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TRADE IN HUMAN CAPITAL: A QUANTITATIVE THEORY OF ECONOMIC GROWTH AND THE IMPORT OF HIGHER EDUCATION

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For a developing economy transitioning into knowledge-intensive sectors, the lack of capacity for advanced education poses a natural challenge. Many successfully industrialized countries used high-skilled foreign teachers to overcome this challenge. I present a stylized quantitative model of trade in high-skilled human capital, in which colleges in a developing country can hire high quality teachers from a developed country. In the model, the use of foreign teachers is proposed as a possible mechanism to build domestic capacity for advanced education. Quantitative calibrations of the model show two main results. First, there are significant frictions in human capital trade, as measured by the wedge between the level of human capital observed in the data versus the level simulated under the assumption of no frictions. Removal of the wedge can narrow the average income gap between the USA and other countries by about 14–24%. Second, relative to countries with the lowest and highest incomes, middle-income countries appear to gain the most from removing the wedge.

Keywords: Catch-up, Growth, Human capital transfer, Productivity

1. INTRODUCTION

As a catching-up economy transitions into technology-intensive sectors, lack of capacity to provide advanced training in science and technology poses a natural challenge, owing to lack of high-skilled individuals who can provide such training. Many observers of successfully industrialized countries (e.g., Japan, Korea, and Taiwan) point to the use of foreign graduates to build domestic training capacity (Mazzoleni (2008)). After the Meji restoration in the late 19th century, Japan relied on foreign scientists to train its domestic students, with the ambition of catching-up with the West in science and technology. The entire faculty in Japan's first engineering college, the Imperial College of Engineering, consisted of British

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scientists (Mazzoleni (2008)). Many Japanese also went abroad to study in the West and later returned and engaged in training Japanese students at domestic colleges in Japan (Nakayama (1989)).

The experiences of Korea and Taiwan also appear to suggest the importance of foreign-trained scientists in building domestic training capacity in science and technology. For example, the Korea Advanced Institute of Science and Technology (KAIST)—a prominent Korean school for advanced training in science and technology—was established primarily by professors from the USA. Leading universities in Taiwan also drew heavily on US-trained professors (Hsieh (1989), Wu et al. (1989)). In this paper, I develop a model of economic growth that allows for such a transfer of human capital from a developed to a developing country.

The model features a globalized market for human capital, in which the transfer of human capital occurs via import of teachers from a developed to a developing country. Although human capital transfer could potentially play a crucial role in technological catch-up, an important question arises regarding the level of market frictions in the global market for human capital. Following the classic paper by Lucas (1990), the extant literature on catch-up has primarily focused on frictions in the transfer of physical capital across borders (Obstfeld (1994), Acemoglu and Zilibotti (1997), Gourinchas and Jeanne (2006), Caselli and Feyrer (2007), Kalemli-Ozcan et al. (2010)). However, as opposed to constraints on physical capital flow, constraints on human capital transfer could be more consequential for long-term development, and they are perhaps more likely to happen.

First, since the economy can accumulate physical capital through domestic savings, constraints on cross-border borrowing of physical capital may not have significant effects on steady-state outcomes (Gourinchas and Jeanne (2006), Azariadis and Kaas (2016), Hassler et al. (2017)). This is unlikely to be the case with human capital transfer since, without the opportunity to learn from those who have already acquired the knowledge, a country may be left with a persistently low level of human capital. Second, there are plausible reasons to suspect that the level of frictions in the market for human capital transfer could be higher than the level in the market for physical capital. The transfer of human capital requires mobility of people (i.e., teachers), which, as compared to mobility of capital, is constrained by a myriad of migration restrictions. Moreover, the return from building domestic training capacity is realized over the long-run through a process by which current teachers train current students, who will in turn teach the next generation of students, and so forth. Hence, underdevelopment of financial markets in developing countries could make it particularly difficult to finance such a risky and long-term investment (Growiec (2010)). I therefore use the model to quantitatively assess the extent of frictions in human capital transfer and the potential gains from removing them.

In the model, I assume that the acquisition of human capital involves an investment of time, both by the teacher and the student. Teaching is done by high-skilled individuals, who could be heterogeneous with respect to their quality (i.e., their level of skills). Students will then choose from a menu of teachers. High quality teachers provide high quality education. Tuition costs are also assumed to increase with teachers' quality. Thus, students weigh the trade-off between the quality and cost of education. In addition to domestic graduates, the menu of teachers also includes foreign teachers (i.e., graduates from the developed economy). Allowing for this possibility of using foreign teachers is the major departure of my model from existing theories of human capital (Erosa et al. (2010), Manuelli and Seshadri (2014)).

I simulate the model for a cross-section of 103 countries using data on income and schooling, and parameters that are mostly standard in the literature. I first calibrate a decentralized long-run equilibrium of the model economy, assuming that there are no frictions in the flow of teachers from the developed to the developing country. I then compare the calibrated cross-country distribution of human capital stock with observed values in the data. As an indicator for the level of frictions in human capital trade, I construct a measure based on the wedge between observed stocks of human capital and the one simulated under the assumption of no frictions.

The calibration results show that the magnitude of this wedge appears quite large. Removing the wedge is found to decrease the gap in human capital stock between the USA and the rest of countries in my sample by about 50–62%. As a result, following removal of the wedge, the income gap between the USA and the rest of the countries decreases by about 14–24%.

I also examine the relationship between the gain from removal of the wedge and initial income. This relationship could be important for global income gaps since, for example, gaps could decrease if poorer countries gain the most. I find that there is a hump-shaped relationship between initial income and the gain from removing the wedge, wherein, as compared to the countries with the lowest and highest income levels, those in the middle of the income distribution tend to gain the most. This hump-shaped pattern is driven by the combination of a relatively low initial human capital and high total factor productivity (TFP) levels of middle-income countries, which situates them in a position to gain the most from removal of the wedge.

The next section presents the model environment. This is followed by discussion of the balanced growth equilibrium (BGE) in Section 3. I present the quantitative results in Section 4. The paper ends with concluding remarks in Section 5.

2. THE MODEL

Consider two countries: a developed *foreign* country, denoted by f, and a developing *domestic* country, denoted by d. The economy in each country has two sectors—the production and the human capital sector. Firms produce goods in the production sector, while schools provide training in the human capital sector. Within each country, markets are perfectly competitive both in the goods and in the human capital sector. Labor is immobile across countries, *except* that schools in the developing economy can import teachers from the foreign economy.[1] I impose this assumption to focus on the case of human capital catch-up by the developing country, as opposed to, for example, the issue of "brain drain" from developing to developed countries (Beine et al. (2008)). Imported teachers are compensated according to the amount they would have received in the developed economy (i.e., their home country). Time is continuous and infinite, $t \in [0, \infty)$. Each individual lives for T_c years, where $c \in \{d, f\}$ represents the country. Population size is constant. In every period, mass 1 of new individuals are born in each country, so that the total population size is T_c. For the sake of brevity, unless they are necessary, I drop identifiers for country (c), birth cohort (τ), and time (t).

2.1. The Output Sector

In the production sector, output is a function of TFP (A), physical capital (K), and human capital (H):

$$Y_c(t) = K_c(t)^{\alpha} \left(A_c(t) H_c(t)\right)^{1-\alpha}. \tag{1}$$

I assume that the productivity term A grows at an exogenously given rate of g. Aggregate human capital stock is a CES combination of the stocks of low-skilled and high-skilled human capital (Jones (2014)):

$$H_c = \left(H_{c,u}^{\frac{\sigma-1}{\sigma}} + H_{c,s}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}. \tag{2}$$

The stocks of low-skilled and high-skilled human capitals are given by:

$$H_{c,u} = \bar{h}_{c,u} N_{c,u} \tag{3}$$

$$H_{c,s} = \bar{h}_{c,s} N_{c,s}, \tag{4}$$

where $\bar{h}_u$ is the average level of low-skilled human capital per low-skilled worker; $\bar{h}_s$ represents the average level of high-skilled human capital per high-skilled worker. N_u and N_s denote the physical quantity of workers in the respective skill categories. Low-skilled and high-skilled workers are imperfect substitutes, with the elasticity of substitution $\sigma > 0$.

I consider a representative firm operating in competitive product and labor markets. Taking wages and the interest rate as given, the firm employs physical capital and the two types of human capital with the objective of maximizing its profit:

$$\begin{aligned} &\max_{H_{c,s}, H_{c,u}, K_c} K_c^{\alpha} (A_c H_c)^{1-\alpha} - w_{c,u} H_{c,u} - w_{c,s} H_{c,s} - (r+\delta) K_c \\ &s.t. \quad (2), \end{aligned} \tag{5}$$

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where $w_{c,u}$ and $w_{c,s}$ are wages per unit of low-skilled and high-skilled human capital, respectively; r and δ, respectively, denote the real interest and depreciation rates. The demands for each of the three inputs ($H_{c,u}$, $H_{c,s}$, and K_c) are as follows:

$$w_{c,u} = \frac{\partial Y_c}{\partial H_c}\frac{\partial H_c}{\partial H_{c,u}} = (1-\alpha)A_c^{1-\alpha}\left(\frac{K_c}{H_c}\right)^{\alpha}\left(\frac{H_{c,u}}{H_c}\right)^{\frac{-1}{\sigma}} \tag{6}$$

$$w_{c,s} = \frac{\partial Y_c}{\partial H_c}\frac{\partial H_c}{\partial H_{c,s}} = (1-\alpha)A_c^{1-\alpha}\left(\frac{K_c}{H_c}\right)^{\alpha}\left(\frac{H_{c,s}}{H_c}\right)^{\frac{-1}{\sigma}} \tag{7}$$

$$r+\delta = \frac{\partial Y_c}{\partial K_c} = \alpha\left(\frac{A_c H_c}{K_c}\right)^{1-\alpha}. \tag{8}$$

2.2. Human Capital Acquisition—the Education Sector

Individuals choose human capital investment with the objective of maximizing expected lifetime earnings, net of tuition costs (Ben-Porath (1967); Bils and Klenow (2000); Manuelli and Seshadri (2014)). I assume that individuals can spend up to 12 years in pre-college education (primary and secondary). Acquisition of college education is assumed to take another 4 years of schooling, so an individual can spend up to 16 years in school.

Non-college graduates with $n \leq 12$ years of schooling acquire $h_u(n)$ units of low-skilled human capital, where

$$h_u(n) = h_u(0)\exp(\theta n). \tag{9}$$

The parameter $\theta > 0$ is the return to an extra year of pre-college schooling. For those with zero years of schooling, $h_u(0) > 0$ represents their level of low-skilled human capital.

I assume that college graduates need to be trained by college professors. Let $\hat{h}_s$ denote the amount of high-skilled human capital that a college professor possesses, and h_s denote that of his student. For a student in country c, the student's human capital (h_s) is assumed to be increasing in both the human capital of the teacher ($\hat{h}_s$) and the average human capital of skilled individuals in the economy ($\bar{h}_{c,s}$):

$$h_s = f(\hat{h}_s; \bar{h}_{c,s}) = \hat{h}_s^{1-\kappa}\bar{h}_{c,s}^{\kappa}, \quad \kappa \in [0, 1]. \tag{10}$$

The parameter $\kappa > 0$ captures an externality effect from the overall quality of skilled workers in the economy (Tamura (2001)). The role of this parameter is to account for the possibility that a developing country may find it challenging to benefit from a few highly qualified imported teachers due to lack of domestic capacity (Nelson and Phelps (1966)). This may arise, for example, if providing an advanced training in a given field (such as engineering) requires capacity to train in complementary fields, such as physics, chemistry, and mathematics (Jones (2008)).

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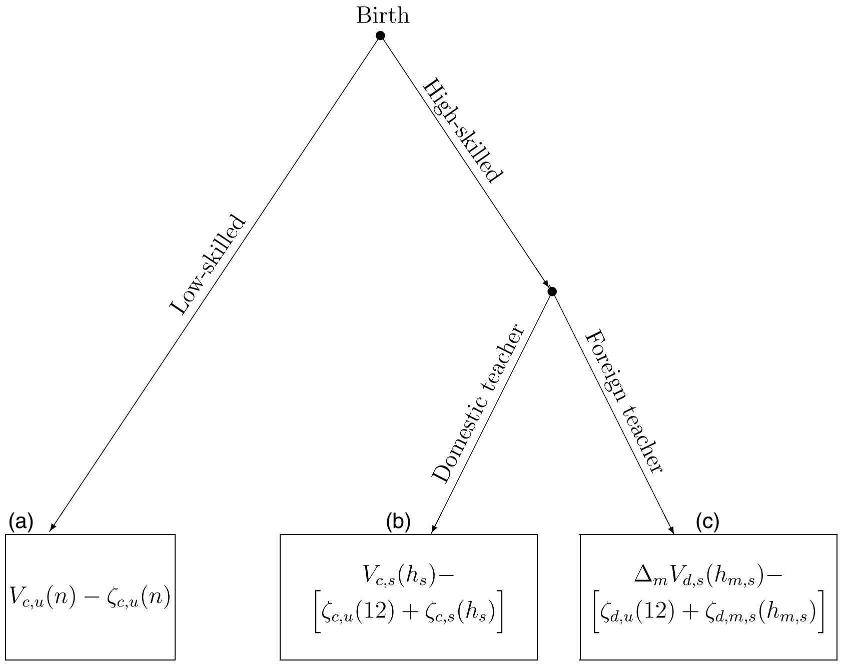

FIGURE 1. Decision on human capital investment.

