The Rate of Technological Progress, Effective Human Capital and the Dynamics of Income Inequality: An Empirical Analysis

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*** PRELIMINARY and INCOMPLETE DRAFT - COMMENTS WELCOME ***

Abstract

Trade liberalization has been widespread throughout developing countries, which has contributed to an increase in the rate of new technologies entering these countries. This paper analyzes how the change in the rate of technological progress affects 1) the effective human capital; 2) the degree of within-country inequality; and 3) the degree of across-country inequality, as measured by the relative wage of the developing country to the U.S. I show, theoretically and empirically, that the growth of within country inequality is lessened when the quality of education is high. Also, the relationship between the effective human capital and the rate of technological progress is positive only if the quality of education is sufficiently high. And finally, developing countries with high educational quality experience a relatively greater convergence to developed countries. These results are broadly consistent with the experience of Latin America and East Asia since 1980.

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1 Introduction

The dynamics of income inequality, both within- and across-developing countries, and more importantly its determinants, are not well understood in the literature. This research links changes in the effective human capital\(^1\) and the dynamics of inequality to changes in the rate of technological progress. Specifically, I consider the quality of education embedded within the effective human capital. I theoretically and empirically show: 1) the effective human capital is either a positive or negative function of the rate of technological change depending on the quality of education; 2) there is a larger percentage growth in within country income inequality during periods of faster technological change when the quality of primary education is low; and 3) a higher quality of education increases the ability for developing countries to “catch up” to the standard of living of advanced economies. Taken together these findings generate policy implications: investment in education should precede entering periods of faster rates of technological change, such as trade liberalization, or within-country inequality can surge, the gains from trade would be decreased, and the effective human capital of the economy may decline.

The growth and inequality literature has been an important topic in economics since the seminal work of Kuznets (1955). However, mixed empirical results have led to difficulty in establishing a consensus on the relationship. For instance, Alesina and Rodrik (1994), Perotti (1996), and others find greater inequality reduces the growth rate. This claim is theoretically backed by a number of arguments, such as political economy turmoil, or harmful effects to education (Galor and Zeira 1993), among others. This claim, however, is challenged by Forbes (2000) and Barro (2000).

On-the-other-hand, a growing literature documents that technological progress is skill-biased (see Galor and Moav 2000 for example). This research suggests a casual link from growth to inequality. This implies an increase in the rate of technological progress increases the returns to education and, therefore, explain changes in income inequality (for evidence, see Chusseau et al. 2008).

The empirical ambiguity of the relationship between technological progress and income distribution is not hard to understand, given both are endogenous within any economic system. This endogeneity implies their comovements are likely to be dependent on the underlying economic structures and policy changes (Lundberg and Squire 2003, Garcia-Penalosa and Turnovsky 2005). Therefore, growth and income inequality should be jointly determined. I follow Galor and Zeira (1993), Benabou (1996), and Viaene and

\(^1\)In this paper, I consider human capital to be composed of skilled and unskilled efficiency units of labor.
Zilcha (2003) who emphasize the role of human capital accumulation and educational fundamentals as the important elements within the growth-inequality relationship.

Along this line of research, I allow the rate of technological progress to, in part, determine the relative productivity of workers of different skill levels, and thus determine income inequality endogenously. The underlying argument is that in periods of rapid technological change (or high growth periods) skilled workers are relatively better able to adapt to the changing technical environment. Bartel and Sicherman (1999) empirically find the education premium is associated with technological change. Unskilled workers, however, are less able to adapt (Bartel and Sicherman 1998). Given this argument, the quality of received education becomes paramount. Higher quality of primary education (received by unskilled workers) increase their ability to cope with new technologies, and therefore, reduce income inequality through higher wages of unskilled workers (the negative relationship between inequality and education is documented in De Gregorio and Lee 2002). Furthermore, I show a lower quality of education is associated with a greater percentage increase in income inequality, and less of a “catch-up” to the developed world during periods of increased technological change. Countries with high quality of education, particularly on the primary level, have less of a rise in within country income inequality, and a greater catch-up to the developed world.

A potential source of the change in the rate of technological progress is policy changes that allowed for an increase in trade openness, which has been widespread throughout developing regions. This story of inequality is consistent with the differences experienced between Latin America and East Asia. East Asia, with a high quality of education at the time of trade liberalization experienced a decline in within country inequality and a period of convergence to the U.S. in terms of GDP per capita. Latin America, on-the-other-hand, had a lower quality of education, and consequently, saw a sharp rise in within country inequality, and virtually no catch up to the developed world. This reinforces the need for investment in education prior to increasing exposure to new technologies. See the Appendix for details.

This paper empirically investigates the role of growth and technological progress in determining: 1) Effective Human Capital, which encompasses the productivity adjusted endogenous supply of skilled and unskilled workers; 2) Within Country Income Inequality; and 3) Across Country Income Inequality. Due to the clear endogeneity of

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2Labor economists recently have examined the linkages between education quality, i.e. pupil/teacher ratio, test scores, investment per student, etc, and the return to education. Hanushek (1996) document that of 277 estimates on the impact of the teacher-pupil, 15 showed a positive and significant relationship, while 13 showed a negative link. Using other measures of education quality showed similar mixed results. However, Hanushek (1995) found education quality matters more for developing countries.
technological progress, I use the country’s geographic proximity to international skills as a proxy for changes in the rate of technological progress. The intuition is straightforward: A high proximity to skills suggests trade liberalization has led to a more pronounced change in new technologies entering through trade. I, therefore, isolate the technological component of trade, or, the skilled factor content of trade. Isolating the factor content of trade, however, is often times problematic (See Feenstra and Hanson 2000, Davis and Weinstein 2000, 2001a, 2001b for examples). I follow a strategy similar to Auer (2006) and Frankel and Romer (1999) by using geographical proximity to skills as measured by the average years of education from Barro and Lee (2000) to serve as a proxy for the actual technological factor content of trade. This gravity model of bilateral trade serves as a first stage to proxy for the changes in the rate of technological progress, before linking (in the second stage) to human capital and the two types of inequality.

