normalized to one.

Young parents face uncertainty regarding the ability of their children z'. Human capital of children is given by

$$h' = z' \left(s^{\eta} e^{1-\eta}\right)^{\xi},$$

where z' evolves according to a discrete Markov transition matrix $Q(z, z')$ and is realized in the second stage of the household's life cycle.

In the second stage, the household is conformed by a child with earnings wh' and a parent with earnings $\psi_o wh$, where the parameter ψ_o captures an exogenous life-cycle growth effect on earnings (experience). Old parents decide savings for retirement a'_o, consumption c_o, and an intergenerational transfer q' for the next household in the dynasty. Retired individuals consume their savings.

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

$$v(z, h, q) = \max_{c_y, e, s, h', a'_y, [c_o, c_r, a'_o, q'](z')} \left\{ U(c_y) + \beta \sum_{z'} Q(z, z') \left[U(c_o) + \beta E v\right] \right\}, \tag{3}$$

subject to

$$\begin{aligned}
c_y + a'_y + e + (w\bar{l} - p)s &= (1-\tau)\left[\psi_y wh + w\Psi_c(1-s) + rq\right] + q, \\
c_o(z') + a'_o(z') + q'(z') &= (1-\tau)\left[\psi_o wh + wh'(z') + ra'_y\right] + a'_y, \\
c_r(z') &= (1-\tau) r a'_o(z') + a'_o(z'),
\end{aligned}$$

$$
\begin{aligned}
e + (w\bar{l} - p)s &\geq 0, \\
\Psi_c &= \psi_c \left(s^{\eta} e^{1-\eta}\right)^{\xi}, \\
h' &= z' \left(s^{\eta} e^{1-\eta}\right)^{\xi},
\end{aligned}
$$

and $s \in [0,1]$, a_y, a_o, $q'(z') \geq 0$, and where

$$
Ev = \left[\phi\left(U(c_r) + v(z', h', q')\right) + (1-\phi)v(z', h', q' + c_r)\right].
$$

ϕ is the probability of survival for a retired adult. ψ_c is a productivity parameter of children. Since old parents know the ability of their children when making consumption, saving, and transfer allocation decisions, these choices are expressed as contingent on their children's ability z' in the dynamic programming problem of young parents. We denote by $g^i(z,h,q)$ for $i = \{c_y, e, s, h', a'_y\}$, $g^j(z,h,q;z')$ for $j = \{c_o, c_r, a'_o, q'\}$ the decision rules implied by the solution to the functional equation in (3).

The decision rules of adult households and the transition matrix Q imply a mapping from the distribution of adult households in a period to the distribution of adult households in two periods (since a new household is formed every two periods in a dynasty line)

$$
\mu'(z', h', q') = T(\mu(z,h,q)), \qquad \forall (z,h,q). \tag{4}
$$

Public Education We assume that public expenditures are financed with a proportional tax τ on household's income and that they are perfect substitutes with private expenditures.

Definition of Equilibrium We focus on stationary equilibria of the model. A stationary recursive competitive equilibrium is a list of functions: $v(z,h,q)$, $g^i(z,h,q)$ for $i = \{c_y, e, s, h', a'_y\}$, $g^j(z,h,q;z')$ for $j = \{c_o, c_r, a'_o, q'\}$ for adult households, a distribution function $\mu(z,h,q)$, demand of factor inputs by firms K^d, H^d, prices w and r , and government expenditures in education p, such that: (i) Given prices and p, v solves (3) and $g's$ are optimal policy functions from this problem; (ii) Given prices, K^d and H^d solve the firm's problem in (2); (iii) μ is time invariant satisfying (4); (iv) the government budget balances,

$$p \int g^s(z,h,q) d\mu(z,h,q) = \tau Y;$$

and (v) markets clear: letting $x = (z,h,q)$

$$\begin{aligned} \int \left(q + g^{a'_y}(x) + \sum_{z'} Q(z,z') g^{a'_o}(x;z') \right) d\mu(x) &= K^d, \\ \int \left[(\psi_y + \psi_o)h + \Psi_c(x)(1 - g^s(x)) + \sum_{z'} Q(z,z') g^{h'}(x;z') \right] d\mu(x) &= H^d. \end{aligned}$$

4 Calibration

As discussed in Section 2, the aggregate implications of TFP differences across countries in our model hinges on the parameters determining the technology for human capital accumulation. In particular, the parameters determining the expenditure elasticity of human capital accumulation $(1-\eta)\xi$ and the share of goods in total expenditures in human capital. Our calibration strategy is to restrict the share of goods in total expenditures in education using estimates from Kendrick (1976) and the U.S. Department of Education (1996) and the elasticity parameters η and ξ using the cross-section heterogeneity of schooling and earnings in U.S. data.

We calibrate our benchmark economy to U.S. data. We assume that a period in our model is 16 years. Because we are interested in comparisons across countries, the level of technology in our benchmark economy is effectively a normalization and therefore we assume $A = A_k = 1$. The mapping between parameters and targets in the data is multidimensional and we thus solve for parameter values jointly. We divide our discussion of calibration into parameters that relate to preferences, demographics, and production of goods and parameters that relate to human capital accumulation. A summary of parameter values and data targets is provided in Table 2.