Figure 1 displays the individual's options regarding investment in human capital. The net earnings (earnings, net of tuition costs) from each option are described in the corresponding boxes at the bottom of the figure. First, the individual chooses between becoming high-skilled or low-skilled. Those choosing to become low-skilled workers could acquire $n \leq 12$ years of pre-college schooling. The present value of a low-skilled individual's lifetime income and the tuition cost are represented by $V_{c,u}(n)$ and $\zeta_{c,u}(n)$, respectively. The net earning equals $V_{c,u}(n) - \zeta_{c,u}(n)$.

College students in the developing country can choose to acquire high-skilled human capital from either domestic or foreign teachers. The center (b) and right (c) boxes in Figure 1 present net earnings from each of these two options. Since college graduates need to finish 12 years of pre-college education, the total financial cost of acquiring college education also includes fees from the first 12 years of pre-college education, $\zeta_{c,u}(12)$. The tuition cost for acquiring h_s level of high-skilled human capital from a domestic college teacher is represented by $\zeta_{d,s}(h_s)$. The cost to acquire $h_{m,s}$ level of high-skilled human capital from an imported teacher is denoted by $\zeta_{d,m,s}(h_{m,s})$. I use the subscript m to identify the foreign education, that is, the education provided by imported teachers. Since my focus on the import of teachers from the developed to the developing country, and not the other way round, I assume that the third option box (c) applies only to students in the developing country.

The difference in net earnings between the foreign and domestic options are affected by three factors. First, the level of human capital received from foreign teachers could be greater than that of domestic teachers, $h_{m,s} > h_s$. This makes the foreign option more attractive. On the other hand, the tuition cost for the foreign option could be higher than that of the domestic one. I will endogenize college tuition, assuming that tuition fees are proportional to teachers' wages in their respective home country. Third, as discussed in the introduction, acquiring the foreign education is likely to be hindered by many obstacles. Some of these obstacles could be related to frictions in mobility of teachers across countries, due to factors such as migration policies and location preferences. Moreover, since foreign education may involve a large amount of financial investment, credit market imperfections in developing countries could have a disproportionate effect on acquiring foreign education. The term Δ_m is meant to capture this friction on import of teachers. $V_d(h_{m,s})$ is the value of foreign education implied by the domestic prices for human capital. Δ_m is the factor by which the observed value of foreign education deviates from the implied value. I will refer to Δ_m as the foreign education wedge. A decrease in Δ_m means a decrease in the value of foreign education after taking into account the effect of barriers to acquire foreign education. My main objective in this paper is to calibrate this wedge under some plausible scenarios and assess the implications for economic development.

The flow of earnings for a worker with n years of pre-college schooling, denoted by $y_{c,u}(t,n)$, is given by

$$y_{c,u}(t,n) = w_{c,u}(t)h_u(n), \tag{11}$$

where $w_{c,u}$ and h_u follow from (6) and (9), respectively.

The average earnings of unskilled workers, relative to that of skilled workers, depends on the relative scarcity of each group and the elasticity of substitution between them:

$$\begin{aligned}\frac{y_{c,u}}{y_{c,s}} = \frac{w_{c,u}\bar{h}_u}{w_{c,s}\bar{h}_s} &= \left(\frac{H_{c,u}}{H_{c,s}}\right)^{\frac{-1}{\sigma}} \frac{\bar{h}_u}{\bar{h}_s} \\ &= \left(\frac{N_{c,u}}{N_{c,s}}\right)^{\frac{-1}{\sigma}} \left(\frac{\bar{h}_u}{\bar{h}_s}\right)^{\frac{\sigma-1}{\sigma}}.\end{aligned} \tag{12}$$

An increase in the physical quantity of a group always decreases its average earnings. A group's average earnings is increasing in the average level of the group's human capital, assuming that skilled and unskilled workers are sufficiently substitutable with each other, so that $\sigma > 1$.

For a worker with n years of pre-college education, the present value of lifetime income, as of birth year τ, becomes

$$V_{c,u}(\tau,n) = \int_n^T \exp(-rx)y_{c,u}(\tau + x, n)\, dx. \tag{13}$$

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Let $i \in \{g = goods, e = education\}$ indicate whether a high-skilled individual works in the goods or education sector. Let $y_{c,g}(t, h_s)$ and $y_{c,e}(t, h_s)$ denote, respectively, the flow of earnings by a high-skilled individual (with h_s units of high-skilled human capital) working in the goods and education sector. The present value of this individual's lifetime income as of birth time τ, $V_{c,i}(\tau, h_s)$, becomes

$$V_{c,i}(\tau, h_s) = \int_{16}^{T} \exp(-rx) y_{c,i}(\tau + x, h_s) dx. \qquad (\mathbf{14})$$

The income from working in the goods sector, $y_{c,g}(h_s, t)$, is given by

$$y_{c,g}(h_s, t) = w_{c,s}(t) h_s, \qquad (\mathbf{15})$$

where w_s follows from (7).

I assume that the annual pre-college tuition costs are increasing in grade levels (i.e., with years of schooling). For an individual born in time τ, the cost (in present-value terms) of acquiring n years of pre-college schooling is

$$\zeta_{c,u}(\tau, n) = P_{c,u} \int_{0}^{n} \exp(-rx) y_{c,u}\,(\tau + x, n)\, dx, \qquad (\mathbf{16})$$

where $P_{c,u}$ is a constant and $y_{c,u}(n)$ follows from (11).

The tuition cost for each year of schooling, $P_{c,u} y_{c,u}\,(\tau + x, n)$, is thus assumed to be proportional to earnings of workers with respective levels of education, $y_{c,u}(\tau + x, n)$. The purpose of this assumption is twofold. First, it makes the model more tractable. It also accounts for the possibility that higher levels of education may require teachers with higher levels of skill. $P_{c,u}$ is a parameter broadly indicating the private cost of pre-college education. Lower $P_{c,u}$ could thus, for example, correspond to a more accessible domestic infrastructure for pre-college education.

I assume that college tuition costs are proportional to teacher's wage. For a student trained by a domestic teacher with $\hat{h}_s$ level of high-skilled human capital, the tuition cost of attending college, in present value terms as of birth year τ, becomes

$$\zeta_{c,s}(\tau, h_s) = P_{c,s} \int_{12}^{16} \exp(-rx) y_{c,e} \left(\tau + x, \hat{h}_s\right) dx, \qquad (\mathbf{17})$$

where an increase in $P_{c,s}$ is meant to represent a larger private cost of college education. A larger value of $P_{c,s}$ could result from, among other reasons, less developed domestic infrastructure for tertiary education. The term $y_{c,e}(\tau + x, \hat{h}_s)$ is the teacher's wage with $\hat{h}_s$ level high-skilled human capital, and as of $t = \tau + x$. The relationship between the teacher's human capital, $\hat{h}_s$, and that of his student, h_s, follows from (10).

For a student trained by an imported teacher with $\hat{h}_{m,s}$ level of human capital, the tuition cost of attending college is given by

$$\zeta_{d,m,s}(\tau, h_{m,s}) = P_{d,s} \int_{12}^{16} \exp(-rx) y_{f,e}(\tau + x, \hat{h}_{m,s}) dx. \quad \textbf{(18)}$$

The difference between (17) and (18) could arise for two reasons. First, foreign and domestic teachers could differ with respect to their levels of skills, that is, $\hat{h}_{m,s} > \hat{h}_s$. Second, the wage for foreign teachers teaching in the developing country is assumed to be the same as the wage that the teachers would have received in their home country. Thus, the wages for foreign teachers depend not only on their level of skill but also on country-level conditions in the foreign country. For example, a higher level of TFP in the foreign country increases the wage for skilled workers in the foreign country, which in turn increases the wage to be paid to foreign teachers teaching in the developing country. On the other hand, the relative abundance of skilled workers in developed countries lowers their wage.

Note that I define the foreign education wedge, Δ_m, in terms of a tax on the value of foreign education (i.e., $\Delta_m = 1 - \omega$, with some tax rate of ω). Instead, one could define an alternative wedge, $\overline{\Delta}_m$, which represents an increase in the cost term. Consider that $\overline{\Delta}_m = 1 + \overline{\omega}$, with some tax rate of $\overline{\omega}$ on spending to acquire foreign education so that the after-tax cost equals $\overline{\Delta}_m \zeta_{d,m,s}$. Whereas the term $P_{d,s}$ in equation (18) captures the effect of factors that are broadly relevant to higher education costs irrespective of the teacher's type (such as efficiency of the education regulatory agencies, subsidies/taxes to all college students, etc.), $\overline{\Delta}_m$ is meant to represent wedges that are associated specifically with foreign education (such as immigration constraints on foreign teachers). In terms of their effect on net earnings, the Δ_m and $\overline{\Delta}_m$ would be equivalent if $\Delta_m V_d - \zeta_{d,m,s} = V_d - \overline{\Delta}_m \zeta_{d,m,s}$. This implies that $\omega = (\overline{\omega} \zeta_{d,m,s}) / V_d$. Thus, Δ_m can also be interpreted in terms of the value of the tax on spending to acquire foreign education, expressed as a percentage of the total value of foreign education.

As shall be shown in equation (44), an important determinant of the value of foreign education is the transferability of human capital across generations. For example, if some of the knowledge that is currently useful becomes obsolete in the future, say, due to technological change, this could lower the value of foreign education. Similarly, some of the graduates may not become teachers due to lack of ability or willingness to teach, and hence, they may not be able to transfer their human capital. I thus assume that not all college graduates can become college teachers. Individuals are assumed to receive a preference/ability shock, so that only a fraction, $\psi \in (0, 1)$, of college graduates have the option to choose whether to become teachers. Since ψ affects the transferability of human capital across generations, it also affects the value of human capital transfer from the developed to the developing economy.

A college graduate's present value of expected lifetime income becomes

$$V_{c,s}(\tau, h_s) = \psi V_{c,e}(\tau, h_s) + (1 - \psi) V_{c,g}(\tau, h_s), \quad \textbf{(19)}$$

where $V_{c,e}(.)$ and $V_{c,g}(.)$, following from (14), represent lifetime incomes from working as a teacher and skilled worker, respectively.

3. BALANCED GROWTH EQUILIBRIUM

The focus of my analysis is the long run. I thus look at the BGE—an equilibrium where all variables grow at a constant rate. In this section, I qualitatively characterize some important features of the BGE. I then present the quantitative calibrations in the next section. Many of the equations derived in this section will be used for the calibrations in the next section. I formally define the BGE as follows:

DEFINITION 1. *Given the foreign education wedge Δ_m and the real interest rate r, the BGE for countries $c \in \{d, f\}$ consists of wages for low-skilled human capital $w^*_{c,u}(t)$, wages for high-skilled human capital $w^*_{c,s}(t)$, pre-college tuition $\zeta^*_{c,u}(\tau, n)$, college tuition for domestic education $\zeta^*_{c,s}(\tau, h_s)$, college tuition for foreign education $\zeta^*_{d,m,s}(\tau, h_s)$, and allocations $H^*_{c,s}(t)$, $H^*_{c,u}(t)$, and $K^*_c(t)$ such that:*

1. *given wages, firms maximize profit;*
2. *given wages and tuition fees, individuals maximize earnings, net of tuition costs;*
3. *students in the developing country are indifferent between domestic and foreign teachers;*
4. *labor markets for low-skilled and high-skilled individuals clear;*
5. *output grows at the rate of TFP growth, g.*

Along this BGE, a fixed fraction $\phi^*_c \in (0, 1)$ of individuals from each cohort enroll in college. The rest, $1 - \phi^*_c$ of the individuals, become low-skilled workers. Moreover, within each skill category, all individuals have the same level of human capital, which remains constant along the BGE. Let $n^*_c \leq 12$ denote the BGE years of pre-college schooling by low-skilled workers. Then, the quantity of high-skilled and low-skilled workers equal the number of individuals with respective education levels that are out of school:

$$N^*_{c,s} = \phi^*_c(T_c - 16) \tag{20}$$

$$N^*_{c,u} = (1 - \phi^*_c)(T_c - n^*_c). \tag{21}$$

Since $h^*_{c,s}$, $h^*_{c,u}$, and $\phi^*_{c,u}$ are all constant along the BGE, the total stocks of both types of human capital, $H^*_{c,u}$ and $H^*_{c,s}$, are also constant. Thus, output, capital stock, wages, and tuition costs all grow at the rate of the exogenously given TFP growth rate, g.