The first question addressed in the second stage is the interaction of effective human capital and changes in the rate of technological progress. More importantly, this interaction depends on the quality of education, both on the primary and secondary level. Is the change in effective human capital following an increase in the rate of technological progress positively linked to the quality of education? Furthermore, can the effective human capital actually decline if the quality of education is sufficiently low? I show that a sufficiently high quality of education ensures an increase in the rate of technological progress increases the effective human capital.

The second question addressed in this paper concerns the dynamics of within country income inequality. Do countries with low quality of education experience a greater percentage increase in income inequality relative to other countries with a higher quality of education? Does this rely more on the quality of primary or secondary education? I show that a high quality of primary education allows all workers, including those without skills, to adapt more quickly to a faster rate of technological change. It is this mechanism in which developing countries with a relatively high quality of primary education are able to open up to new technologies throughout trade, without the high growth of income inequality.

The quality of education is also an important determinant for the degree of “catch up” of developing countries following trade liberalization. The dynamic interaction between human capital and the rate of technological progress, as addressed in the first question of this paper, also determines the steady-state gains from trade liberalization. Consider two developing countries 1 and 2, in which country 1 has a higher quality of education. If both countries open to trade, both will experience an initial increase in their country specific rate of innovation (or imitation) through greater exposure to new
technologies. For the case of country 1 with a high quality of education, this jump will increase the effective human capital, which further increases the rate of innovation. A positive feedback loop emerges. In the case of country 2, the effective human capital is adversely affected by the rise in rate of innovation, and the lower level of human capital serves to decrease the rate of innovation in the transition. Thus, the gain from trade in terms of technological progress is greater when the quality of education is high. Considering across country inequality to be the average income of the developing country relative to the developed world, the relative income of a developing country with high educational quality will increase following trade liberalization more than a country with lower quality of education.

The conclusions of the paper are not interpreted such that positive gains from trade are dependent on a sufficiently high quality of education. In fact, I suspect the positive gain in the growth rate of new technologies entering the production process following opening to trade will dominate any welfare analysis regardless of educational quality. However, the three questions (and results) suggest a low quality of education at the time of trade liberalization can have harmful effects. Specifically, the effective human capital may decline, income inequality will increase, and less of a gain relative to the developed world. What emerges is the policy implication that investment in education to improve its quality enhances the gain from trade liberalization or increased R&D productivity.

The remainder of the paper is structured as follows: Section 2 provides theoretical motivation for the research questions; Section 3 is the empirical methodology and results; and Section 4 concludes.

2 Theoretical Motivation

To motivate the paper theoretically, I simplify the model in Hall (2008). Hall (2008) captures the transitional dynamics of income inequality in a context of North-South trade and endogenous innovation and imitation. The results show the interaction of human capital and the rate of innovation is crucial to the dynamics of income inequality. Specifically, following trade liberalization, there is a transitional fall in income inequality within developing countries with sufficiently high quality of education, whereas an increase in inequality in the other developing countries.

I simply this model in significant ways. Here, I model only a developing country that invests in research and development (R&D) in order to imitate a latent growing global technological frontier. Trade in intermediate goods is implicit in this model. Hall (2008), in a North-South context, explicitly allows for trade between the countries. Here, the
structure is as follows: the domestic market is supplied by either a monopolistic domestic firm whom successfully imitated a state-of-the-art technology, or import intermediate goods in those industries in which there was not successful imitation by a domestic firm. In either case, all intermediate goods used in final goods production is from the technological frontier.

On the technological frontier, I assume that, with an instantaneous probability $p_I$, an innovation increases the quality of an intermediate good by a exogenous amount $q > 1$ from $q^{k_j}$ to $q^{k_j+1}$. $k = 1, 2, ... j$ is therefore defined as the “quality rung” for industry $j$. Furthermore, I assume $p_I$ is a negative function of trade barriers $\tau$. Hall (2008) shows in a general equilibrium model that Southern trade liberalization, trade liberalization increases the demand for and the profitability of innovative firms. Thus, trade liberalization increases the incentives to innovation which increases $p_I$, or $p_I \equiv p_I(\tau)$ where $\frac{\partial p_I}{\partial \tau} < 0$.

I define $Q_N$ to be the technological frontier for intermediate goods $j \in [0, 1]$, where $Q_N = \int_0^1 q^{k_j/(1-\alpha)}dj$. The technological frontier grows at a rate which is a positive function of the probability of innovation:

$$\Delta Q_N = \int_0^1 \left( q^{(k_j+1)/(1-\alpha)} - q^{k_j/(1-\alpha)} \right) p_I(\tau) \, dj$$

or

$$\frac{\dot{Q}_N}{Q_N} = (q^{\alpha/(1-\alpha)} - 1) p_I(\tau) \equiv \gamma(p_I)$$

which grows at a constant (exogenous) rate $\gamma$ which is a positive function of the probability of innovation, or $\gamma \equiv \gamma(p_I)$, and thus a negative function of $\tau$.

The developing country, on-the-other-hand, conducts R&D to imitate the frontier technology in a given industry. The probability of imitation $p_C$ is endogenous, and will be shown to be equal to the probability of innovation in steady-state. Finally, I define $Q_S$ to be the aggregate level of technology in the developing country, where $Q_S < Q_N$ as long as $p_C < 1$.