4.1 Parameters and Targets

Preferences, Demographics, and Production of Goods We set the relative-risk-aversion parameter σ to 2. There is not a direct empirical counterpart for this parameter in the empirical literature since our model period is 16 years and there is an infinite inter-temporal 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. (See Keane and Wolpin, 2001 and Restuccia and Urrutia, 2004 for discussions of these estimates.) The discount factor β is set to target an annual interest rate of 5 percent which is roughly the return on capital in the U.S. economy. (See Poterba, 1997.)[3] In our model, retired adults live until real age 85. The National Center for Health Statistics (2004) reports that in 1990

[3]Average return on non-financial corporate capital net of taxes in 1990-96.

the average life expectancy at birth in the U.S. was 76 years. Therefore, we calibrate the probability of survival for retired adults (ϕ) to 0.4 so that the life expectancy at birth in our model matches 76 years. The capital-share parameter is set to 0.33 consistent with the capital income share in the U.S. economy from the National Income and Products Accounts. The depreciation rate δ is selected to match an investment to output ratio of 20 percent as documented in the Economic Report of the President (2004). (We obtain a similar target if instead we take the average of the investment to output ratio in the PWT6.1 for the period 1990 to 1996, see Heston, et al., 2002)

Human Capital Technology The human capital technology is given by

$$h' = z' \left(s^{\eta} e^{1-\eta} \right)^{\xi},$$

where z' follows a Markov process, s denotes schooling time, and e educational expenditure. The time-share parameter η and returns-to-scale parameter ξ play an important role in determining the behavior of human capital in our benchmark economy. These parameters are also important for how changes in TFP (A) affect aggregate and distributional properties of human capital accumulation across countries. We assume that ability follows an $AR(1)$ process (in logs):

$$\log(z') = \rho_z \log(z) + \epsilon_z,$$

where $\epsilon_z \sim N(0, \sigma_z)$. In our computations, we approximate this stochastic process with a discrete first-order Markov chain that takes 7 possible values for ability z. We use the approximation procedure in Tauchen (1986) to compute transition probabilities. There are five additional parameters determining human capital accumulation in our benchmark economy: schooling cost $\bar{l}$, public education subsidy p, and life-cycle productivity parameters (ψ_c, ψ_y, ψ_o) affecting relative labor earnings of children, young adults, and old adults.

In summary, our calibration procedure needs to restrict 9 parameters: time share η, returns to scale ξ ,standard deviation and persistence of the ability shock, σ_z, and ρ_z, schooling cost $\bar{l}$, public education subsidy p, and life-cycle productivity parameters (ψ_c, ψ_y, ψ_o). We restrict these parameters so that the equilibrium of our model reproduces the following 9 targets from U.S. data:

1. Intergenerational correlation of log-earnings of 0.5 from Mulligan (1997). (See also excellent surveys of the empirical literature on the intergenerational correlation of earnings by Stokey, 1998 and Solon, 1999.)

2. Variance of log permanent earnings of 0.36. (See Mulligan 1997 and 1999.)

3. Average years of schooling of 12.9 from the U.S. Department of Education (2004) in 1990. (See also Barro and Lee, 1996).

4. The distribution of people across education categories in 1990 as follows: 24 percent of people with college degree or more from the Historical Tables of the U.S. Census Bureau (2004).

5. Public education expenditures as a fraction of GDP of 3.9 percent from the Statistical Abstract of the U.S. (1999). In computing this statistic in the data, we treat as public expenditures all state and federal expenditures. We exclude pubic local expenditures in

education because these expenditures are closely tied to property values and therefore the income of parents. (See Restuccia and Urrutia, 2004 for a discussion.)

6. The ratio of earnings for full-time, year-round workers of ages 35-54 to ages 25-34 of 1.40 in 2003 from the U.S. Census Bureau, Historical Income Tables.

7. The ratio of earnings for full-time, year-round workers of ages 55-64 to ages 25-34 of 1.57 in 2003 from the U.S. Census Bureau, Historical Income Tables.

8. Mincer returns to schooling of 10 percent. Heckman et al. (2005) report a Mincer-return of between 10 to 13 percent during the period 1980 to 1990. Psacharopolous (1994) estimates a Mincer-return of 10 percent for the U.S. for the period 1990-95. Because Psacharopolous also provides data on Mincer-returns for a large set of countries, we follow Bils and Klenow (2000) in using Psacharopoulos' estimate for the U.S. economy. In our model, we measure returns to schooling by regressing log-wages on schooling years:

$$\log(wh_i') = b_0 + b_1 (16 s_i) + u_i,$$

where b_1 gives the Mincer-return to schooling in our economy.

9. The share of labor inputs in the total cost of investment in education. Kendrick (1976) and the U.S. Department of Education (1996) estimate this share to be 90 percent for the U.S. economy.

Table 2: Parameters and Data Targets

Parameter		Value	Target	U.S.	B.E.
CRRA	σ	2	Empirical literature	–	–
Discount factor	$\beta^{1/16}$	0.94	Interest rate	5%	5%
Survival probability	ϕ	0.4	Life expectancy at birth	76	76
Capital share	α	0.33	Capital income share	0.33	0.33
Annual depreciation	δ	0.07	Investment to output	0.2	0.2
H.C. time share	η	0.66	Share of labor in total ed. cost	0.9	0.9
H.C. RTS	ξ	0.79	Mincer return to schooling	10%	10%
Schooling cost	$\bar{l}$	0.89	Average years of schooling	12.9	12.9
Tax rate on income	τ	0.039	Public Education (% of GDP)	3.9%	3.9%
Child's productivity	ψ_c	0.13	Fraction with college degree	24%	24%
Young-adult productivity	ψ_y	1.4	Relative earnings	1.4	1.4
Old-adult productivity	ψ_o	1.08	Relative earnings	1.57	1.57
Ability variance	σ_z	$(0.51)^2$	VAR(log-earnings)	0.36	0.36
Ability correlation	ρ_z	0.17	CORR(log-earnings)	0.5	0.5

4.2 Discussion

In our model, heterogeneity in earnings across people arises from uninsurable idiosyncratic ability shocks. The cross-sectional inequality in parental resources is then partially transmitted to the next generation through unequal investment in human and physical capital. The inequality in parental investment occurs for two reasons in our model: Heterogeneity in the schedules of expected marginal returns to education and borrowing constraints. The three parameters characterizing human capital accumulation (ξ, η, $\bar{l}$) affect the extent to which heterogeneity in parental resources transmits to earnings heterogeneity of the offspring generation.