For low-skilled individuals, this equilibrium level of $h_u(n^*_c)$ is determined by the optimal year of pre-college schooling, n^*_c:

$$n^*_c = \underset{n \in [0,12]}{\text{argmax}}\ V^*_{c,u}(\tau, n) - \zeta^*_{c,u}(\tau, n). \tag{22}$$

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From (13) and (16), the net earnings of low-skilled individuals with n_c^* years of pre-college schooling become

$$
\begin{aligned}
&V_{c,u}^*(\tau, n_c^*) - \zeta_{c,u}^*(\tau, n_c^*) \\
&\quad = \int_{n_c^*}^{T} \exp(-rx) y_{c,u}^* \left(\tau + x, n_c^*\right) dx - P_{c,u} \int_0^{n_c^*} \exp(-rx) y_{c,u}^* \left(\tau + x, n_c^*\right) dx.
\end{aligned} \tag{23}
$$

Since $y_{c,u}^*$ grows at the rate of g, (23) becomes

$$V_{c,u}^*(\tau, n_c^*) - \zeta_{c,u}^*(\tau, n_c^*) = y_{c,u}^*(\tau, n_c^*) D_{c,u}, \tag{24}$$

where $D_{c,u}$ captures discount factors for net earning:

$$D_{c,u} = \frac{\exp(g-r)n_c^* - \exp(g-r)T_c}{r-g} - P_{c,u} \frac{1 - \exp\left((g-r)n_c^*\right)}{r-g}. \tag{25}$$

The first ratio in (25) discounts earnings, which begin flowing n_c^* years after birth and continue to the end of life, T_c. The second ratio captures discounting for tuition fees. Tuition is paid for n_c^* periods, starting from birth. The TFP growth rate affects the discount factor, because both earning and tuition grow at the rate of g.

Assuming an interior solution to the maximization problem (22), the optimal value of n_c satisfies

$$\exp\left((r-g)\, n_c^*\right) = \frac{(\theta - r + g)(1 + P_{c,u})}{\theta \exp\left((g-r)\, T_c\right) + \theta P_{c,u}}. \tag{26}$$

This expression shows how life expectancy and the private cost of education affect years of schooling. Assuming the realistic scenario of $r > g$, an increase in T_c increases the years of schooling among low-skilled individuals. On the other hand, an increase in $P_{c,u}$ decreases the optimal years of pre-college schooling.

College graduates taught by domestic teachers are indifferent with respect to working as skilled workers or teachers.[2] Their lifetime earnings, net of college tuition, following from (14) and (17), are given as:

$$
\begin{aligned}
&V_{c,s}^*(\tau, h_{c,s}^*) - \zeta_{c,s}^*(\tau, h_{c,s}^*) \\
&\quad = \int_{16}^{T} \exp(-rx) y_{c,s}^*(\tau + x, h_{c,s}^*) dx - P_{c,s} \int_{12}^{16} \exp(-rx) y_{c,s}^*(\tau + x, h_{c,s}^*) dx \\
&\quad = y_{c,s}^*(\tau, h_{s,c}^*) D_{c,s},
\end{aligned} \tag{27}
$$

where $y_{c,s}^*(\tau, h_{c,s}^*)$ is the period-τ earnings of a worker with $h_{c,s}^*$ level of high-skilled human capital, and discount terms for net earnings of high-skilled workers are captured by $D_{c,s}$, where

$$D_{c,s} = \frac{\exp((g-r)16) - \exp((g-r)T_c)}{r-g} - P_{c,s}\frac{\exp((g-r)12) - \exp((g-r)16)}{r-g}. \quad \textbf{(28)}$$

The first ratio in (28) includes discount factors for earnings after graduation. Earnings begin at year 16 and continue to the end of life, T_c. The second ratio captures discount factors for college tuition, payment of which begins at year 12 and continues for the next 4 years (until year 16). Both earnings and tuition costs are proportional to the teacher's wage, $y^*_{c,s}(\tau, h^*_{c,s})$. The TFP growth rate, g, appears in the discount factor, since it affects the growth of both earnings and tuition fees.

The difference in net earnings between college graduates versus non-graduates is such that individuals are indifferent about becoming high-skilled or low-skilled workers:

$$V^*_{c,u}(\tau, n^*) - \zeta^*_{c,u}(\tau, n^*) = V^*_{c,s}(\tau, h^*_{c,s}) - \zeta^*_{c,s}(\tau, h^*_{c,s}) - \zeta^*_{c,u}(\tau, 12). \quad \textbf{(29)}$$

Inserting the values of earnings and tuition fees from (24) and (27), the indifference condition of (29) becomes

$$y^*_{c,u}(\tau, n^*_c)D_{c,u} = y^*_{c,s}(\tau, h^*_{s,c})D_{c,s} - y^*_{c,u}(\tau, 12)\overline{D}_{c,u}, \quad \textbf{(30)}$$

where the last term represents tuition fees from the first 12 years of pre-college education, with $\overline{D}_{c,u}$ defined as:

$$\overline{D}_{c,u} \equiv P_{c,u}\frac{1 - \exp\,((g-r)12)}{r-g}. \quad \textbf{(31)}$$

Rearranging (30) and inserting the values of relative earnings from (12),

$$\frac{D_{c,s}}{D_{c,u} + \overline{D}_{c,u}} = \left(\frac{N^*_{c,u}}{N^*_{c,s}}\right)^{\frac{-1}{\sigma}} \left(\frac{h^*_{c,u}}{h^*_{c,s}}\right)^{\frac{\sigma-1}{\sigma}}. \quad \textbf{(32)}$$

The left side of this equality is independent of the relative quantity of workers in the two skill categories. The right side is strictly monotonic in the ratio for the physical quantity of the two groups of workers. Hence, along with (20) and (21), it uniquely determines ϕ^*_c (the share of college graduates).

The level of high-skilled human capital in the foreign country, $h^*_{f,s}$, is determined by history, in the sense that it is given as an initial condition by the quality of available teachers within the country. This simply follows from the assumption that the developed country has to rely on its own teachers, that is, the mobility of teachers occurs only from the developed to the developing economy. The role of college education in the developed country is thus assumed to be limited to transferring this historically determined level of skill across generations. In the developing country, however, the BGE level of high-skill human capital is determined by the trade-off between foreign and domestic teachers. Let $h^*_{m,s}$ denote the level of high-skilled human capital that students trained by imported teachers could acquire. Students in the developing country are indifferent between foreign and domestic education:

$$V^*_{d,s}(\tau, h^*_{d,s}) - \zeta^*_{d,s}(\tau, h^*_{d,s}) = \Delta_m V^*_{d,s}(\tau, h^*_{m,s}) - \zeta^*_{d,m,s}(\tau, h^*_{m,s}), \qquad \textbf{(33)}$$

where the left and right sides of (33) are lifetime earnings—net of college tuition—for students trained by domestic and imported teachers, respectively.

Along the BGE, following from (10), the level of human capital received by a student who is trained by an imported teacher is determined according to:

$$h^*_{m,s} = f(h^*_{f,s}, \bar{h}^*_{d,s}) = f(h^*_{f,s}, h^*_{d,s}) = h^{*1-\kappa}_{f,s} h^{*\kappa}_{d,s}. \qquad \textbf{(34)}$$

Equations (33) and (34) illustrate effect of the wedge Δ_m on the domestic level of high-skilled human capital. Consider the realistic case where high-skilled workers in the foreign country have a higher level of human capital than those in the developing country. That is, imported teachers provide a higher level of human capital, $h^*_{m,s} > h^*_{d,s}$. Assume also that net earnings of college graduates, given by (27), is positive and increasing in the individual's level of high-skilled human capital. Then, according to (33), an increase in Δ_m implies an increase in $h^*_{d,s}$, that is, an increase in the BGE level of high-skilled human capital in the developing country.

Since students in the developing country are indifferent between foreign and domestic teachers, there is no import of teachers along the BGE. Thus, along the BGE, education by foreign teachers is an available option that has known potential benefits and costs but domestic students may choose not to pursue it. Although I do not explicitly model the transitional dynamics toward the BGE, my interpretation is that such a transfer of human capital is a transitory phenomena that occurs until the developing country achieves a level of domestic skills (as captured by the quality of domestic teachers, $h^*_{d,s}$) that satisfies the indifference condition (33). That is, even though there is no import of teachers along the BGE, the indifference condition still determines the domestic skill level that the economy needs to achieve, so that there is no longer a desire to import teachers.

The benefits and costs of foreign education are represented by the right side of (33). The tuition fee for foreign education follows from (18), with the wage of imported teachers, $y_{f,e}(t, h^*_{s,f})$, given by the equilibrium wage and human capital of skilled workers in the developed country, $w^*_{f,s}(t)h^*_{s,f}$:

$$\begin{aligned} \zeta^*_{d,m,s}(\tau, h^*_{m,s}) &= P_{d,s} \int_{12}^{16} \exp(-rx) w_{f,s}(\tau + x) h^*_{s,f} dx \\ &= P_{d,s} w^*_{f,s}(\tau) h^*_{f,s} \int_{12}^{16} \exp\left((g - r)\, x\right) dx. \end{aligned} \qquad \textbf{(35)}$$

In order to derive $V^*_{d,s}(\tau, h^*_{m,s})$, I focus on some marginal individual who is indifferent between foreign and domestic education. Such an individual takes the BGE

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path for aggregate quantities and prices as given, since the individual-level quantities are infinitesimally small and, hence, the individual considers them to have no effect on the aggregate path.

As can be seen from (19), the value of foreign education could depend on the skilled individual's prospect of working in the goods sector (as a skilled worker) versus the education sector (as a college teacher). A student who acquires foreign education can train the next generation of students, who can in turn teach the generation that follows, and so forth. Let $f^{(j)}(h^*_{f,s})$ represent the human capital of the jth generation of foreign trainees, that is, the jth generation of students in this line of transferring imported human capital across the successive generations. Given the relationship between the human capital of a teacher and his student by (10), along the BGE, $f^{(j)}(h^*_{f,s})$ is given by the following recursion:

$$\begin{aligned} f^{(0)}(h^*_{f,s}) &= h^*_{f,s} \\ f(h^*_{f,s}) &= h^{*1-\kappa}_{f,s} h^{*\kappa}_{d,s} \\ f^{(j)}(h^*_{f,s}) &= f\left(f^{(j-1)}\left(h^*_{f,s}\right)\right), \qquad j = 1, 2, 3, \ \ldots \end{aligned} \tag{36}$$

Then, following from (19),

$$\begin{aligned} V^*_{d,s}(\tau, h^*_{m,s}) &= V^*_{d,s}\left(\tau, f^1\left(h^*_{f,s}\right)\right) \\ &= \psi V^*_{d,e}\left(\tau, f^1\left(h^*_{f,s}\right)\right) + (1-\psi) V^*_{d,g}\left(\tau, f^1\left(h^*_{f,s}\right)\right). \end{aligned} \tag{37}$$

The present value of earnings from working in the goods sector, $V^*_{d,g}\left(\tau, f^1\left(h^*_{f,s}\right)\right)$, can be derived by integrating the discounted flow of earnings, given the BGE wage for high-skilled human capital:

$$\begin{aligned} V^*_{d,g}\left(\tau, f^1\left(h^*_{f,s}\right)\right) &= \int_{16}^{T} \exp(-rx) y^*_{d,g}\left(\tau + x, f^1\left(h^*_{f,s}\right)\right) dx \\ &= f^1\left(h^*_{f,s}\right) w^*_{d,s}(\tau) \int_{16}^{T} \exp\left(-(r-g)x\right) dx. \end{aligned} \tag{38}$$

Similarly, given the equilibrium wage of a teacher with $f^1\left(h^*_{f,s}\right)$ level of high-skilled human capital, $y^*_{d,e}\left(\tau, f^1\left(h^*_{f,s}\right)\right)$, the present value of earnings from working as a teacher in (37) is given by:

$$\begin{aligned} V^*_{d,e}\left(\tau, f^1\left(h^*_{f,s}\right)\right) &= \int_{16}^{T} \exp(-rx) y^*_{d,e}\left(\tau + x, f^1\left(h^*_{f,s}\right)\right) dx \\ &= y^*_{d,e}\left(\tau, f^1\left(h^*_{f,s}\right)\right) \int_{16}^{T} \exp\left(-(r-g)x\right) dx. \end{aligned} \tag{39}$$

The teaching wage of the jth generation of foreign trainees, $y^*_{d,e}\left(\tau, f^j\left(h^*_{f,s}\right)\right)$, is determined by the demand for $f^{j+1}\left(h^*_{f,s}\right)$ levels of human capital by the next generation of students. Along the BGE, tuition fees are such that students are indifferent

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across the menu of teachers, so that, for all $j \geq 1$,

$$V^*_{d,s}(\tau, h^*_{d,s}) - \zeta^*_{d,s}(\tau, h^*_{d,s}) = V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right) - \zeta^*_{d,g}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right). \quad \textbf{(40)}$$

Since tuition fees are assumed to be proportional to teachers' wages (see (17)), this indifference condition implies that

$$\begin{aligned} &V^*_{d,s}(\tau, h^*_{d,s}) - \zeta^*_{d,s}(\tau, h^*_{d,s}) \\ &\quad = V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right) - P_{d,s} y^*_{d,e}\left(\tau, f^{j}\left(h^*_{f,s}\right)\right) \int_{12}^{16} \exp\left((g-r)\,x\right) dx. \end{aligned} \quad \textbf{(41)}$$

This equation describes the teaching wage for the jth generation of foreign trainees, $y^*_{d,e}(\tau, f^j(h^*_{f,s}))$, as a function of the value of $f^{j+1}(h^*_{f,s})$ level of high-skilled human capital to the $(j+1)$th generation of students, $V^*_{d,s}(\tau, f^{j+1}(h^*_{f,s}))$. I use this relationship to recursively solve for the value of foreign education for the first generation of students in (37), $V^*_{d,s}(\tau, h^*_{m,s})$. I provide details of the derivation in Appendix A.