I use this framework to consider the effects of trade liberalization on income inequality, where there is an ambiguous relationship between effective human capital ($H$) and the rate of new technologies entering the production process. In steady state equilibrium $H \equiv H(p_I)$, where $H'(p_I)$ can be positive or negative based on the quality of education.

### 2.1 The Model

The aggregate production function is defined as
\[ Y = AF \left( H, \bar{X} \right), \text{ where } \bar{X} \equiv \int_{0}^{1} q^{k_{j}} x_{j} \, dj \] (1)

where \( Y \) is aggregate final goods output, \( A \) is the total factor productivity, \( H \) is the effective human capital, and \( \bar{X} \) is the aggregate quality adjusted amount of intermediate good input. \( q > 1 \) is the size of quality improvements in quality in each period, and \( k \) represents the current “rung” of quality for industry \( j \). Using a Cobbs-Douglas functional form,

\[ Y = AH^{1-\alpha} \int_{0}^{1} \left( q^{k_{j}} x_{j} \right)^{\alpha} \, dj. \] (2)

The effective human capital \( H \) is assumed to be a function of the quality of education, and the lagged probability of imitation. Embedded within \( H \) is a continuum of workers \( i \) (with a mass of unity) differentiated by innate ability, \( a_{i} \in (0, 1) \), who, at each point in time, make the decision of whether to invest in education. Considering the cost of education to be decreasing in ability, I show that there is an individual with ability \( a^{*} \) such that they are indifferent to acquiring education and working as a skilled worker, or remaining unskilled. As such, all individuals with ability \( 1 > a_{i} > a^{*} \) become skilled, and the remaining workers choose to be unskilled. I leave \( H \) in its general form, thus

\[ H \equiv H \left( \beta, p_{I} \right), \text{ where } H_{\beta} > 0 \text{ and } H_{p_{I}} \in (-, +) \] (3)

where \( \beta = \left( \beta^{h}, \beta^{l} \right) \) is a vector of educational quality parameters, where \( \beta^{h} \) is the quality of secondary education attained by skilled workers, and \( \beta^{l} \) is the quality of primary education. Again, \( p_{I} \) is the exogenous rate of innovation and is a negative function of trade barriers. To motivate the ambiguous partial derivative \( \partial H/\partial p_{I} \), consider two competing, embedded effects: the productivity effect, and the erosion effect. The first suggests the return of education is directly increasing in the rate of imitation. Faster rates of innovation are biased towards those with the education to adapt to the new technologies, relative to unskilled (uneducated) workers. This effect is increasing in the quality of secondary, or tertiary, education. The erosion effect is modeled to capture the loss of production from unskilled workers due to the need to learn new technologies. Thus, faster rates of innovation increase the time needed for unskilled workers to adapt to the changing technological frontier, and furthermore, decrease the workers allocation of time towards production. This effect is decreasing in the quality of primary education. Given these two effects, a rise in the rate of innovation can either increase or decrease the effective human capital, depending on the quality of education.

Intermediate firms face the following domestic demand curve, derived from the first order condition of the production function, where the domestic demand for intermediate
good j is
\[ x_j = H \left( \alpha A \frac{1}{p_j} \right)^{1/(1-\alpha)} q^{k_j \alpha/(1-\alpha)} \]  
(4)
where \( p_j \) is the price of good j.

As in Hall (2008), I assume the successful imitators charge a limit price such that it serve the entire domestic market. For simplicity, I assume the marginal cost for innovating firms is the numeraire, and the marginal cost of imitating firms is \( MC_S < 1 \). Given these general restrictions, the limit price for domestic imitators is \( p_j = 1 + \tau \), and profits are given by
\[ \pi_j = H (1 + \tau - MC_S) \left( \alpha A \frac{1}{1+\tau} \right)^{1/\alpha} q^{k_j \alpha/(1-\alpha)} \]
\[ \pi_j = H (p_I) \bar{\pi} (\tau) q^{k_j \alpha/(1-\alpha)} \]  
(5)
where \( \bar{\pi} \) is the same across industries and time. From equation 5,
\[ \frac{\partial \pi_j}{\partial H} > 0 \]
\[ \frac{\partial \bar{\pi}}{\partial \tau} = 1 - \frac{1+\tau-MC_S}{(1+\tau)(1-\alpha)} \in (-, +) \]

The expected value of an imitation is the flow of profits discounted by the real interest rate, \( r \), and the probability of losing the monopoly standing. Monopoly rents can be lost given a further innovation within the industry \( j \). This, of course, happens with the constant probability \( p_I \). Innovation shifts the production of intermediate good \( j \) away from a domestic firm, and the state-of-the-art technology is acquired through imports.

The expectation of the present value of profits for any industry is given by
\[ E \left[ V_{k_j} \right] = \pi_j / (r + p_I) = \bar{\pi} (\tau) H (\beta, p_I) q^{k_j \alpha/(1-\alpha)} / (r + p_I) \]  
(6)
where \( r + p_I \) is the appropriate discount factor.

To determine the R&D effort, I first consider the determinants of the rate of imitation. First, the rate of imitation depends positively on the total R&D expenditure. Let \( Z_j \) be the aggregate flow of resources expended by potential imitators in industry \( j \). Second, \( p_C \) depends positively on a constant productivity parameter \( \phi \); third, I assume \( p_C \) is decreasing in the global technological frontier, or imitating gets increasing difficult given the complexity of new innovations; and finally, \( p_C \) becomes more difficult as the average technology in the domestic market approaches the technological frontier. Let \( \hat{Q} \equiv \frac{Q^S}{Q_N} \) be the relative average quality in the developing country. Given these considerations,
the probability of research success is
\[ p_C = \phi \hat{Q}^{1-\sigma} q^{-(k_j+1)\alpha/(1-\alpha)} Z \] (7)

where \( \sigma > 1 \) is a parameter that affects how quickly the cost of imitation rises as the technology gap falls.