Returns to Scale Differences in expected learning ability translate into differences in human capital accumulation and earnings. How these differences in ability expand to differences in human capital accumulation and earnings depend on the degree of returns to scale in human capital accumulation. Moreover, disparities in investment in human capital are amplified through credit constraints for human capital accumulation. A higher degree of returns to scale ξ increases marginal returns to education at all levels of investment. This causes optimal investment levels to rise for time and resources in human capital in unconstrained households. A higher degree of returns to scale increases the expenditure in education per unit of schooling time and the average percentage wage gain per unit of schooling time. Therefore, an average Mincer rate of return to schooling presents a convenient target for ξ. Moreover, poor households are more likely to be credit constrained for investment decisions in human capital than rich households, therefore, higher ξ increases the variance of investments in education and the variance in earnings. More importantly, it increases the variance of earnings due to endogenous investment in education (inequality of parental resources). This implies that higher ξ also increases the persistence of earnings inequality across generations.

Schooling Time Our model explicitly incorporates the schooling time decision because the best available cross-sectional data on investments in human capital is reported in terms of schooling years. Hence, our calibration of the human capital technology intends to draw on these observations. Similarly to the returns to scale parameter that controls how differences in expected learning ability affect overall investment decisions in human capital, the time share parameter η controls the proportion of the overall investment that is done with the time input as opposed to the resource input. Hence, a higher time share η in the human capital technology increases the variance of schooling-time investment. In our calibration, we restrict η to match the dispersion in schooling-time input observed in the data. Notice that the variance of earnings may not increase because the share of expenditures in education $(1 - \eta)$ falls. Instead, a higher η reduces the persistence of earnings inequality across generations caused by borrowing constraints because households are homogeneous in their time endowment. Restricting the parameters of the human capital technology (η and ξ) using cross-section heterogeneity is crucial for the results of our paper since the cross-country implications of TFP differences on aggregate and distributional statistics hinge on these parameters.

Cost of Education and Public Subsidy In addition to foregone earnings, schooling time has a resource cost: $\bar{l}$ units of market human capital services per unit of schooling. A portion of this cost is subsidized by the government at the rate p per unit of schooling time. An increase in the resource cost of education would result in lower schooling time for all agents, as a result, our calibration restricts p and $\bar{l}$ so that the equilibrium in the model reproduces both the fraction of expenditures provided by the government as well as the average level of schooling time in the U.S. economy. Notice that public education has important distributional consequences in our theory since it tends to equalize school investment across households. Because we use cross-section heterogeneity to restrict the human capital technology, it is important that we do not abstract from the distributive impact of public education in our benchmark economy.

5 Properties of Benchmark Economy

In this section we describe relevant statistics in the benchmark economy that were not used as targets in our calibration procedure. Our purpose in this section is to evaluate our model as a theory of within country heterogeneity. We show that our model is consistent with several dimensions of heterogeneity in the data.

Distribution of Schooling According to the U.S. Department of Education (2004) the proportion of people between 25 and 34 years of age (all sexes and races) in 1990 that had primary schooling (1 to 8th grade) was 4 percent, secondary schooling (9 to 12th grade) 50 percent, some college (1 to 3 years of college) 22 percent, and completed college or more 24 percent. Our model matches these statistics reasonably well as documented in Table 3. However, we note that schooling time is a continuous variable in our model, making its comparison with the data non-trivial.

Table 3: Distribution of Schooling

	Model	Data
Primary	0.08	0.04
Secondary	0.28	0.50
Some College	0.40	0.22
College	0.24	0.24

Schooling and Earnings The model matches well the joint distribution of earnings and schooling in the data. From the U.S. Department of Education (2004) relative earnings ratios for males in 1998, all relative to high school graduates, is 1.7 for people with college degree or more, 1.17 for people with some college (no college degree), and 0.62 for people with only primary education. The respective ratios for the model are reported in Table 4. Recall that the model was calibrated to match the average Mincer returns to education. In Panel B of Table 4 we also show that the model matches reasonably well the distribution of Mincer returns in the data.

Table 4: Earnings and Schooling − Model and Data

Panel A: Earnings by Schooling

	Model	Data
Primary	0.66	0.62
Secondary	1.00	1.00
Some College	1.41	1.17
College	1.78	1.70

Panel B: Mincer Returns (%)

	Model	Data
Primary	15.6	21.8
Secondary	9.3	11.5
College	10.3	9.6

Mincer returns data from Willis (1986).