Let Q denote the factor by which—before taking the effect of Δ_m into account—the value of education by foreign teachers, $V^*_{d,s}(\tau, h^*_{m,s})$, exceeds that of education by domestic teachers, $V^*_{d,s}(\tau, h^*_{d,s})$:

$$V^*_{d,s}(\tau, h^*_{m,s}) = Q \times V^*_{d,s}(\tau, h^*_{d,s}). \quad \textbf{(42)}$$

In Appendix A, I show that this factor is given as follows:

$$Q(h^*_{f,s}, h^*_{d,s}) = \frac{\psi - \beta}{1-\beta} + (1-\psi)\sum_{j=1}^{\infty} \beta^{j-1}\left(\frac{f^{(j)}(h^*_{f,s})}{h^*_{d,s}}\right), \quad \textbf{(43)}$$

where

$$\beta = \frac{\psi}{P_{d,s}} \frac{\int_{16}^{T_d} \exp^{-x(r-g)}\,dx}{\int_{12}^{16} \exp^{-x(r-g)}\,dx}. \quad \textbf{(44)}$$

According to (43), the relative value of foreign education is increasing in the relative quality of foreign teachers (the difference between $h^*_{f,s}$ and $h^*_{d,s}$). Notice that $Q(.)$ will collapse to 1 if $h^*_{f,s} = h^*_{d,s}$. That is, foreign teachers are equally valued to domestic ones as long as they are of the same quality.

Another interesting feature of (43) is that the value of foreign education is given by a summation over the infinite horizon. This reflects the fact that since human capital can be transferred across generations, the value of foreign education depends not only on the use of human capital in the production sector by first-generation students, but also on the potential use by successive generations of students. Thus, the effect of the quality gap between foreign and domestic teachers on the relative value of foreign education depends on the amount of resources needed to transfer human capital across generations. This is captured by the discount factor β, which, according to (44), is:

- decreasing in $P_{d,s}$: transferring human capital becomes more expensive due to an increase in the cost of college education;
- decreasing in the number of years it takes to complete college $(16 - 12 = 4)$: this also relates to the cost of human capital transfer, as the amount of time spent on college education affects both tuition costs and forgone earnings;
- increasing in ψ: an increase in ψ implies that a high-skilled individual has a higher likelihood of transferring their human capital to future generations.

Thus, the value of human capital transfer depends not only on the productivity of human capital in the goods sector, but also on the amount of resources needed to undertake the transfer of human capital across generations within the domestic education sector. When this resource need is lower due to, for example, improved domestic infrastructure for college education, so that $P_{d,s}$ is lower, the discount factor β will increase, and could result in an increase in the value of foreign teachers in the developing country.

4. RESULTS

4.1. Baseline Calibration Results

I calibrate my two-country model for pairs of countries, where each pair consists of the USA and another country in my sample. Appendix B presents the list of countries in the sample, along with data on educational attainment and income. I treat the USA as the foreign country and the other countries as potential importers of human capital. I selected the USA as the foreign country because it is found to have the highest level of high-skilled human capital, h_s.

The calibration involves the following four major steps:

1. I first quantify the stocks of human capital in each country.
2. Given H_c^*, equations (1) and (8) imply that output in a domestic country d, relative to that of the US output, can be described as a function of the relative values of TFP and human capital stock:

$$\frac{y_d^*(t)}{y_f^*(t)} = \frac{A_d^*(t)}{A_f^*(t)} \frac{h_d^*}{h_f^*}, \tag{45}$$

   where $y_c = Y_c/(N_{c,s} + N_{c,u})$ and $h_c = H_c/(N_{c,s} + N_{c,u})$ are, respectively, output and human capital stock per worker. Using data on gross domestic product (GDP) per worker, and given the human capital stocks from Step 1, I back out the TFP gap in (45).
3. Given the TFP values and other model parameters, I calibrate the wedge Δ_m in (33).
4. Finally, I undertake a counterfactual exercise, wherein I set Δ_m equal to 1, and given the TFP values and other model parameters, I simulate the counterfactual level of human capital stock, $\tilde{h}_d^*$. Using this counterfactual value of human

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capital stock, I compute the ratio of the counterfactual output, $\tilde{y}_d^*(t)$, to the actual output, $y_d^*(t)$. According to (1) and (8), the ratio between $\tilde{y}_d^*(t)$ and $y_d^*(t)$ is equal to the ratio between the counterfactual and the actual human capital stocks:

$$\frac{\tilde{y}_d^*(t)}{y_d^*(t)} = \frac{\tilde{h}_d^*}{h_d^*}. \tag{46}$$

I interpret this ratio as the potential income gain from removing the wedge in human capital transfer.

The calibration of human capital stocks and TFP rely on fairly common procedures in the literature. In quantifying the human capital stock in Step 1, I closely follow Jones (2014). Using data on years of schooling among the population with pre-college education, n_c^*, and the parameter for return to schooling, θ, I calibrate $h_{c,u}^*$ according to the schooling technology given by (9). I normalize $h_u(0)$ to 1, so that $h_{c,u}^*$ is defined relative to the human capital of workers with 0 years of schooling. I use educational attainment data in year 2000 from Barro and Lee (2013), who provide the data for a number of countries. They do not report the average years of schooling. Instead, they report the share of the adult population by education levels, which include nine categories ranging from no schooling to college degrees.

I first split these categories into those who completed college and those who did not. I then calculate the average years of schooling among the population without college degrees as follows:

$$\begin{aligned} n_c^* = & Share_{c,SomePrimary} * 3 + Share_{c,CompletePrimary} * 6 + \\ & Share_{c,SomeSecondary} * 9 + Share_{c,CompleteSecondary} * 12, \end{aligned} \tag{47}$$

where the shares represent proportions of the adult population by levels of pre-college education (primary versus secondary) and completion status (some versus complete). Following the commonly adopted practice in the literature, I assume that those with some (but not complete) primary or secondary education are assumed to have attended half of the years needed to complete the respective levels (Hendricks and Schoellman (2018)).

I set θ to 0.1, which implies a 10% annual rate of return to an extra year of schooling. This rate of return is consistent with the average annual return to schooling in a cross-section of countries (Montenegro and Patrinos (2014)). Actual estimates of Mincer coefficients vary substantially across countries. However, some of the available estimates of Mincer coefficients may not be that reliable due to the problem of data accuracy in developing countries. Hence, I keep the assumption of 10% now for the sake of transparency (Banerjee and Duflo (2005)). However, as a robustness check, I also report results using actual Mincer estimates from the literature.

I then turn to calibrating $h_{c,s}^*$, the level of high-skilled human capital. Given the relative physical quantity of workers and their earnings by skill category, the elasticity of substitution σ, and the low-skilled human capital $h^*_{c,u}$, I back out $h^*_{c,s}$ using

$$h^*_{c,s} = \left(\frac{y^*_{c,s}(t)}{y^*_{c,u}(t)}\right)^{\frac{\sigma}{\sigma-1}} \left(\frac{N^*_{c,s}}{N^*_{c,u}}\right)^{\sigma-1} h^*_{c,u}, \tag{48}$$

where (48) follows from the expression for relative earnings given by (12). Since both $y^*_{c,s}(t)$ and $y^*_{c,u}(t)$ grow at the constant rate of g, the earning ratio in (48) is constant. I compute this ratio by using the empirical relationship between earnings and years of schooling. With college graduates and non-college graduates having 16 and n^*_c years of schooling, respectively, and assuming that an extra year of schooling is associated with a 10% increase in earnings, the earning ratio is set according to:

$$\frac{y^*_{c,s}(t)}{y^*_{c,u}(t)} = \exp\big(0.1\,\left(16 - n^*_c\right)\big). \tag{49}$$

In order to determine the ratio for the quantity of workers, as described by equations (20) and (21), I need the values for T_c and ϕ^*_c. I set ϕ^*_c equal to the share of the population with college education, as reported in Barro and Lee (2013). Assuming a retirement age of 64, and deducting the first 6 years of life, I set T_c equal to 58. Using data on life expectancy, I also undertake robustness check by allowing the retirement age to fall below 64 for countries whose life expectancy is less than 64 years.

Empirical estimates by Ciccone and Peri (2005) suggest that σ is about 1.5, while Katz and Murphy (1992) report a slightly smaller value of 1.41. Estimates by Acemoglu and Autor (2012) range between 1.6 and 2.8, with the elasticity found to be larger for longer time horizons. I first report the result for $\sigma = 2$, a somewhat intermediate value of the estimates, and present robustness checks for alternative values of σ. I compute the total quantity of human capital stock in the economy, H^*_c, by aggregating the per worker values of human capital stock ($h^*_{c,u}$ and $h^*_{c,s}$) and the physical quantities of workers ($N^*_{c,u}$ and $N^*_{c,s}$), according to the aggregation equations (2), (3), and (4).

Having quantified the human capital stock, I back out the TFP gap in (45) by using the purchasing power parity (PPP) adjusted data on GDP per worker in 2000, which I source from Penn World Tables (Feenstra et al. (2015)).

Turning to the third major step in the calibration, quantifying Δ_m, I need to compute the discounted earnings and tuition fees in (33). A few more parameters have yet to be determined. I set the annual interest rate and the TFP growth rate equal to 4% and 2%, respectively.[3] The share of capital, α, is set to one-third. In order to calibrate the parameter for the cost of domestic pre-college education, $P_{c,u}$, I set n^*_c in the optimality condition for pre-college education, given by (26), equal to the years of pre-college schooling in the data. Then, I use the indifference condition between college and pre-college education, given by (32), to determine the cost parameter for college education, $P_{c,s}$.[4] Earnings for low-skilled and high-skilled workers are calibrated according to the wage and earning equations (6),

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TABLE 1. Parameter values for the baseline simulation

Parameter	α	r	σ	T	θ	κ	ψ
Value	1/3	0.04	2	58	0.10	0.05	0.0064

Notes: The parameters are: the income share of capital (α), real interest rate (r), the elasticity of substitution between high-skilled and low-skilled human capital (σ), years of working life (T), annual return to years of schooling (θ), the externality from the average level of high-skilled human capital (κ), and the likelihood that a college graduate can become a teacher (ψ).

(7), (11), and (15). Thus far, we have sufficient information to compute the left side of (33), which can readily be done by inserting the values for parameters $T_c, r, g, P_{c,s}$, and earnings $y^*_{c,s}(h^*_{c,s})$ into (27) and (28).

The tuition fees in the right side of (33) can be computed directly from (35). It now remains to compute $V^*_{d,s}(\tau, h^*_{m,s})$, the value of foreign education, before taking the effect of Δ_m into account. I use (42) and (43) for this computation. Two more parameters are needed to quantify Q, the value of foreign education as a ratio of the domestic one. The first parameter is the likelihood that a college graduate can work as a teacher, ψ, which affects the discount factor β, as shown in (44). The second one is κ, the externality parameter in the education sector (see (36)). There are no empirical estimates of ψ that I am aware of. So, I take a conservative approach and select the minimum plausible value of ψ. The value of foreign education is generally found to be increasing in ψ (through increasing the discount factor β). Thus, the simulated gain, assuming the minimum value of ψ, could be considered as a lower bound on the gain.

Since a fraction, ϕ^*_c, of individuals within groups aged 12 to 16 years attend college, the quantity of college students at any given time equals $4 \times \phi^*_c$. A fraction ϕ^*_c of those within the age groups of 16 to T are college graduates, which implies that there are $\phi^*_c \times (T - 16)$ mass of college graduates. If the student-to-teacher ratio equals γ, at least $4/\left(\gamma\left(T-16\right)\right)$ of high-skilled individuals must be able to work as teachers, so that there will be enough number of teachers in the BGE. According to the 2011 report by *US News* (2011), the average student-to-teacher ratio among US colleges was 14.8 in 2011. Thus, I set ψ to equal $4/\left(14.8\left(58-16\right)\right) = 0.0064$.

Estimates of the human capital externality are available for the general labor market, but not separately for the education sector. These estimates are in the range of 2–5% (Acemoglu and Angrist (2000)). Given that the education sector is more knowledge-intensive, the externality effect could perhaps be larger in the education sector. I first present the result setting κ to 0.05, and I do robustness checks with alternative values. Table 1 summarizes the list of parameter values in my baseline calibration.