R&D will therefore be conducted so long as the expected return to successful imitation is at least as large as the cost, \( Z \). Assuming free entry, it must be the case that
\[ p_C E \left[ V_{k_j+1} \right] - Z = 0 \] (8)

Using appropriate substitutions, I reduce the free entry condition to be a function of two endogenous variables, \( r \) and \( \hat{Q} \),
\[ r = \phi \hat{Q}^{1-\sigma} \pi (\tau) H (\beta, p_I) - p_I (\tau) \] (9)

To close the model, each household wishes to maximize overall utility, \( U \), as given by
\[ U = \int_0^\infty u (C) e^{-\rho t} dt \] (10)

where \( \rho \) is the rate of time preference. Assuming a constant intertemporal elasticity of substitution (\( \sigma = 1/\theta \)) functional form \( u (C) = C^{1-\sigma - 1} \), the optimal growth rate of consumption is
\[ \frac{\dot{C}}{C} = \frac{1}{\theta} (r - \rho) \] (11)

The solution to the model is given by the condition that the growth rate in the developing country is equal to the growth rate of technology on the global frontier. The aggregate resource constraint is \( Y = C + Z + X \), where each variable in increasing in a linear fashion with respect to \( Q_N \). To solve, each variable must grow at a rate equal to the exogenous growth rate of the global frontier, or \( \dot{Y} = \frac{\dot{C}}{C} = \frac{\dot{Z}}{Z} = \frac{\dot{X}}{X} = \frac{\dot{Q}_S}{Q_S} = \gamma \). The condition for endogenous steady-state growth is
\[ \frac{1}{\theta} (r - \rho) = \left( q^{\alpha/(1-\alpha)} - 1 \right) p_I \] (12)

Equation 12 pins down the steady state interest rate. This solution for \( r \) is then inserted into the free entry condition, equation 9 which pins down the relative average quality of the developing country. Finally, to close the model it must hold in steady state that \( \hat{Q} \) is constant. Thus, using the definition of \( \hat{Q} = Q_S/Q_N \), the relative average quality of
the South evolves according to
\[
\frac{\dot{Q}}{Q} = \left( q^{1-\alpha} - 1 \right) (p_C - p_I).
\]

or, in steady state, the probability of imitation is exactly equal to the probability of innovation. The model is solved by,
\[
p_C = p_I (\tau)
\]
\[
r = \theta \left( q^{\alpha/(1-\alpha)} - 1 \right) p_I (\tau) + \rho
\]
\[
\dot{Q} = \left[ \frac{\phi(n)H(p_I, \beta)}{\theta(q^{\alpha/(1-\alpha)} - 1) p_I (\tau) + \rho + p_I (\tau)} \right]^{\frac{1}{\sigma-1}}
\]
\[
\frac{Y}{Q_N} = \frac{1}{2} A^{1-\alpha} \left( \frac{\alpha}{1+\tau} \right)^{\frac{1}{\sigma}} H(p_I, \beta)
\]
\[
\frac{X}{Q_N} = \frac{1}{2} \left( \frac{\alpha A}{1+\tau} \right)^{\frac{1}{\sigma}} H(p_I, \beta)
\]
\[
\frac{Z}{Q_N} = \frac{p_I (\tau)}{\theta} \hat{Q}^{\sigma-1}
\]
\[
\frac{C}{Q_N} = \frac{Y}{Q_N} - \frac{X}{Q_N} - \frac{Z}{Q_N}
\]

Furthermore, I show in the next section how the probability of innovation also characterizes the relative wages of skilled workers (income inequality), where \( \Omega = \Omega (\beta, p_I) \).

### 2.2 Theoretical Implications

I focus on three crucial results/assumptions within the model following a reduction of trade barriers \( \tau \) from \( \tau_{High} \) to \( \tau_{Low} \): 1) the degree of “catch up” as determined by changes in \( \dot{Q} \); 2) changes to the effective human capital; and 3) changes in within-country income inequality.

Beginning with the degree of catch-up of the developing country, I turn to the steady state result for \( \dot{Q} \):
\[
\dot{Q} = \left[ \frac{\phi(n)H(p_I, \beta)}{\theta(q^{\alpha/(1-\alpha)} - 1) p_I (\tau) + \rho + p_I (\tau)} \right]^{\frac{1}{\sigma-1}}
\]

Trade liberalization reduces \( \tau \) and \( \dot{Q} \) responds in the following manner: the denominator in equation 14 increases with a reduction in \( \tau \), which serves to reduce \( \dot{Q} \) and implies the developing country falls further behind in terms of aggregate quality of intermediate goods. Furthermore, it is likely (though not unambiguous) that the flow of the profits
in the domestic market will fall during trade liberalization, again putting downward pressure on \( \hat{Q} \).

The final effect comes from the sign of \( \partial H/\partial p_I \). For developing countries, with a sufficiently high quality of education \( \beta \), the effective human capital will increase with an increase in \( p_I \). This puts upward pressure on \( \hat{Q} \), which if sufficiently strong, leads to an overall increase in \( \hat{Q} \), or, the developing countries catches up to the developed world in terms of technological ability. On-the-other-hand, a lower quality of education such that \( \partial H/\partial p_I \) is negative, trade liberalization unambiguously reduces \( \hat{Q} \) and the developing country will lose ground to the technological frontier.