Expenditures in Education The share of total expenditures in education over GDP increases with the returns to scale parameter in the human capital production function as discussed in our calibration section. Therefore, in light of that discussion, it is interesting to see what proportion of GDP is in the form of educational expenditures in our model compared with the data. In the Statistical Abstract of the U.S. (2005), educational expenditures amount to 7.2 percent of GDP in 1990, where 3.9 percentage points are non-government expenditures (i.e. excluding federal and state components). Haveman and Wolfe (1995) report that expenditures on children ages 0-18 are as large as 14.5 percent of GDP. This share includes not only public investment, but also private costs, such as food, housing, transportation and foregone parental earnings in child care. Parental costs are about 10 percentage points of this total. In our model, total education expenditures correspond to $(e + w\bar{l}s)$ aggregated over all people. In the benchmark economy total expenditures on education amount to 12 percent of GDP. This number lies in the range of numbers referred to above.

6 Quantitative Results

In this section we use our quantitative theory to assess the aggregate and distributional consequences of TFP differences across countries. We know that changes in TFP affect human capital accumulation since human capital investment requires goods as an input in our calibrated model economy (see the discussion in Section 2). The question we address in this section is *how important* this effect is. We find that TFP has a large effect on human capital accumulation and output even though goods represent only a small proportion of the total cost of human capital accumulation in our benchmark economy (less than 10%). Moreover, TFP has substantial effects on economic mobility and inequality within a country.

6.1 Aggregate Implications

We assume that countries are identical in terms of preferences and technologies except for their TFP level in the production of goods. Then, by construction of our experiment, all cross-country differences in output per worker in our model are generated by differences in TFP. Since TFP has an indirect effect on output per worker through factor accumulation, we investigate in this section by how much the impact of TFP on output per worker is amplified in our calibrated model economy by factor accumulation and what is the relative contribution of physical and human capital accumulation on this amplification effect. In Table 5 we compare summary aggregate statistics for economies that differ on their TFP (we consider economies with relative TFP levels of 1, 0.5, and 1/3).

Table 5: Aggregate Implications of TFP Differences in the Model

Relative TFP (A)	1.00	0.5	1/3
Goods Production:			
Output (Y)	7.70	1.50	0.37
Physical Capital (K)	1.34	0.21	0.06
Human Capital (H)	5.40	2.42	1.36
Rel. Y	1.00	0.15	0.05
Rel. H	1.00	0.34	0.25
K/Y	2.8	2.7	2.7
Average Years of Schooling	12.9	7.1	4.3
Returns to Schooling (%)	10.0	14.5	22.6
Public Ed. Expenditures (% of GDP)	3.9	3.9	3.9
Total Ed. Expenditures (% of GDP)	11.7	13.5	14.3

Amplification Effect We show a simple way of measuring the amplification effect of TFP in our calibrated model economy. To this end, note that changes in TFP induce a linear relationship (with slope equal to 1) between log output and log physical capital. This result is a consequence of the fact that in Bewley-type economies (dynastic economies with uninsurable idiosyncratic risk), the equilibrium interest rate is close to the rate of time preference (see for instance Aiyagari, 1994 and Fuster, 2000). As a result, in equilibrium the marginal product of capital is close to the rate of time preference plus the depreciation rate of capital, i.e., $\frac{\partial y}{\partial k} = \alpha \frac{y}{k} \approx \rho + \delta$. Using this relationship to solve for k as a function of output we obtain $k = c_k y$ for some constant c_k (or alternatively we can express this relationship in logs as $\log(k) = \log(c_k) + \log(y)$). Similarly, as indicated in Figure 1, there is a log-linear relationship between human capital and output as TFP varies across economies in our model, but the slope of this relationship is less than one. Using this observation, we write human capital as a function of output as $\log(h) = c_h + \gamma \log(y)$, which implies that $h = exp(c_h) y^{\gamma}$. Substituting the expressions derived for k and h (in terms of y) in the production function of goods and solving for y we obtain

$$y = c_y A^{\frac{1}{(1-\alpha)(1-\gamma)}}, \tag{5}$$

for some constant c_y. Then, the TFP elasticity of output per worker in our model is given by

$$\eta_{y,A} = \frac{1}{(1-\alpha)(1-\gamma)}.$$

In our benchmark economy, $\alpha = 0.33$ and $\gamma = 0.46$ (as indicated in Figure 1). As a result, we obtain that the TFP elasticity of output is equal to 2.77. It follows that if TFP differs by a factor of 2 between two economies, the model implies that their output per worker would differ by a factor of 6.8. Another way of expressing this result is to compute the TFP differences required in the model to generate a given difference in output per worker between two countries. Using equation (5) the ratio of output per worker between any arbitrary economies i and j is related to their relative TFP levels:

$$\frac{y_i}{y_j} = \left(\frac{A_i}{A_j}\right)^{\frac{1}{(1-\alpha)(1-\gamma)}} = \left(\frac{A_i}{A_j}\right)^{\eta_{y,A}}.$$

Using $\eta_{y,A} = 2.77$ from our previous calculations, it follows that an output ratio of 20 can be generated by a TFP ratio of 2.94. We thus conclude that our calibrated model implies a large amplification effect of TFP differences across countries. Moreover, we note that the amplification effect provided by human capital is $\frac{1}{1-\gamma(1-\alpha)} = 1.85$ and the one provided by physical capital is $\frac{1}{1-\alpha} = 1.49$. Human capital thus represents an important source of amplification.

Human Capital and Mincer Returns To the extent that schooling quality affects the intercept term in a Mincer regression (as discussed in Section 2), the use of estimated Mincer returns to measure human capital stocks across countries may underestimate the actual differences in human capital across countries. Since Mincer returns are frequently used to measure human capital in growth accounting exercises, it is interesting to assess the importance of this bias in our calibrated model economy. To this end, we use Mincer returns to measure human capital across model economies that differ on their TFP. We consider country-specific Mincer returns and we allow each year of schooling to have a different return, depending on whether the year of schooling corresponds to primary, secondary, or college education. We add across people using the population share in each schooling category to obtain an aggregate measure of human capital per worker. Our findings are reported on Table 6 and Figure 2. We conclude that Mincer returns underestimate human capital differences across countries by a large margin. While the economy with relative TFP level 1/3 has a human capital equal of 0.25 (relative to the benchmark economy), the Mincer measure would imply a human capital value of 0.5.