Figure 2 shows the relationship between schooling attainment and GDP per worker for a cross-section of the 104 countries in my sample. The top panel shows the average years of schooling among the population with pre-college education. The bottom plot presents the share of population with college education. Figure 3

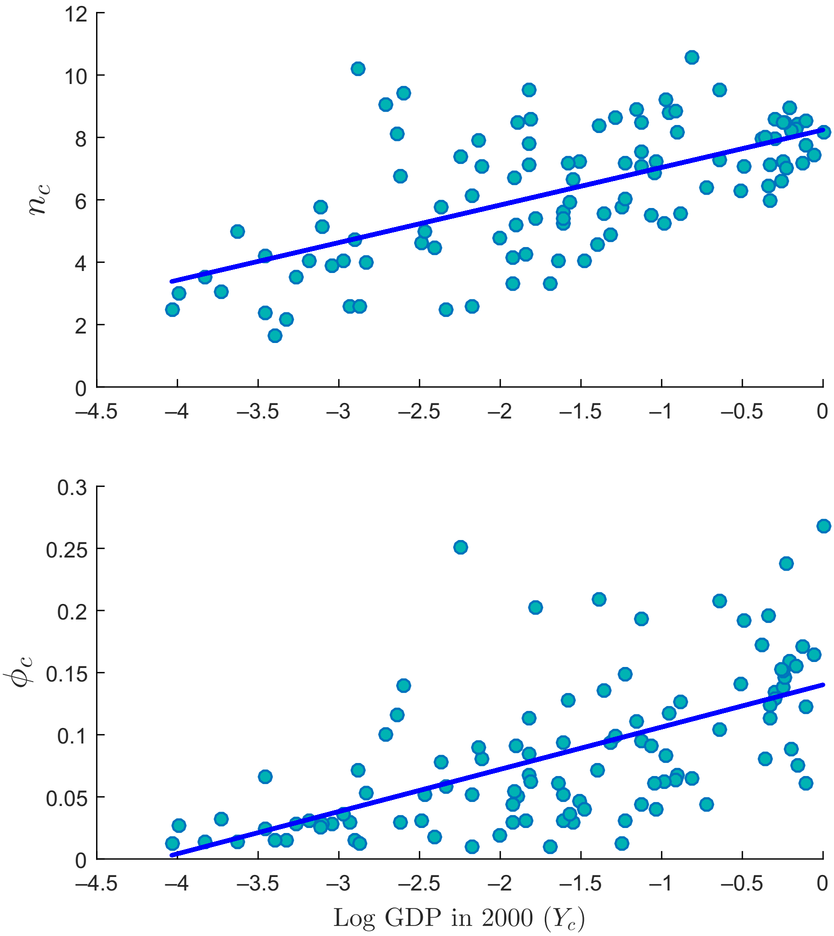

FIGURE 2. Years of pre-college schooling (n_c), college enrollment (ϕ_c), and GDP per worker (Y_c).

reports the calibrated values of TFP and the aggregate human capital stock, H_c. I set the US TFP and per worker GDP equal to 1, so that the TFP and GDP of other countries are expressed relative to the US values. Not surprisingly, TFP, schooling attainment, and the human capital stock all show strong positive relationships with GDP per worker. The correlation with TFP, however, looks stronger and more precise than the correlation with schooling attainment and human capital stock.

Table 2 reports distribution of the foreign education wedge for the cross-section of countries in my sample, calibrated using the parameter values in Table 1. Columns [a] and [b] present, respectively, the means and standard deviations for all countries in the sample. I also report the 25th, 50th, and 75th percentiles of Δ_m in columns [c], [d], and [e], respectively. The mean value of Δ_m stands at

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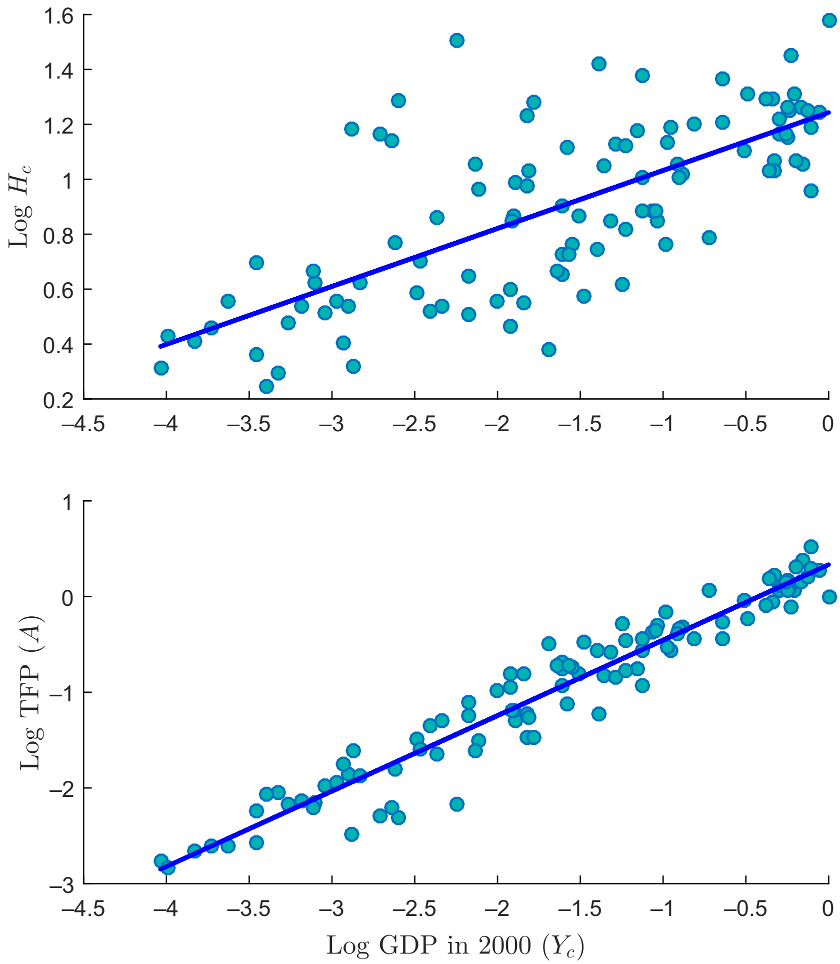

FIGURE 3. Human capital stock (H_c), TFP (A_c), and GDP per worker.

0.418, implying that the observed value of foreign education is less than half of the value implied by the prices for human capital. As can be seen from the three percentiles, there is also a significant variation across countries, where the 75th percentile exceed the 25th percentile by a factor of 2.7.

One could expect that developing countries could face stronger barriers to human capital transfer due to a number of potential factors. First, students in developing countries are likely to face greater financial constraints due to lack of wealth and underdeveloped financial markets. Since investing in a high quality college education involves a large amount of resources and could be a risky venture, financial constraints could be more consequential for students in poorer countries. Second, lack of complementary institutions in developing countries

TABLE 2. The foreign education wedge (Δ_m) from the baseline simulation

Moments		Percentiles		
[a] Mean	[b] St. dev.	[c] 25th	[d] 50th	[e] 75th
0.418	0.356	0.196	0.320	0.535

Notes: This table reports moments and percentiles of the foreign education wedge from the baseline simulation, using parameter values in Table 1.

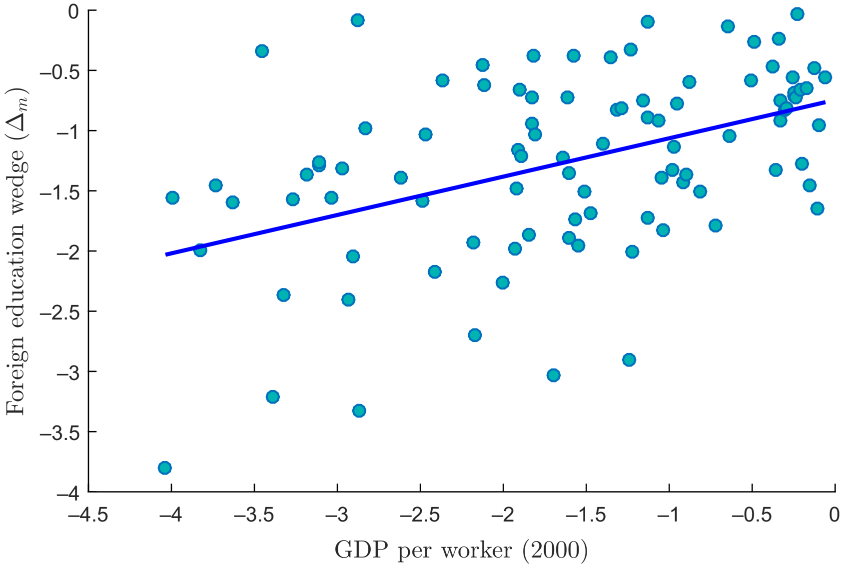

FIGURE 4. GDP per worker and the foreign education wedge, log scales.

could make it more costly to transfer human capital. In practice, the investment in high quality college education is risky not only to students, but also to universities, since establishing high quality universities requires a significant amount of long-term investment in facilities and human resources. In poorer countries, states are often fragile, and property rights tend to be weak (Besley and Persson (2011)). Thus, the greater political uncertainty and weaker property rights in poorer countries could discourage such an investment in human capital transfer.

The pattern in Figure 4 seems to suggest that poorer countries face greater barriers. The figure shows the relationship between per worker GDP (horizontal axis) and the wedge (vertical axis), with both variables in log scales. As GDP increases, Δ_m also tends to increase.

The relationship between initial income and the gain from removing the wedge could have an important implication for cross-country income gaps. For example, if poorer countries gain the most, this may help lower global income inequality.

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One could perhaps expect that poorer countries are poised to benefit the most from the removal. First, as shown in Figure 4, the barrier tends to get stronger among poorer countries. Second, the gap in initial level of human capital tends to be greater for poorer countries (Figure 3). Thus, to the extent that removal of the wedge helps narrow the gap in human capital, poorer countries could gain more. On the other hand, since the level of TFP tends to decrease with decreases in income levels, as shown in Figure 3, the value of high-skilled human capital could be lower in poorer countries. This suggests that gains from removing the wedge may not necessarily be higher for the poorer countries.

Figure 5 appears to capture these counteracting factors with regard to the relationship between initial income and the gain from removal of the wedge. I plot the gain as a function of initial income. The gain is defined as the ratio of the counterfactual levels to that of the actual levels, as in (46). The horizontal axes in all of the three subplots represent initial GDP per worker, defined relative to the US level and in log scales.

In the top and middle panels, respectively, I have the gains in high-skilled human capital and the gains in college enrollment (the ratio of the counterfactual to the actual values). Removal of the wedge affects human capital stock through two channels. First, the average level of high-skilled human capital among high-skilled individuals could increase, owing to an improved access to better quality teachers. Second, the improvement in the quality of teachers increases the value of college education and, hence, increases college enrollment (equation (32)). The top and middle panels of Figure 5 show these two effects. The bottom panels plot the gains in output.

The relationship between initial GDP and the gains appears to exhibit a hump-shaped pattern. Countries with the lowest incomes tend to gain less than those with middle incomes, suggesting that the lowest income countries are hampered by the low level of TFP. Countries with the highest incomes also do not tend to gain as much as the middle ones, since, to begin with, the initial gap in human capital stock is lower among former ones. The pattern in Figure 5 suggests that it is the combination of a sufficiently large TFP and a lower level of initial human capital that leads to a larger gain from the removal of the wedge.

In Figure 6, we take a closer look into the role that TFP differences may play in generating the hump-shaped relationship between initial income and the gains from removing the wedge. I plot the relationship between the gains and initial income after taking the effect of TFP into account. I first run two regressions: (1) I regress the gain on TFP; and (2) I regress the initial income on TFP. In Figure 6, I plot the residuals from the former regression against the residuals from the latter regression. We see that the hump-shaped pattern more or less disappears, suggesting that TFP differences are driving the hump-shaped pattern.