The testable implication is whether developing countries with high quality of education will benefit more than other developing countries following trade liberalization in terms of catching up to technological ability. This test investigates the empirical validity of the cross partial \( \frac{\partial^2 \hat{Q}}{\partial \beta \partial \tau} > 0 \). The sign of \( \hat{Q}/\partial \tau \) depends crucially on \( \beta \).

The dynamics of income inequality within countries also depend on the quality of education. To see this, consider a function form for the effective human capital that is a weighted some of efficiency units of skilled \( (h) \) and unskilled \( (l) \) workers. Let the return to education be

\[
R \left( \beta^h, p_I \right) \quad \text{where} \quad \frac{\partial R}{\partial \beta^h} > 0, \quad \frac{\partial R}{\partial p_I} > 0, \quad \text{and} \quad \frac{\partial^2 R}{\partial p_I \partial \beta^h} > 0,
\]

where \( \beta^h \) is the quality of secondary, or tertiary, education. The return to education is increasing in the rate of imitation, and the quality of skilled education. Let \( E \left( \beta^l, p_I \right) \) represent the productivity of unskilled workers. Unskilled workers must adapt to the change in technologies in production, and thus become less productive when the rate of imitation is high. Also, let \( \beta^l \) be the quality of primary education, received by all unskilled workers, where

\[
E \left( \beta^l, p_I \right) \quad \text{where} \quad \frac{\partial E}{\partial \beta^l} > 0, \quad \frac{\partial E}{\partial p_I} < 0, \quad \text{and} \quad \frac{\partial^2 E}{\partial p_I \partial \beta^l} > 0.
\]

where \( R > E \).

The effective human capital is given by

\[
H \left( \beta, p_I \right) = R \left( \beta^h, p_I \right) h + E \left( \beta^l, p_I \right) l
\] (15)

where \( h \) is the aggregate efficiency units of skilled labor, and \( l \) is the aggregate efficiency units of unskilled labor. Each worker is endowed one unit of labor in each point in time. To become skilled (educated) the worker \( i \) pays a cost in terms of labor endowment \( 1 - a_i \).
which is decreasing in ability. The individual indifferent between attaining an education or remain unskilled is solved by

$$a^* (\beta, p_I) = \frac{E \left( \beta^l, p_I \right)}{R \left( \beta^h, p_I \right)}$$

where $$\frac{\partial a^*}{\partial p_I} < 0$$ and $$\frac{\partial^2 a^*}{\partial \beta^l \partial p_I} > 0.$$  \(16\)

Equation 16 says faster rates of imitation endogenously induces more individuals to choose to become skilled. Given the endowment cost of education $$(1 - a_i)$$, $$a_i$$ is the skilled efficiency for individual $$i$$, while 1 is the unskilled labor endowment for every individual not choosing to attain an education. As such

$$h = \int_{a_i^*}^1 a_i da_i = \frac{1}{2} \left[ 1 - (a^*)^2 \right] \equiv h (\beta, p_I)$$

$$l = \int_0^{a^*} 1 da_i = a^* \equiv l (\beta, p_I)$$  \(17\)

and updating equation 15 yields

$$H (\beta, p_I) = R \left( \beta^h, p_I \right) h (\beta, p_I) + E \left( \beta^l, p_I \right) l (\beta, p_I).$$ \(18\)

The change in the effective human capital with respect to a change in the probability of innovation is given by

$$\frac{\partial H}{\partial p_I} = R_{p_I} \left( \beta^h, p_I \right) h (\beta, p_I) + E_{p_I} \left( \beta^l, p_I \right) l (\beta, p_I)$$

where

$$\frac{\partial h}{\partial \beta^l} > 0$$

$$\frac{\partial l}{\partial \beta^l} > 0.$$ \(19\)

which can be positive or negative.

Within country inequality is given by dividing the average income of skilled workers by the average income of skilled workers. Inequality within countries is given by

$$\Omega (\beta, p_I) = \frac{1}{2} \frac{R \left( \beta^h, p_I \right)}{E \left( \beta^l, p_I \right)} \left( 1 + a^* (\beta, p_I) \right) = \frac{1}{2} \left( 1 + \frac{R \left( \beta^h, p_I \right)}{E \left( \beta^l, p_I \right)} \right) > 1$$ \(20\)

What is of interest is the change in inequality with respect to the probability of innovation, but also, how this effect is interacted with the quality of education. In steady state,

$$\frac{\partial \Omega}{\partial p_I} = -\frac{1}{2 (a^*)^2} \frac{\partial a^*}{\partial p_I} > 0.$$ \(21\)
Equation 21 states that a steady state increase in the probability of innovation will increase the steady state level of inequality. The magnitude of such effect, however, is determined by the quality of education. Specifically,

$$\frac{\partial^2 \Omega}{\partial p_I \partial \beta} = -\frac{1}{2a^*} \left( \frac{E_{p_I}^d E - 2E_I E_{\beta I}}{E^2} \right) < 0$$

(22)

which states that the for a given increase in $p_I$, the increase in income inequality will be greater for those countries with a low quality of education.

The testable hypotheses come from: 1) equation 19: does the change in effective human capital during periods of faster technological change depend on the quality of education; 2) equations 21 and 22: is the percentage rise in income inequality decrease with the quality of education; and 3) there a greater gain from trade relative to the developed world, when the quality of education is high. This questions, taken together, highlight the importance, from a policy perspective, of increasing investment into primary education before engaging in trade liberalization, or other increased exposure to new technologies.