Table 6: Human Capital across Economies in the Model

TFP Ratio	1	0.5	1/3
(1) Human Capital Ratio:	1	0.45	0.25
(2) Mincer H.C. Ratio:	1	0.69	0.51
(3) Ratio (2) to (1):	1	1.5	2.0

Schooling Quality Our quantitative theory implies that schooling-quality is important for understanding differences in human capital and output per worker across countries. This result raises the question: Are the schooling-quality differences implied by our theory reasonable? While there are no reliable cross-country measures of schooling quality, the literature has used the empirical evidence on immigrant earnings as an indirect approach to measuring human capital differences across countries. Therefore, we compare our findings with those of Borjas (1987). Looking at immigrant wages in the U.S., Borjas estimates that, on average, the wage that a worker with a given amount of education earns in the United States is 0.12 percent higher when the income per person in the immigrant's country of origin is 1 percent higher.

Table 7 shows that the average earnings of a person in the benchmark economy is between 3.5 and 4 times the average earnings of a similar worker in the economy with relative TFP level 0.5 (depending on the schooling level of individuals) and it is more than 7 times the earnings of an equally educated worker in a country with relative TFP level 1/3. The earnings ratio is largest for people with primary education. The bulk of cross-country earnings differences can be attributed to differences in relative prices. If a person from the economy with relative TFP 0.5 were to migrate to the benchmark economy, the wage rate of this person would increase by a factor of 2.8. If the immigrant comes from an economy with relative TFP 1/3, his wage rate would increase by a factor of 5.2. Our model is thus consistent with the observed migration pressures from poor to rich countries. On average immigrants in the benchmark economy would not earn the same as natives. Native workers with primary and college education in the benchmark economy earn between 20 to 40 percent more than a potential immigrant with same level of schooling and born in the the economy with relative TFP 0.5. The information on Tables 7 can be used to obtain an estimate of the income elasticity of schooling quality across countries as follows:

$$\eta_{quality,y} = \frac{\log(\frac{H_1}{H_j})}{\log(\frac{Y_1}{Y_j})},$$

where H_1 and Y_1 stand for human capital and per capital income in the benchmark economy (relative TFP 1) and j represents a country with relative TFP j. When considering potential immigrants from economies with relative TFP 0.5 and 1/3, we obtain schooling-quality elasticities that are consistent with the estimates of Borjas (1987).

6.2 Discussion of Related Literature

We now discuss our findings relative to the results in the related literature. In particular, we compare our results with those of Bils and Klenow (2000) [hereafter BK] and Mankiw,

Table 7: Schooling Quality (relative to benchmark economy)

Schooling	Earnings Ratio	Quality Ratio	Elasticity
	Panel A: relative TFP 0.5		
Primary	4.0	1.4	0.18
Secondary	3.5	1.2	0.10
Some college	3.5	1.2	0.10
	Panel B: relative TFP 1/3		
Primary	10.6	2.0	0.23
Secondary	7.4	1.4	0.11
Some college	7.1	1.4	0.11

Romer and Weil (1992) [hereafter MRW]. BK argue that, by using a one-sector model with no distinction between the production of goods and human capital, MRW may have overstated the importance of human capital in accounting for cross-country income differences. Since, according to Kendrick's (1976) study, time inputs represent 90% of the total costs of human capital accumulation, BK consider a two-sector model in which the production of human capital only requires time inputs. Given that in fact education does require some goods (such as, computers, books, buildings, paper, pencils), the following question arises: Is it important to take goods inputs into account when evaluating the consequences of TFP differences across countries? Our findings could not be more striking. By calibrating our benchmark economy to the estimates in Kendrick (1976) and the U.S Department of Eduction (1996) and although this calibration implies that goods account for only 10% of the cost of human capital investment, we find that human capital still implies a large amplification effect of TFP differences across countries. In fact, the amplification effect in our benchmark model is larger than the one implied in MRW's economy.

MRW consider a one sector growth model with $Y = C + I_K + I_H = AK^{\alpha}H^{\beta}L^{1-\alpha-\beta}$, where $\alpha = 0.30$ and $\beta = 0.28$. Then, the ratio of output per worker across countries differing in TFP can be expressed as follows:

$$\frac{y_h}{y_l} = \frac{A_h}{A_l} \left(\frac{A_h}{A_l}\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\frac{A_h}{A_l}\right)^{\frac{\beta}{1-\alpha-\beta}} = \left(\frac{A_h}{A_l}\right)^{\frac{1}{1-\alpha-\beta}},$$

In MRW, factor differences in TFP are amplified by a factor of $\frac{1}{1-\alpha-\beta} = \frac{1}{1-0.30-0.28} = 2.38$. Thus, the amplifier effect in our benchmark economy is 16 percent larger than the one implied by MRW. This finding may seem paradoxical: While MRW advocate that factor accumulation can account for cross-country income differences, we find that TFP differences of a factor of 3 are needed for explaining the large variation of per capita income across countries. How can we reconcile these findings? The explanation is, as pointed by Klenow and Rodriguez-Clare (1997), that MRW overstate the true cross-country variation in human capital when doing their growth accounting exercise.