Table 3 presents a summary of the effects of removing the wedge on gaps in human capital and income. I report the initial values of income (y) and human capital stock (h), and the counterfactual values of income ($\tilde{y}$) and human capital stock ($\tilde{h}$). I also report the TFP levels (A). I present the results for a sample of all

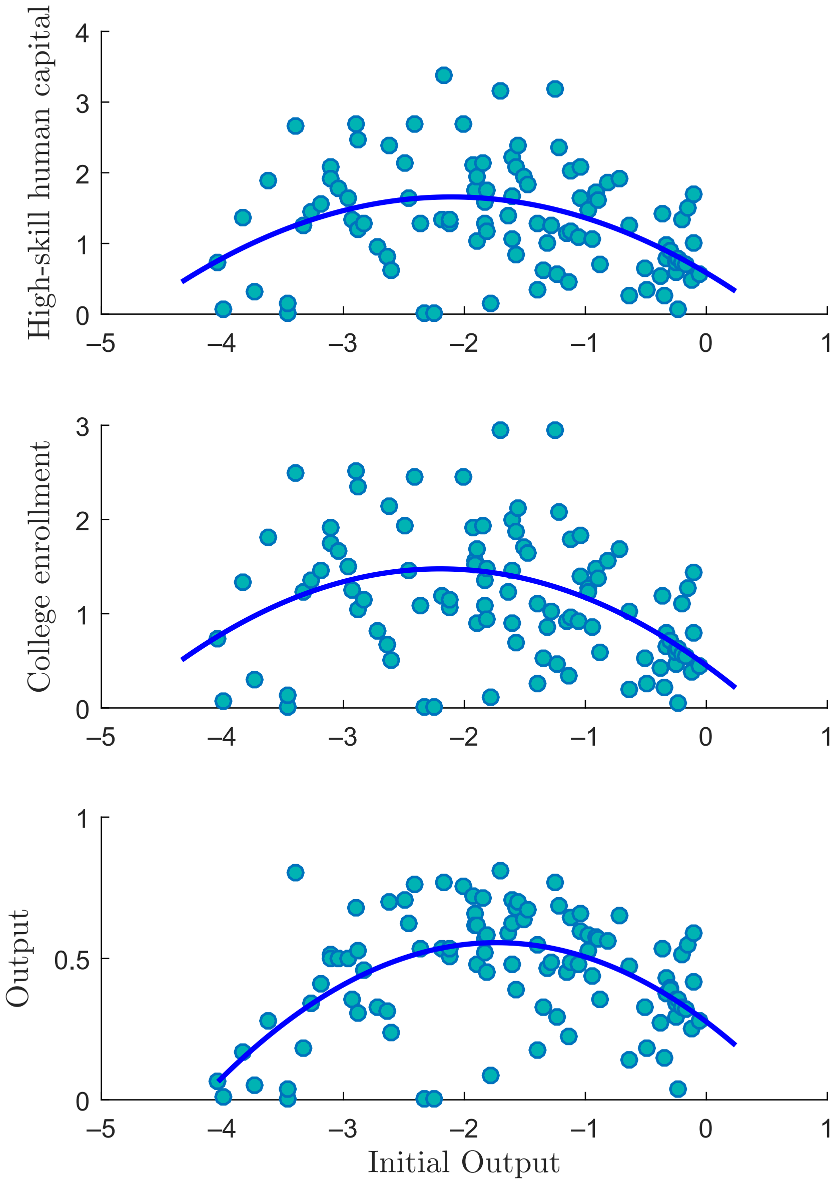

FIGURE 5. Gains from removal of the foreign education wedge: the ratio of counterfactual values of h_s (top panel), ϕ (middle panel), and output per worker (bottom panel) to actual levels, in log scales.

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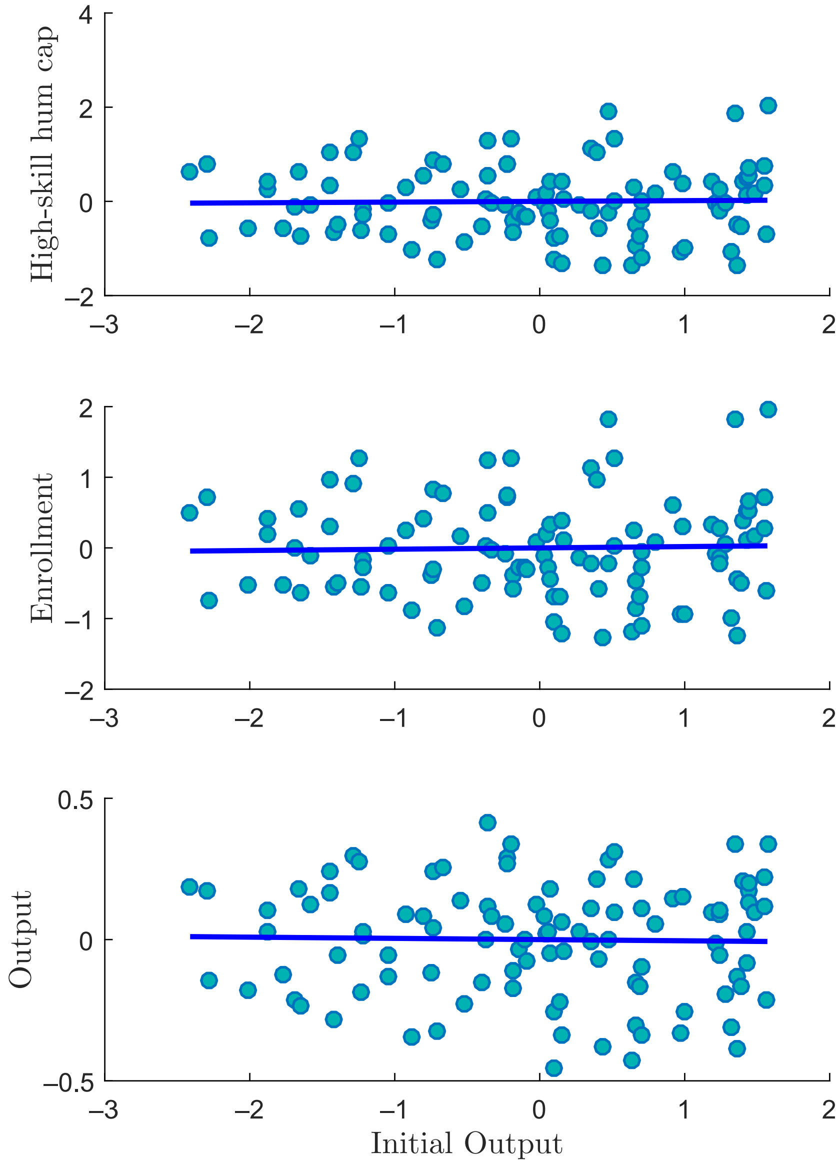

Notes: These plots show the relationship between the gains and initial income after taking the effect of TFP into account. I first run two regressions: (1) I regress the gains on TFP; and (2) I regress the initial income on TFP. Then, I plot the residuals from the former regression against the residuals from the latter regression.

FIGURE 6. Gains from removal of the foreign education wedge after taking into account the effect of TFP: the ratio of counterfactual values of h_s (top panel), ϕ (middle panel), and output per worker (bottom panel) to actual levels, in log scales.

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TABLE 3. Output (y), human capital stock (h), and TFP (A), as a percent of US values

	Income category (percentile)			
	[a] All	[b] (0,25]	[c] (25,50]	[d] (50,75]
y	32.1	11.7	34.8	66.2
$\tilde{y}$	48.2	19.3	59.1	93.5
$\tilde{y}/y$	1.50	1.65	1.70	1.41
h	52.9	45.0	56.5	68.4
$\tilde{h}$	82.3	72.1	93.8	95.1
A	53.2	25.2	63.5	98.6
Observations	103	58	21	11

Notes: This table reports the mean values of output and human capital stock. The values are reported for all countries (column [a]), as well as for the three groups of countries categorized by their level of income (columns [b]–[d]). I report both the actual values and the counterfactual values. The counterfactual values are from simulations after removing the foreign education wedge (see Section 4.1). All values are in per worker terms and expressed relative to US values, that is, as a percent of US values. The first row (y) reports PPP-adjusted output per worker in 2000. The second row ($\tilde{y}$) is the counterfactual output in the baseline simulation. The actual human capital stock (h) and the counterfactual values ($\tilde{h}$) are reported in the fourth and fifth rows, respectively. The last row (A) presents TFP.

countries as well as subgroups categorized by initial income. Column [a] includes all countries. Column [b] includes countries with initial incomes, expressed as a percent of US level, which are less than 25%. Columns [c] and [d] include countries whose initial incomes are, respectively, in the intervals (25, 50] and (50, 75] percent of the US income.

The average initial per worker output in the sample of all the countries is 32.1. The counterfactual output equals 48.2, representing a 50% increase in per capita income. This increase in income corresponds to closing a quarter of the average income gap between the USA and other countries, $(48.2 - 32.1)/(100 - 32.1) = 0.24$. For the lowest income group (column [b]), the initial income gap is 88.3%. Removal of the wedge narrows the gap to 80.7% and, hence, removes 9% of the initial gap, $(19.3 - 11.7)/(100 - 11.7) = 0.086$. For the second lowest group, output per worker increases by about from 34.8 to 59.1, closing over one-third of the initial gap. For the group of countries for which initial incomes are between 50% and 75% of the US level, the income gap narrows from 34 to 6%.

Across the income groups, there is a substantial decrease in the gap in human capital stock. The mean initial human capital stock for the sample of all countries (column [a]), again expressed as a percent of US human capital stock, stands at 52.9. In the counterfactual simulation, the human capital stock increases to 82.3, hence eliminating about 62% of the initial gap in human capital stock. For the lowest income group (column [b]), the gap decreases from 55 to 28%. For the middle- and upper-income groups, for which initial gaps in human capital stock stand at 43% and 32%, respectively, the counterfactual gaps decrease to less than

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TABLE 4. Sensitivity analysis: foreign education wedge (Δ_m)

		Moments		Percentiles		
	Obs.	Mean	St. dev.	25	50	75
Baseline (Table 1)	103	0.418	0.356	0.196	0.320	0.535
$\sigma = 2.8$	103	0.684	0.414	0.450	0.642	0.762
$\sigma = 1.6$	103	0.232	0.314	0.053	0.120	0.306
Life expectancy	103	0.490	0.382	0.239	0.401	0.572
Estimated Mincer	76	0.304	0.287	0.123	0.215	0.435

Notes: This table reports moments and percentiles of the foreign education wedge from robustness simulations. The first row reproduces the baseline simulation, that is, using the parameter values in Table 1. The second and third rows alter σ. The fourth row utilizes life expectancy when life expectancy is less than 64. The last row replaces θ with estimated Mincer returns.

7%. Since much of the gap in human capital stock is eliminated in the counterfactual simulation, particularly for the middle- and upper-income groups, we see that the counterfactual income gaps are more aligned with the TFP gaps. Thus, while the group of countries in column [d], with relatively higher initial incomes and higher TFP, eliminate nearly all of the income gap in the counterfactual simulation, a significant part of the income gap still remains for the other two groups due to the gaps in TFP.

4.2. Sensitivity Analysis and Further Discussions

In Tables 4, 5, and 6, I report a number of sensitivity analyses in which I undertake the simulations under alternative assumptions regarding parameter values. This exercise is meant to shed light on which of the assumptions matter most for the results. Table 4 presents the simulated wedge. For ease of comparison, the first row in Table 4 repeats the baseline parameter values from Table 2. The second and third rows report sensitivity of the simulation results to changing values of the elasticity of substitution, σ. This parameter is crucial, as it determines the calibrated values of human capital stock and TFP. I consider the two values estimated by Acemoglu and Autor (2012), $\sigma = 1.6$ and $\sigma = 2.8$. The smaller value is closest to estimates by Katz and Murphy (1992) and Ciccone and Peri (2005). Acemoglu and Autor (2012) derived the smaller (larger) estimate from data covering a shorter (longer) period, suggesting that the long-run elasticity of substitution is larger than the short-run one. The long-run elasticity is larger, possibly because firms have more time to adjust their technology choices in response to changes in the relative price and quantity of skilled versus unskilled workers (Acemoglu and Autor (2012), Caselli (2017), Rossi (2017), Hendricks and Schoellman (2018), Caselli and Ciccone (2019)).

In this case, 2.8 is perhaps a relevant scenario to consider for value of σ. First, my focus is the long run, for which the larger elasticity is particularly relevant.

TABLE 5. Sensitivity analysis: Output (y), human capital stock (h), and TFP (A), as percent of US values

	Income category			
	[a] All	[b] (0, 25]	[c] (25, 50]	[d] (50, 75]
Actual output (y)	32.1	11.7	34.8	66.2
Panel I: $\sigma = 2.8$				
$\tilde{y}$	41.8	15.8	50.4	84.1
$\tilde{y}/y$	1.30	1.35	1.45	1.27
h	60.9	52.9	65.7	75.5
$\tilde{h}$	80.2	68.4	93.8	95.1
A	46.4	21.2	54.2	88.8
Panel II: $\sigma = 1.6$				
$\tilde{y}$	59.8	25.8	75.2	109.9
$\tilde{y}/y$	1.87	2.21	2.16	1.66
h	43.0	35.4	45.3	59.2
$\tilde{h}$	85.2	77.3	93.8	95.1
A	65.7	32.8	80.7	115.6

Notes: This table shows the sensitivity of results to altering the values of σ (elasticity of substitution). I report the mean values of output and human capital stock. The values are reported for all countries (column [a]), as well as for the three groups of countries categorized by their level of income (columns [b]–[d]). I report both the actual values (h and y) and the counterfactual values ($\tilde{h}$ and $\tilde{y}$). The counterfactual values are from simulations after removing the foreign education wedge (see Section 4.1). All values are in per worker terms and expressed relative to US values, that is, as percent of US values.

Second, the implied wage differences across countries, which also depend on the value of σ, appear more realistic for $\sigma = 2.8$. Using data on earnings of US immigrants before and after migration, Hendricks and Schoellman (2018) examine the difference between post-migration wage (immigrants' earnings in the USA) with the pre-migration wage (immigrants' earnings in their home countries prior to their migration). For high-skilled immigrants who migrated from countries whose per capita income is less than a quarter of the US value, Hendricks and Schoellman (2018) find that the post-migration wage exceeds the pre-migration wage by about a factor of 2. In my model, if a high-skilled worker moves from country c to the USA, their wage increases by a factor of the ratio $w_{US,s}/w_{c,s}$, where $w_{c,s}$ is the wage per unit of high-skilled human capital in country c. Thus, the wage gain reported by Hendricks and Schoellman (2018) suggests that the ratio of $w_{US,s}$ to the mean value of $w_{c,s}$ for countries for which per capita income is less than a quarter of the US value should be about 2. In the simulation, when I set σ to equal 1.6, this ratio is found to be 0.74, a much lower number than 2. However, when σ is set to equal 2.8, the ratio equals 2, which is more consistent with the data on wage gain at migration.