3 Empirical Methodology

This simple model motivates several important empirical considerations. To test the validity of the model and its predictions for the interaction of technological change and the effective and both within- and across-country inequality, I focus on three empirically testable relationships:

1. Interaction between the effective human capital and the change in the rate of technological change. Specifically, is there an ambiguous relationship, in which the sign depends on the quality of education? Does the effective human capital increase from trade liberalization and an increase in technological change when the quality of education, both primary and/or secondary, is high? Does the opposite hold true when the quality of education is low? This question tests the validity of

$$\frac{\partial H}{\partial p_I} = R'_{p_I} \left( \beta^h, p_I \right) h \left( \beta, p_I \right) + E_{p_I}^d \left( \beta^h, p_I \right) l \left( \beta, p_I \right) \in (+, -)$$

where

$$\frac{\partial^2 H}{\partial p_I \partial \beta h} > 0$$

$$\frac{\partial^2 H}{\partial p_I \partial \beta l} > 0.$$
2. Interaction between within-country income inequality and the change in the rate of technological change. Does inequality increase more with the quality of primary education is low? What about when the quality of secondary, or tertiary, education is high? Does this explain the dynamics of income inequality and its differences among Latin America, Africa and East Asia? Specifically, this question tests

\[
\frac{\partial \Omega}{\partial p_I} = -\frac{1}{2 (a^* (\beta, p_I))^2} \frac{\partial a^* (\beta, p_I)}{\partial p_I} > 0
\]

and, more importantly, the signs of

\[
\frac{\partial \Omega}{\partial \beta^R}, \quad \frac{\partial \Omega}{\partial \beta^T}.
\]

3. The “catch-up” difference interacted with the rate of technological change and quality of education.

Taken together, these relationship not only provide validity to the theoretical model, but also tells a story that partially explains the diversity in the dynamics of inequality in recent decades. Consider the case of Latin America and East Asia. The quality of education on the primary level was higher in East Asian countries, as well the breadth of education. Both regions become significantly more open to trade, and the exposure to new technologies that come with it. However, following trade liberalization, income inequality within East Asia declined, while experiencing for a greater convergence to the standard of living of the developed world. The Latin American region, with relatively poorer quality of education, experienced growth in income inequality, and did experience the convergence of East Asia.

In this section, I, first, deal with the problem of endogeneity of the changes to the rate of technological change, followed by empirically addressing the three testable relationships listed above.

### 3.1 Proxy for the Rate of Technological Change

Empirically, the three defined relationships potentially suffer with the endogeneity of rate of technological change. One potential value of the rate of technological change is in the total factor productivity (TFP). However, the effective human capital clearly influences the TFP of the county.
To proxy for the change in the rate of innovation, I derive a measure for the predicted skill factor content of trade (FCT) using a gravity model of bilateral, industry specific trade. Almost all countries have engaged in trade liberalization policies in recent decades. And while the timing and specifics of the individual liberalization policies are not essential, the level of technology embedded within the increased trade flows is. This suggests the factor content of trade is a proxy for the change in new technologies entering the production process. This is proxied by utilizing a gravity model based on the geographical proximity to skills. Greater proximity to skills imply a greater embedded level of technology within a country’s imports, and thus a faster rate of new innovations entering the production process. Therefore, the change in the rate of innovation or imitation is captured by the predicted skilled factor content of trade, \( skFCT \).

To derive the \( skFCT \) for country \( i \), I regress (always in logarithms) a gravity equation that relates geographical distance, country size and the level of skills of the export country between bilateral country pairs. Let \( i \) denote the importing country, and \( o \) denote the exporting country.

\[
\log(\text{actualFCT}_{i,o}) = \beta_0 + \beta_1 \log(\text{dist}_{i,o}) + \beta_2 \log(\text{Pop}_o) + \beta_3 \log(\text{Edu}_o) + \bar{\epsilon}
\]

where \( \text{actualFCT}_{i,o} \) is the actual skilled FCT between exporter \( o \) and importer \( i \), and \( \text{Edu} \) is the average years of education of the exporting country. Summing the right hand side over all the trading partners of country \( i \) yields the country specific skilled FCT \( (skFCT) \). I expect the distance between the two countries to reduce overall trade flows, and thus the skilled factor content of trade, likewise, I expect the opposite relationship in terms of the population. Finally, the level of education in the exporting country increases the skilled FCT.

At the point, I use the skilled and unskilled factor content of trade from Auer 2006.

### 3.2 The Effective Human Capital

The first empirical investigation is to examine the relationship between rates of innovation and the effective human capital. This question tests the empirically validity of equation 19, which implies, the change in effective human capital can be positive or negative depending the quality of education. Higher quality of education should increase the change in human capital with respect to changes in the rate of technological progress.

To test this hypothesis the reduced form specification would be

\[
\Delta EHC_i = \alpha_0 + \alpha_1 Edu_i + \alpha_2 \Delta Inn_i + \alpha_3 (Edu_i) (\Delta Inn_i) + \Theta_i + \epsilon
\]

15
where $i$ is the country subscript, $EHC$ is the effective human capital, $Edu$ is a measure of the quality of education, $\Delta Inn$ is change in the rate of innovation, and $\Theta_i$ is a vector of additional explanatory variables for country $i$, such as GDP per capita or general trade openness for example, and their interactions with $Edu$.

Based on the theoretical predictions $\alpha_1$ should be positive, which implies a higher quality of education increases the change in effective human capital; $\alpha_2$ should be negative and $\alpha_3 > 0$, which implies the increase in the rate of technological change decreases the change in effective human capital unless the quality of education is sufficiently high. The partial on $\Delta Inn$ is $(\alpha_2 + \alpha_3 Edu)$ which is increasing in $Edu$.