Given the stark contrast between our results and BK, we use our framework to compare the implications of modeling or not goods inputs.[4] To this end, we consider a special case of our framework in which the share of goods in the human capital technology is set to 0 ($\eta = 1$). We refer to this model as the "time-only" model. We calibrate the time-only economy to the targets used in our benchmark economy (with the exception that this economy by design will not match the target on the share of goods in human capital accumulation). We find that the calibrated time-only economy does as well as the benchmark economy in matching the

[4]There is a related discussion in the taxation literature where the tax effect on human capital accumulation hinges on whether or not goods enter in the production of human capital, see for instance Trostel (1993) and Davies and Whalley (1989).

calibration targets discussed in Table 2. The parameter values needed to match those targets are summarized in Table 8 where for convenience we also report the relevant parameter values in the benchmark economy.

Table 8: Parameter Values − Time-Only and Benchmark

Parameter		Time-Only	BE
H.C. time share	η	1	0.66
H.C. RTS	ξ	0.69	0.79
Child's productivity	ψ_c	0.18	0.13
Ability correlation	ρ_z	0.28	0.17

Parameter values not reported are the same as in the benchmark economy.

One lesson we draw from this calibration is that the time-only model does well in matching our distributive statistics. Hence, the time-only economy and the benchmark economy seem to be equally good as theories of the U.S. income distribution. However, there are a number of dimensions where the two models perform differently. First, the time-only economy is inconsistent with the evidence in Kendrick (1976) and implies no amplification of TFP differences through human capital accumulation. Second, while the two economies have a similar distribution of schooling across agents and average Mincer returns, the returns to education decrease faster with the level of schooling in the benchmark economy than in the time-only economy. As a result, the benchmark economy is closer to the cross-section evidence on returns to schooling across education groups in the U.S. data (see Table 9). Third, the time-only economy is *inconsistent* with the empirical findings of Borjas (1987) and Hendricks (2002) about the relative earnings of immigrants. Since in the time-only economy there are no cross-country differences in schooling quality, potential immigrants would earn the same amount as natives regardless or their country of origin, an implication that is at odds with the data. Fourth, changes in TFP in our benchmark model imply a negative schooling-income elasticity across economies and a negative relationship between average years of schooling and output per worker. Both of these implications are consistent with the cross-country data (see Figures 3 and 4). The time-only model, on the contrary, implies that average years of schooling and Mincer returns do not vary across countries. In the next section we show that the two models can also be distinguished in terms of the distributional implications of TFP differences.

Table 9: Mincer Returns (%)

	Model		Data
	BE	Time-Only	
Primary	15.6	12.7	21.8
Secondary	9.3	9.3	11.5
College	10.3	10.6	9.6

Mincer returns data from Willis (1986).

6.3 Distributional Implications

Our theory has also implications for how TFP affects cross-section inequality and intergenerational mobility within countries. We find that TFP has important distributional implications in our benchmark economy. However, TFP does not have a distributional impact when human capital accumulation only requires time inputs.

We simulate economies that differ from our benchmark economy on their level of TFP. We find that low TFP, relative to the benchmark economy, is associated with high inequality

Table 10: Distributional Implications of TFP Differences

	Relative TFP (A)			
	Benchmark		Time-Only	
	1	1/3	1	1/3
Intergenerational mobility (correlation in logs):				
Earnings	0.50	0.64	0.50	.50
Income	0.68	0.78	0.65	.65
Cross-section inequality (Gini coefficient):				
Earnings	0.32	0.36	0.32	.32
Income	0.45	0.48	0.45	.45

(in terms of earnings, income, and consumption) and with low intergenerational mobility of earnings. However, TFP does not have a distributional impact when human capital only requires time inputs (see Table 10. The explanation for this finding is simple. By reducing the value of time, a decrease in TFP reduces both the benefits and costs of human capital accumulation. Since these two effects cancel out when human capital requires only time inputs, TFP does not affect average years of schooling and the return to schooling. When human capital accumulation requires time inputs, a decrease in TFP makes the goods costs of human capital accumulation relatively more expensive and, hence, reduces the incentives to accumulate human capital. Since this effect is particularly important among poor households, inequality and its persistence across generations rise with a decrease in TFP. Although there is very little systematic data on inequality and mobility for a wide array of countries, we think that the implications of our benchmark model agree with the conventional view that poor countries tend to be more unequal and less mobile. (See for instance the survey by Solon, 2002.)

7 Sensitivity Analysis

TBW.

8 Conclusions

In this paper we developed a theory of human capital accumulation with heterogeneous agents to quantitatively assess the aggregate and distributional effects of TFP differences across countries. We show that the aggregate impact of TFP differences across countries hinges on the parameters of the human capital technology and the proportion of goods in the cost of human capital accumulation. We found that TFP has a large effect on human capital accumulation and output even though goods represent only a small proportion of the total cost of human capital accumulation in our benchmark economy (less than 10 percent). In particular, in our benchmark calibration, a factor difference in TFP of 3 translates into a factor difference in output per worker of 20. The same factor difference in TFP would translate into a factor difference in output per worker of 5 if the model abstracts from goods in human capital accumulation. Hence, human capital provides a large amplification mechanism of TFP differences across countries. Moreover, we showed that TFP has substantial effects on economic mobility and cross-section inequality within a country.