TABLE 6. Sensitivity analysis: Output (y), human capital stock (h), and TFP (A), as percent of US values

	Income category			
	[a] All	[b] (0, 25]	[c] (25, 50]	[d] (50, 75]
Panel I: Life expectancy				
y	32.1	11.7	34.8	66.2
$\tilde{y}$	48.4	19.7	59.1	93.5
h	53.1	45.3	56.5	68.4
$\tilde{h}$	84.1	75.4	93.8	95.1
A	53.1	25.1	63.5	98.6
Panel II: Mincer coefficient from Montenegro and Patrinos (2014)				
y	33.8	11.7	35.0	67.7
$\tilde{y}$	85.5	28.5	80.2	174.1
h	37.6	33.6	43.6	40.5
$\tilde{h}$	85.7	73.2	95.7	100.8
A	89.4	36.2	84.0	173.6

Notes: This table presents sensitivity analysis for simulated gains from removing the foreign education wedge. I report the mean values of output and human capital stock. The values are reported for all countries (column [a]), as well as for the three groups of countries categorized by their level of income (columns [b]–[d]). I report both the actual values (h and y) and the counterfactual values ($\tilde{h}$ and $\tilde{y}$). The counterfactual values are from simulations after removing the foreign education wedge (see Section 4.1). All values are in per worker terms and expressed relative to US values, that is, as percent of US values. Panel I utilizes life expectancy when life expectancy is less than 64. In Panel II, I replace θ with estimated Mincer returns.

Table 4 shows that the simulation results are quite sensitive to the value of σ. As the elasticity decreases, the simulated value of Δ_m decreases. The mean value of Δ_m is 0.68 for $\sigma = 2.8$; it decreases to 0.42 for $\sigma = 2$, and decreases further to 0.23 for $\sigma = 1.6$. All of the percentiles also decrease with decreases in σ.[5]

In Panels I and II of Table 5, I report the simulated values of output, TFP, and human capital stocks for the two values of σ. For ease of comparison, I present the actual per worker output on the first row. As noted by Jones (2014) and others, a smaller value of σ implies a larger gap in human capital stock between richer and poorer countries. In contrast, the gap in TFP tends to increase with an increase in σ. Hence, the role of human capital stock in explaining income gaps decreases with an increase in σ. This is also the case in my simulation. When $\sigma = 2.8$, the mean of the initial human capital stock gap in the sample of all countries is 39%, but the gap increases to 57% when I assume $\sigma = 1.6$. Correspondingly, the TFP gap decreases from 54 to 34% as σ decreases from 2.8 to 1.6. These patterns of the gaps in response to the change in σ hold for all of the three income groups.

Since a smaller value of σ implies a larger gap in human capital stock, there is a greater room to narrow down the gap in human capital stock as σ decreases. In my simulation, removal of the wedge decreases the human capital stock gap by 49% when $\sigma = 2.8$, while the gap decreases by a much larger amount of 74% when $\sigma = 1.6$. Moreover, since the gap in human capital explains a greater share of the income gap for smaller values of σ, each decrease in the human capital gap leads to a greater decrease in the output gap. Thus, the impact of removal of the wedge on output gap is larger when σ is smaller. For $\sigma = 2.8$, the mean decrease in the output gap is 14%, while the gap decreases by 41% for $\sigma = 1.6$.

Table 6 presents sensitivity analysis for the demographic and education parameters (i.e., life expectancy and Mincer returns). In the baseline simulation, I assumed a retirement age of 64 for all countries. I relax this assumption, by allowing for the retirement age to vary based on life expectancy. Instead of assuming a retirement age of 64 for all countries, I replace retirement age with life expectancy when the latter is less than 64 years.[6] As one can see from the fourth row of Table 4, the mean of Δ_m increases to 0.49 (from 0.42). As compared to the effect of changing σ, this change is relatively small. Panel I of Table 6 presents the counterfactual simulations using life expectancy. For the upper income groups, the use of life expectancy has no effect since the expectancy is already above 64. For the lower income groups, the differences in the gains are less than 1 percentage point, hence, quantitatively negligible.

I also alter my assumption about returns to schooling. In my baseline calibration, I assumed that a 10% annual return to schooling holds for all countries. I now use actual estimates of the returns instead, which vary quite a lot across countries. I use the relatively recent estimates by Montenegro and Patrinos (2014), whose sample includes the most comprehensive set of countries. Montenegro and Patrinos (2014) report estimates of Mincer returns using household income data that were collected over several years, and report separate coefficients for each year with available data. I would like to offer a word of caution that there is a great deal of imprecision in these coefficients. Often, the coefficients vary greatly across survey samples within the same country and, hence, the choice of a 10% annual return for all countries is perhaps a preferable assumption.

I use the returns from surveys conducted in year 2000. If an estimate is not available for 2000, I use one from the year closest to 2000. I have 76 countries with Mincer coefficients in my sample, as the estimates are not available for all countries. The calibrated wedge using these Mincer coefficients are reported in the last row of Table 4. Both the mean and the percentiles of Δ_m tend to be less than their counterparts in the baseline calibration, suggesting that the level of the barrier, as implied by the use of estimated coefficients, is stronger than reported in the baseline calibration.

The gains calibrated using the Mincer estimates are reported in Panel II of Table 6. Given that not all of the countries in the baseline sample are included in the calibration using Mincer estimates, Panel II reports the actual output for the sample of countries with Mincer returns, with which I make the counterfactual comparisons in the calibration using Mincer estimates. The mean of initial output among the sample of all countries is 34, implying an initial output gap of 66%. In the counterfactual simulation, this gap decreases to 14%. The human capital stock gap also decreases substantially. This pattern of larger gains when using estimated coefficients, as compared to the baseline results, holds across income groups.

I have also assessed the sensitivity of the simulation to changes in the two remaining parameters of human capital transfer in Table 1, namely, κ and ψ. The simulation results do not appear to change much for reasonable alteration of these parameters. In the baseline simulation, I set κ to equal 0.05, which is based on the estimates of the human capital externality for the general labor market. However, since the complementarity among various fields of knowledge could perhaps be more pronounced in tertiary education, I run the simulations assuming $\kappa = 0.1$ and $\kappa = 0.15$, which are, respectively, double and triple the baseline value of 0.05. In the baseline simulation, ψ was set using a rather conservative criteria that the number of college graduates who can become teachers is such that there are just enough number of teachers to train existing students. I also run the simulation by doubling the value of ψ. These changes in κ and ψ are found to affect the counterfactual values by less than 1 percentage point and, hence, are quantitatively negligible.

To sum up, depending on the assumed parameter values, the mean value of the wedge varies from 0.23 to 0.68. The level of output per worker, with an initial value of 32, ranges from 42 to 85 in the counterfactual simulations after removal of the wedge. In terms of sensitivity to parameter choices, the elasticity of substitution is particularly relevant. The available empirical estimates of σ vary roughly between 1.6 and 2.8. Given that my focus is on the long-run, values in upper ranges of these estimates are perhaps more relevant for this case. In the baseline scenario of $\sigma = 2$, which is an intermediate value in the range of available empirical estimates, removal of the wedge increases output by 50%. This gain decreases to 30% when I consider the larger value of 2.8. Thus, considering the values of σ in the range of 2–2.8, removal of the wedge decreases the output gap by about 14–24%.

The results could also be sensitive to alterations of assumptions in my model that I have not quantified in this paper. The education function abstracts from a number of possibly relevant factors. For example, I assume that the quality of college graduates has no impact on the quality of pre-college education. If one considers a potentially positive externality of improved college education on the quality of non-college education because of, for instance, college graduates working as high school teachers, the impact of removal of the wedges could be higher. The education function abstracts from differences in student abilities. In a setting with heterogenous student ability, since the return to the marginal student is likely to be lower than the average return (Oreopoulos and Petronijevic (2013)), the impact of increased enrollment due to removal of the wedges is likely to be lower.

I also abstract from possible technological biases with respect to skill categories. The implication of this assumption is not trivial. The choice of technology may be endogenous to the stock of available workers and their relative prices. As a result, some of the income gap between skilled and unskilled workers might be due to biases in technology, as opposed to the level of human capital embodied in workers (Acemoglu (2002), Okoye (2016), Caselli (2017), Rossi (2017)).

To the extent that earning differences between skilled and unskilled workers reflect technological biases (as opposed to differences in human capital embodied in skilled workers), the potential gains from human capital transfer would be lower. On the other hand, if one allows for endogenous technological choice, changes in the skill composition of workers could be amplified by the endogenous technological shifts in response to the changes in the relative supply of skilled workers. Thus, the effect of changes in the stock of skilled human capital stock (from foreign education) could be propagated by the endogenous technological change, and the human capital transfer could have an outsized effect on the country's technology and output.

5. CONCLUDING REMARKS

As a developing country catches-up, transitions into technology-intensive sectors, and becomes more reliant on high-skilled workers, the capacity for providing education in advanced science and technology proves essential. This poses a natural challenge since, to begin with, a developing country may not have high-skilled individuals who can provide such training. The historical experience of countries such as Japan, Korea, and Taiwan suggests the use of foreign graduates as a possible way to address this challenge.

In this paper, I develop a model of economic growth that allows for the use of high-skilled foreign teachers to train domestic students. I use the model to assess the extent of frictions in the import of teachers and to evaluate the gains from removing the frictions. I first simulate the model with the assumption that there are no frictions in the import of teachers. The distribution of human capital stocks from this simulation is then compared with the human capital stocks observed in the data. I find that there is a large wedge between the simulated and observed distributions of human capital stocks.

Removal of the wedge is found to eliminate much of the gap in human capital stock between the USA and the rest of the countries in the sample. I also find that the removal of the wedge lowers the income gap by about 14–24%.

Compared to countries with the lowest and highest incomes, middle-income countries appear to gain the most from removal of the wedge. Though poorer countries have a lower level of initial human capital stock and, hence, greater room to raise their income through raising human capital, their low level of TFP means there is no much benefit from raising their human capital using imported teachers. On other hand, richer countries have a higher level of initial human capital stock, and hence, they do not have much room to raise their income with imported teachers. The middle-income countries, with a combination of relatively high TFP and low initial human capital stock, appear to be situated to benefit the most from removal of the wedge.

Despite its potential role in catch-up, the issue of human capital transfer has received little attention in the growth literature. Many related questions beg for future research. The calibrated wedges are results of model assumptions, which are not always easy to verify. For example, the issue of human capital measurement, upon which the model calibration relies, is still a subject of much debate and warrants further research (Jones (2014), Okoye (2016), Rossi (2017), Caselli and Ciccone (2019)). The simulations also fall short of a full welfare analysis of the gains from human capital trade, as such an analysis would have required more assumptions than I would like to make due to data limitations. However, given the size of the wedge in the simulation, one naturally wonders whether, left alone to market forces, countries may underinvest in human capital transfer. Detailed welfare analysis of specific policies, such as China's "Project 211," which channels state subsidies for recruiting international faculty by Chinese universities, could therefore have the potential to provide useful insights on catch-up strategies.

NOTES

1. Alternatively, the import of teachers can occur when domestic students study abroad and choose to return and teach at domestic universities.
2. In order for skilled individuals to be indifferent about working in the goods or education sector, I am implicitly assuming that ψ is large enough, so that some skilled individuals who work in the goods sector can also engage in teaching.
3. Note that the interest rate is exogenous, and hence, I do not impose an aggregate resource constraint in the goods market. This is a short-hand for imputing the interest rate from endogenizing saving/consumption, or from the discount rate for time-preference (Manuelli and Seshadri (2014)).
4. The terms $D_{c,u}$, $D_{c,s}$, and $\overline{D}_{c,u}$ in equation (32) are given by equations (25), (28), and (31), respectively.
5. In the extreme case of $\sigma = \infty$, $\Delta_m = 1$ for all countries.
6. Data on life expectancy are from World Development Indicators online database, accessed on June 6, 2017.

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APPENDIX A

A.1. THE VALUE OF DOMESTIC VERSUS FOREIGN EDUCATION

In this appendix, I derive $Q(h^*_{f,s}, h^*_{d,s})$ in (43), that is, the factor by which the value of foreign education exceeds that of the domestic one.

Rewriting (37),

$$\begin{aligned} V^*_{d,s}(\tau, h^*_{m,s}) &= V^*_{d,s}\left(\tau, f^1\left(h^*_{f,s}\right)\right) \\ &= (1-\psi)V^*_{d,g}\left(\tau, f^1\left(h^*_{f,s}\right)\right) + \psi V^*_{d,e}\left(\tau, f^1\left(h^*_{f,s}\right)\right), \end{aligned} \tag{A1}$$

where $f^j()$ is given by the recursion (36).