Explanatory variables included the GDP per capita (from the Penn World Table 6.2) and general openness to trade, which to control for potential endogeneity, I utilize the Frankel-Romer trade instrument. This is a gravity model of bilateral trade, which trade openness is proxied by size and distance of potential trading partners. I use focus here on the education expenditures per student to proxy the quality of education. Other potential measures include the pupil/teacher ratio or the simple literacy rates. Finally, I use the additional explanatory variable of the unskilled factor content of trade.

The effective human capital is inherently difficult to approximate. To address this problem I take two approaches: first, I use the average years of education to measure the effective human capital; and second, I back out the expected value of human capital utilizing growth accounting methods.

Using the average years of education to proxy for the effective human capital is commonly used (See Galor and Mountford 2008 for example). However, it is problematic for this paper, because the theoretical predictions for the effective human capital and the acquisition of skills are different. Two differences are of consequence. First, for sufficiently low quality of education, $\partial H / \partial p_C^*$ can be negative, but $\partial a^*/\partial p_C^* < 0$ which states that an increase in the rate of imitation unambiguously increases the acquisition of skills. Simply stated, the effective human capital can decreases despite a rise in the acquisition of skills.

The second problem deals with the interaction of the quality of education and the rate of technological change. The theory suggests an increase in quality of education increases the change in effective human capital. However, an increase in the quality of primary education lessens the change in the acquisition of skills. Updating regression 24 to account for these differences yields

$$
\Delta YEARS_i = \gamma_0 + \gamma_1 Edu_i + \gamma_2 \Delta Inn_i + \gamma_3 (Edu_i) (\Delta Inn_i) + \Theta_i + \epsilon 
$$

where I expect $\gamma_1$ to be positive, $\gamma_2$ to be positive, and $\gamma_3$ to be negative. Given the
data constraints on the skilled factor content of trade, and the education expenditure per student, I run this regression on a sample of 49 developed and developing countries. The dependent variable is the change in the average years of education from 1980 to 1990 as measured by the Barro-Lee data set for everyone 15 years and older. Table 3.2 presents the OLS results.

Table 3.2:

<table>
<thead>
<tr>
<th>Regression</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dep. Variable</td>
<td>Intercept</td>
<td>Change in Average Years of Education 1980 – 1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1980 log Expenditure</td>
<td>0.317</td>
<td>0.405***</td>
<td>2.479</td>
<td>1.891*</td>
<td>0.917</td>
<td>0.287</td>
<td>0.311</td>
<td>-1.079</td>
<td>0.765</td>
<td>0.765</td>
<td>0.765</td>
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<td>(0.523)</td>
<td>(3.51)</td>
<td>(0.90)</td>
<td>(1.98)</td>
<td>(0.38)</td>
<td>(0.54)</td>
<td>(0.54)</td>
<td>(-0.25)</td>
<td>(1.46)</td>
<td>(1.46)</td>
<td>(1.46)</td>
<td>(1.46)</td>
<td>(1.46)</td>
</tr>
<tr>
<td>1980 log GDP p.c.</td>
<td>0.123</td>
<td>0.008</td>
<td>0.123</td>
<td>0.008</td>
<td>0.123</td>
<td>0.008</td>
<td>0.123</td>
<td>0.008</td>
<td>0.149</td>
<td>0.010</td>
<td>0.113</td>
<td>0.113</td>
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<tr>
<td>(0.24)</td>
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<td>(0.13)</td>
<td>(0.24)</td>
<td>(0.13)</td>
<td>(0.24)</td>
</tr>
<tr>
<td>GDP p.c. * Expen</td>
<td>-0.252</td>
<td>-0.179**</td>
<td>-0.252</td>
<td>-0.179**</td>
<td>-0.252</td>
<td>-0.179**</td>
<td>-0.252</td>
<td>-0.179**</td>
<td>0.072</td>
<td>-0.214</td>
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<td>(-1.72)</td>
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<td>(-1.72)</td>
<td>(-0.75)</td>
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<td>(-0.75)</td>
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<tr>
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<td>0.017</td>
<td>0.003</td>
<td>0.017</td>
<td>0.003</td>
<td>0.017</td>
<td>0.003</td>
<td>0.017</td>
<td>0.008</td>
<td>0.019</td>
<td>0.019</td>
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<td>(0.05)</td>
<td>(0.05)</td>
<td>(0.05)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>Trade * Expen</td>
<td>-0.002</td>
<td>-0.010</td>
<td>-0.002</td>
<td>-0.010</td>
<td>-0.002</td>
<td>-0.010</td>
<td>-0.002</td>
<td>-0.010</td>
<td>-0.007</td>
<td>-0.011</td>
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<td>(-0.07)</td>
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<td>(-0.61)</td>
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<td>(-0.07)</td>
<td>(-0.61)</td>
<td>(-0.07)</td>
</tr>
<tr>
<td>(1.64)</td>
<td>(3.51)</td>
<td>(1.34)</td>
<td>(1.67)</td>
<td>(1.44)</td>
<td>(1.52)</td>
<td>(0.62)</td>
<td>(0.52)</td>
<td>(0.52)</td>
<td>(0.59)</td>
<td>(0.59)</td>
<td>(0.59)</td>
<td>(0.59)</td>
</tr>
<tr>
<td>(-1.36)</td>
<td>(-2.60)</td>
<td>(-1.22)</td>
<td>(-1.19)</td>
<td>(-0.55)</td>
<td>(-0.47)</td>
<td>(-0.58)</td>
<td>(-0.59)</td>
<td>(-0.59)</td>
<td>(-0.59)</td>
<td>(-0.59)</td>
<td>(-0.59)</td>
<td>(-0.59)</td>
</tr>
<tr>
<td>(0.03)</td>
<td>(3.51)</td>
<td>(1.44)</td>
<td>(1.52)</td>
<td>(0.62)</td>
<td>(0.52)</td>
<td>(0.59)</td>
<td>(0.59)</td>
<td>(0.59)</td>
<td>(0.59)</td>
<td>(0.59)</td>
<td>(0.59)</td>
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<tr>
<td>(-0.02)</td>
<td>(-0.33)</td>
<td>(0.05)</td>
<td>(0.05)</td>
<td>(-0.63)</td>
<td>(-0.33)</td>
<td>(0.05)</td>
<td>(-0.63)</td>
<td>(-0.33)</td>
<td>(0.05)</td>
<td>(-0.63)</td>
<td>(-0.33)</td>
<td>(0.05)</td>
</tr>
</tbody>
</table>