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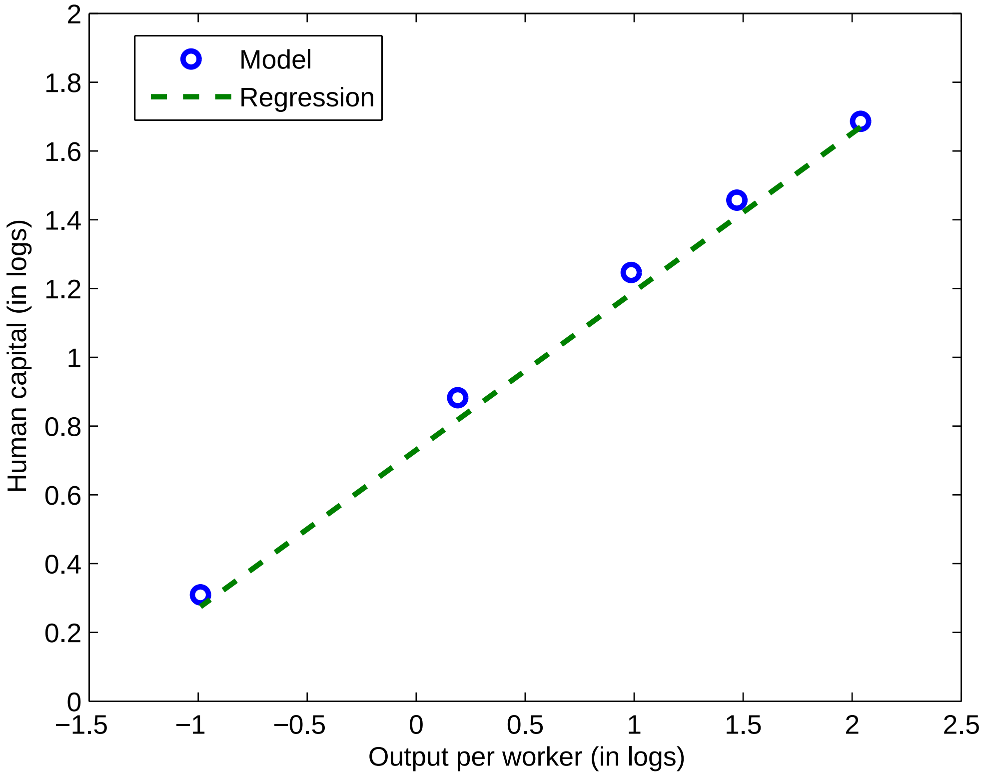
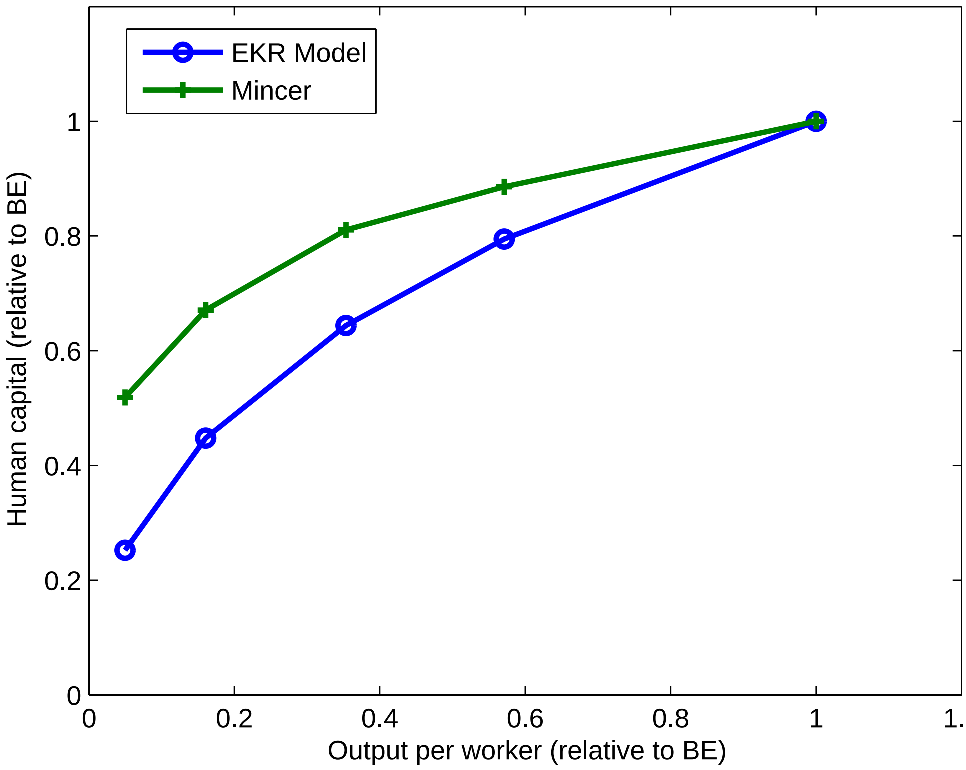
Figure 1: Human Capital and Output