Along the BGE, earnings grow at the rate of g. Following from (38),

$$\begin{aligned} V^*_{d,g}\left(\tau, f^j\left(h^*_{f,s}\right)\right) &= \int_{16}^{T} \exp(-rx) y^*_{d,g}\left(\tau + x, f^j\left(h^*_{f,s}\right)\right) dx \\ &= f^j\left(h^*_{f,s}\right) w^*_{d,s}(\tau) \int_{16}^{T} \exp\left(-(r-g)x\right) dx \\ &= f^j\left(h^*_{f,s}\right) w^*_{d,s}(\tau) D_1, \end{aligned} \tag{A2}$$

where

$$D_1 \equiv \int_{16}^{T} \exp\left(-(r-g)x\right) dx. \tag{A3}$$

Similarly, following from (39),

$$\begin{aligned} V^*_{d,e}\left(\tau, f^j\left(h^*_{f,s}\right)\right) &= \int_{16}^{T} \exp(-rx) y^*_{d,e}\left(\tau + x, f^j\left(h^*_{f,s}\right)\right) dx \\ &= y^*_{d,e}\left(f^j\left(h^*_{f,s}\right), i\right) \int_{16}^{T} \exp\left(-(r-g)x\right) dx \\ &= y^*_{d,e}\left(f^j\left(h^*_{f,s}\right), i\right) D_1. \end{aligned} \tag{A4}$$

Inserting (A2) and (A4) into (A1),

$$V^*_{d,s}(\tau, f^j\left(h^*_{f,s}\right)) = (1-\psi)\psi D_1 f^j\left(h^*_{f,s}\right) w^*_{d,s}(\tau) + \psi D_1 y^*_{d,e}\left(f^j\left(h^*_{f,s}\right), i\right). \tag{A5}$$

Rearranging (41),

$$y^*_{d,e}\left(\tau, f^j\left(h^*_{f,s}\right)\right) \\ \frac{1}{P_{d,s}\int_{12}^{16}\exp\left((g-r)x\right)dx}\left[V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right) - V^*_{d,s}(\tau, h^*_{d,s}) + \zeta^*_{d,s}(\tau, h^*_{d,s})\right]. \tag{A6}$$

Combining with (35) and (A2),

$$\begin{aligned} y^*_{d,e}\left(\tau, f^j\left(h^*_{f,s}\right)\right) &= \frac{1}{P_{d,s}D_2}\left[V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right) - V^*_{d,s}(\tau, h^*_{d,s}) + \zeta^*_{d,s}(\tau, h^*_{d,s})\right] \\ &= \frac{1}{P_{d,s}D_2}\left[V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right) - h^*_{d,s}w^*_{d,s}(\tau)D_1 + h^*_{d,s}w^*_{d,s}(\tau)P_{d,s}D_2\right] \\ &= \frac{1}{P_{d,s}D_2}\left[h^*_{d,s}w^*_{d,s}(\tau)P_{d,s}D_2 - h^*_{d,s}w^*_{d,s}(\tau)D_1\right] + \frac{1}{P_{d,s}D_2}V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right) \\ &= \frac{1}{P_{d,s}D_2}h^*_{d,s}w^*_{d,s}(\tau)\left[P_{d,s}D_2 - D_1\right] + \frac{1}{P_{d,s}D_2}V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right), \end{aligned} \tag{A7}$$

where

$$D_2 \equiv \int_{12}^{16}\exp\left((g-r)x\right)dx. \tag{A8}$$

Inserting (A7) into (A5),

$$\begin{aligned} V^*_{d,s}(\tau, f^j\left(h^*_{f,s}\right)) &= (1-\psi)D_1 f^j\left(h^*_{f,s}\right) w^*_{d,s}(\tau) \\ &\quad + \psi D_1\left[\frac{1}{P_{d,s}D_2}h^*_{d,s}w^*_{d,s}(\tau)\left[P_{d,s}D_2 - D_1\right] + \frac{1}{P_{d,s}D_2}V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right)\right] \\ &= (1-\psi)V^*_{d,s}(\tau, h^*_{d,s})\frac{f^j\left(h^*_{f,s}\right)}{h^*_{d,s}} + \Gamma V^*_{d,s}(\tau, h^*_{d,s}) + \beta V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right), \end{aligned} \tag{A9}$$

where

$$\beta = \frac{\psi D_1}{P_{d,s}D_2} \tag{A10}$$

$$\Gamma = \frac{\psi}{P_{d,s}D_2}(P_{d,s}D_2 - D_1) = \psi - \beta \tag{A11}$$

$$V^*_{d,s}(\tau, h^*_{d,s}) = D_1 h^*_{d,s} w^*_{d,s}(\tau). \tag{A12}$$

Forwarding (A9) to $j+1$,

$$V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right) \\ = (1-\psi)V^*_{d,s}(\tau, h^*_{d,s})\frac{f^{j+1}\left(h^*_{f,s}\right)}{h^*_{d,s}} + \Gamma V^*_{d,s}(\tau, h^*_{d,s}) + \beta V^*_{d,s}\left(\tau, f^{j+2}\left(h^*_{f,s}\right)\right). \quad \textbf{(A13)}$$

Inserting (A13) back into (A9),

$$\begin{aligned} V^*_{d,s}\left(\tau, f^{j}\left(h^*_{f,s}\right)\right) &= (1-\psi)V^*_{d,s}(\tau, h^*_{d,s})\frac{f^{j}\left(h^*_{f,s}\right)}{h^*_{d,s}} + \Gamma V^*_{d,s}(\tau, h^*_{d,s}) + \beta V^*_{d,s}\left(\tau, f^{j+1}\left(h^*_{f,s}\right)\right) \\ &= (1-\psi)V^*_{d,s}(\tau, h^*_{d,s})\frac{f^{j}\left(h^*_{f,s}\right)}{h^*_{d,s}} + \Gamma V^*_{d,s}(\tau, h^*_{d,s}) \\ &\quad + \beta\left((1-\psi)V^*_{d,s}(\tau, h^*_{d,s})\frac{f^{j+1}\left(h^*_{f,s}\right)}{h^*_{d,s}} + \Gamma V^*_{d,s}(\tau, h^*_{d,s}) + \beta V^*_{d,s}\left(\tau, f^{j+2}\left(h^*_{f,s}\right)\right)\right). \end{aligned} \quad \textbf{(A14)}$$

Repeating this recursion indefinitely,

$$\begin{aligned} V^*_{d,s}\left(\tau, f^{j}\left(h^*_{f,s}\right)\right) &= \Gamma V^*_{d,s}(\tau, h^*_{d,s})\sum_{k=0}^{\infty}\beta^k + (1-\psi)V^*_{d,s}(\tau, h^*_{d,s})\sum_{k=0}^{\infty}\beta^k\frac{f^{j+k}\left(h^*_{f,s}\right)}{h^*_{d,s}} \\ &= \Gamma V^*_{d,s}(\tau, h^*_{d,s})\sum_{k=0}^{\infty}\beta^k + (1-\psi)V^*_{d,s}(\tau, h^*_{d,s})\sum_{k=0}^{\infty}\beta^k\frac{f^{j+k}\left(h^*_{f,s}\right)}{h^*_{d,s}} \\ &= \left(\frac{\Gamma}{1-\beta} + (1-\psi)\sum_{k=0}^{\infty}\beta^k\frac{f^{j+k}\left(h^*_{f,s}\right)}{h^*_{d,s}}\right)V^*_{d,s}(\tau, h^*_{d,s}) \\ &= \left(\frac{\psi-\beta}{1-\beta} + (1-\psi)\sum_{k=0}^{\infty}\beta^k\frac{f^{j+k}\left(h^*_{f,s}\right)}{h^*_{d,s}}\right)V^*_{d,s}(\tau, h^*_{d,s}). \end{aligned} \quad \textbf{(A15)}$$

Thus, the value of acquiring $h^*_{m,s}$ units of high-skilled human capital is given by:

$$\begin{aligned} V^*_{d,s}(\tau, h^*_{m,s}) &= V^*_{d,s}\left(\tau, f^{1}\left(h^*_{f,s}\right)\right) \\ &= QV^*_{d,s}(\tau, h^*_{d,s}), \end{aligned} \quad \textbf{(A16)}$$

where

$$Q = \left(\frac{\psi-\beta}{1-\beta} + (1-\psi)\sum_{j=1}^{\infty}\beta^{j-1}\frac{f^{j}\left(h^*_{f,s}\right)}{h^*_{d,s}}\right) \quad \textbf{(A17)}$$

captures the factor by which the value of foreign education, $V^*_{d,s}(\tau, h^*_{m,s})$, exceeds that of the domestic one, $V^*_{m,s}(\tau, h^*_{d,s})$.

APPENDIX B

B.1. COUNTRY LIST, EDUCATIONAL ATTAINMENT, AND INCOME

TABLE B1. Years of pre-college schooling (n), percent of college graduates (ϕ), GDP per worker (y, % of US)

Country	n	ϕ	y	Country	n	ϕ	y
Albania	8.47	5.05	15.11	Jordan	6.72	5.39	14.74
Argentina	7.22	4.03	35.58	Kazakhstan	9.52	11.30	16.17
Armenia	9.42	13.92	7.44	Kenya	4.03	3.05	4.15
Australia	8.92	15.91	81.21	Kyrgyzstan	9.05	10.06	6.65
Austria	8.44	7.58	85.95	Laos	3.53	2.77	3.82
Bahrain	5.55	12.68	41.46	Latvia	8.63	9.87	27.63
Bangladesh	3.86	2.83	4.80	Liberia	3.00	2.69	1.85
Belgium	7.41	16.44	94.33	Lithuania	8.88	11.06	31.46
Belize	7.22	4.63	22.03	Malaysia	7.19	3.13	29.39
Benin	2.17	1.48	3.60	Mauritania	2.57	1.19	5.66
Bolivia	5.79	7.80	9.42	Mauritius	5.75	1.21	28.84
Botswana	6.67	2.92	21.24	Mexico	5.50	9.14	34.58
Brazil	5.25	5.23	20.04	Mongolia	8.09	11.58	7.13
Bulgaria	7.20	12.74	20.72	Morocco	2.56	5.12	11.33
Canada	8.26	15.56	84.54	Namibia	4.80	1.88	13.45
CA Rep.	2.50	1.25	1.77	Nepal	2.39	2.45	3.14
Chile	7.05	9.48	32.42	Netherlands	8.49	14.58	78.89
China	6.76	2.88	7.32	New Zealand	7.06	19.17	61.12
Colombia	5.63	9.36	19.98	Norway	8.54	12.23	90.31
Congo	4.72	1.56	5.49	Pakistan	2.46	5.86	9.72
Costa Rica	5.56	13.58	25.87	Panama	6.04	14.87	29.25
Cóte d'Ivoire	2.57	2.98	5.33	Paraguay	4.99	5.18	8.48
Croatia	8.15	6.75	40.65	Peru	5.42	20.25	16.89
Cyprus	6.44	19.56	71.23	Philippines	7.08	8.02	12.02
Czech Rep.	10.57	6.49	44.37	Poland	9.20	8.34	37.76
Denmark	8.56	13.44	74.46	Portugal	6.39	4.42	48.78
Dom. Rep.	5.38	3.09	20.10	Korea	7.27	20.77	52.52
Ecuador	5.18	9.16	14.98	Romania	8.61	6.24	16.33
Egypt	4.24	3.05	15.87	Russia	8.38	20.93	24.91
El Salvador	4.22	6.61	3.17	Slovakia	8.85	6.39	40.16
Estonia	8.48	19.29	32.31	Slovenia	9.53	10.40	52.88
Fiji	7.77	6.77	16.10	Spain	5.98	12.35	71.70
Finland	7.25	13.87	78.20	Sri Lanka	7.93	9.00	11.90
France	8.20	8.80	81.94	Swaziland	3.31	1.03	18.37
Gabon	4.58	7.09	24.70	Sweden	8.45	15.11	78.24
Gambia	1.63	1.47	3.36	Syria	4.06	3.54	5.14

TABLE B1. Continued

Country	n	ϕ	y	Country	n	ϕ	y
Germany	7.93	12.90	74.03	Taiwan	8.02	8.02	69.68
Ghana	5.13	2.81	4.47	Tajikistan	10.18	7.15	5.63
Greece	6.29	14.07	60.07	Thailand	4.12	4.40	14.69
Guatemala	3.31	2.92	14.57	Togo	3.51	1.35	2.18
Honduras	4.60	3.12	8.33	T. & Tobago	7.54	4.32	32.45
Hungary	8.80	11.70	38.73	Tunisia	4.05	4.01	22.86
Iceland	7.10	11.33	71.83	Turkey	5.23	6.27	37.43
India	3.99	5.28	5.89	USA	8.14	26.73	100.00
Indonesia	4.45	1.82	9.00	Uganda	3.06	3.21	2.39
Iran	4.86	9.32	26.85	Ukraine	7.37	25.14	10.61
Iraq	4.06	6.08	19.40	UK	6.62	15.23	77.48
Ireland	7.16	17.09	88.32	Uruguay	6.87	6.07	35.28
Israel	7.01	23.83	79.64	Venezuela	5.94	3.64	20.91
Italy	7.73	6.13	89.65	Vietnam	5.76	2.51	4.47
Jamaica	7.12	8.47	16.14	Zambia	4.98	1.44	2.66
Japan	7.96	17.19	68.79	Zimbabwe	6.12	1.03	11.41

This table presents the list of countries in our sample, along with data on years of pre-college schooling (n), the percent of adult population with college education (ϕ), and per worker output as a percent of US per worker output (y).

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