Observations: 49 49 49 49 49 49 49 49 49 49 49 49
R squared: 0.0790 0.1301 0.5777 0.0791 0.5520 0.5505 0.4994 0.1317 0.5784 0.0498 0.3360

Significance: *** 1%; ** 5%; * 10%
t-values in parentheses

Table 3.2 shows the signs of the coefficients are as the theory predicts, particularly regression 2, 4 and 6. The coefficient on the log education expenditure per student is positive and mostly significant. The coefficient on the skilled FCT is positive and mildly significant, while the coefficient on the interaction term is negative and again marginally significant. This supports the theory that faster inflows of new technologies increases the acquisition of skills, but higher quality of education softens this effect. The intuition is that unskilled workers with a high quality of primary education are better able to adapt to the new technologies, and therefore, are less sensitive to changes in the rate of technological progress. This result, however, is lost when including the unskilled FCT content of trade.

This result, however, does not accurately capture the dynamics of the effective human capital. The acquisition of skills is only one component of the change in the effective human capital. For a more direct measurement of effective human capital, I utilize...
growth account procedures to back out the $H$ in the production function. **TO BE COMPLETED**...

### 3.3 Within Country Income Inequality

In this section, I turn to the dynamics of income inequality during periods of increased technological change. The theoretical predictions are summarized in equations 21 and 22. They state an increase in the rate of innovation should unambiguously increase within country income inequality, but this increase is lessened if the quality of education, particularly primary, is high. Similar to 24, I regress the equation

$$\Delta\text{inequality}_i = \beta_0 + \beta_1 Edu_i + \beta_2 \Delta Inn_i + \beta_3 (Edu_i) (\Delta Inn_i) + \Theta_i + \epsilon$$

(26)

where I expect $\beta_1$ to be ambiguous or insignificant since there are competing effects based on whether the quality of primary education or secondary education is measured; $\beta_2$ to be positive because technological progress is skill biased, and thus $\Delta Inn$ increases inequality; and $\beta_3$ to be negative, as higher quality of education lessens the impact of technological change on inequality.

Table 3.3 summarizes the OLS results, where *inequality* is given by the University of Texas THEIL index of inequality, for a subset of 46 countries for which data was available. The change in the probability of innovation is, again, proxied by the skilled factor content of trade derived in Auer (2006).

Table 3.3:
The results are as expected, and robustly significant. A higher skilled FCT increases the change in income inequality, but the interaction term is negative and significant. Higher quality of education lessens the growth of income inequality within countries. This result is robust to including any of the explanatory variables. Also, the unskilled FCT is negative and significant. This implies that country whose imports are less skilled intensive, have a lower change in inequality. The intuition is in line with theory as well. Workers are exposed less to state of the art technologies and are therefore not becoming relatively less productive.

To show the robustness of the results, I (TO BE COMPLETED...)

- Change the year intervals.
- Use different measurements for the quality of education.

## 3.4 Across Country Income Inequality

TO BE COMPLETED...

## 4 Conclusions and Extensions

The empirical findings provide evidence that a poor quality of education, especially on the primary level, is associated with a decline in the effective human capital, greater
increases in within country income inequality, and a divergence in per capita income on a cross country level, during periods of increased technological change. Here, the degree of increased technological change is measured by the factor content of international trade. This measured is of particular interest given the recent decades of widespread, pronounced trade liberalization.

This results suggest a cautious policy implication. Investment in human capital through education is an important component to realize all potential gains from trade. The long run gains to opening to trade is well understood, however, given the ensuing change in the growth of technical change, I show the potential for harmful, short-run effects when the quality of education is sufficiently low.

5 Appendix

5.1 Cross country dynamics of inequality

In recent decades of trade liberalization and increased technological change have contributed to a growth in inequality within many developing countries, especially within much of Latin America and Africa. However the experience in East Asia looks very different, where inequality has maintained steady, or even declining. Figure 5.1 highlights the different dynamics using the University of Texas THEIL index of inequality for the years 1973 til 2000 between Latin America and East Asia.

Figure 5.1

![Inequality Within Countries](image)

Select East Asian and Latin American Countries: 1973-1999

- Latin American Countries: Bolivia, Chile, Colombia, Ecuador, Mexico
- East Asian Countries: Hong Kong, Korea, Singapore, Taiwan
The dynamics of inequality across countries also differs between countries. Figure 5.1 looks the GDP per capita relative to that of the U.S. for a subset of countries in Latin America, Africa and East Asia. On average, East Asia countries have converged to the living standards of the U.S., while Latin America and Africa have fallen further behind.

![Relative wages of Developing Countries](image)

**Figure 5.1:**

- Latin American Countries: Bolivia, Chile, Colombia, Ecuador, Mexico, Peru
- East Asian Countries: Hong Kong, Korea, Singapore, Taiwan
- African Countries: Congo, Ethiopia, Ghana

6 References