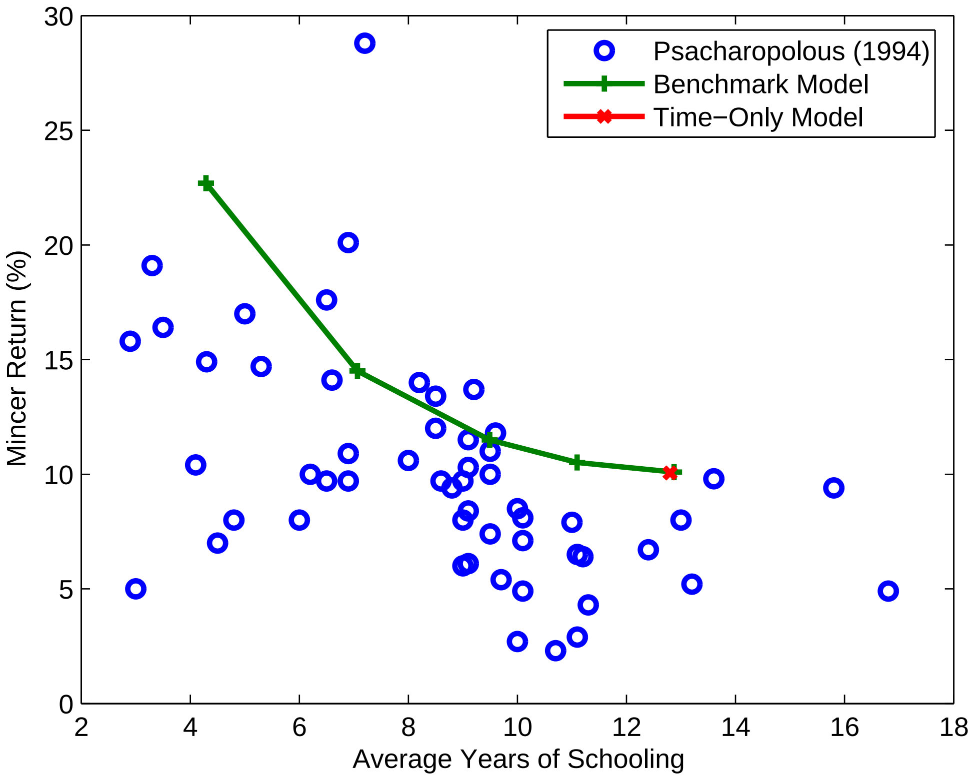
Model refers to relative TFP economies 1.0, 0.8, 0.67, 0.5, and 0.33 in our benchmark calibration. Regression refers to an OLS regression of log human capital on log output with a constant term resulting in: $\log(H) = 0.7307 + 0.4605 \log(Y)$.

Figure 2: Human Capital Differences − Model vs. Mincer



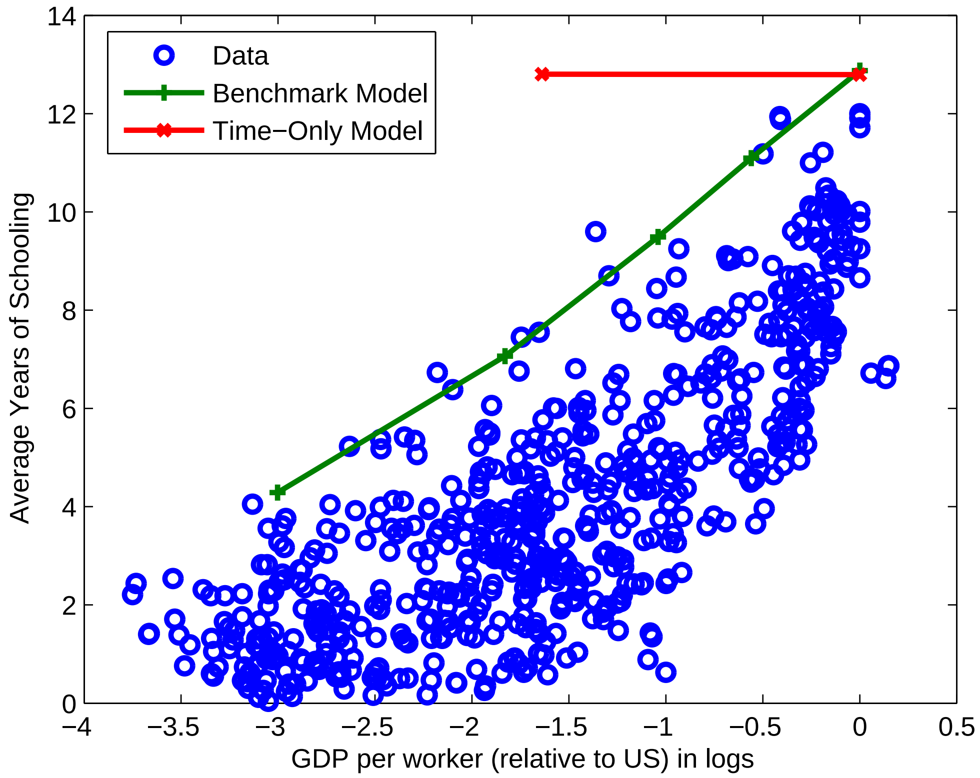
EKR Model refers to relative TFP economies 1.0, 0.8, 0.67, 0.5, and 0.33 in our benchmark calibration. Mincer refers to an average human capital calculated using economy-specific mincer returns to schooling for primary, secondary and post-secondary education in our model.

Figure 3: Mincer Returns to Schooling – Data vs. Model



Benchmark model refers to relative TFP economies 1.0, 0.8, 0.67, 0.5, and 0.33 in our benchmark calibration. Time-only model refers to relative TFP economies 1.0 and 0.33 when human capital accumulation features only time inputs, i.e., $\eta = 1$.

Figure 4: Schooling and Output – Data vs. Model



Data are from Barro and Lee (1996) and PWTV6.1. We take averages (five-year intervals) of GDP per worker in the PWT data. Data span 1960 to 1995. Benchmark model refers to relative TFP economies 1.0, 0.8, 0.67, 0.5, and 0.33 in our benchmark calibration. Time-only model refers to relative TFP economies 1.0 and 0.33 when human capital accumulation features only time inputs, i.e., $\eta = 1$.