Economic growth and trade in human capital

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Abdulaziz B. Shifa[*]

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Abstract

A salient empirical pattern in the East Asian "miracle" is a large increase in output and factor accumulation (both human and physical capital) *despite* only a modest increase in TFP. I present a simple model of growth and economic catch-up that provides a possible explanation. A novel element of the model is a global market for education that allows for human capital transfer from frontier to developing economies. This assumption is motivated by the fact that, during the technological catch-up of countries like Korea and Taiwan, domestic universities usually relied on graduates of Western universities to provide advanced training in science and engineering. I find that this channel of human capital transfer can substantially amplify the impact of a TFP increase in the catching-up economy, providing a rationale for the empirical pattern. A TFP increase has a larger impact in the catching-up economy than in the frontier economy because it increases the demand for foreign education in the former (but not in the latter), leading to an increase in human capital. Assuming a standard production function with physical and human capital as inputs, the increase in human capital in turn induces the accumulation of physical capital, further amplifying the impact of a TFP increase. Using plausible parameter values from the literature and the data, I simulate the model to quantify the extent of this amplification. I find that the possibility of human capital transfer can double the impact of a TFP increase in a typical catching-up economy.

JEL Code: O11, O47, O15
Key words: *Growth; human capital transfer; productivity; catch-up.*

1 Introduction

Over the past decades, several East Asian economies narrowed their income gaps to developed economies through rapid growth – a phenomenon that Lucas (1993) referred to as a "miracle" since it lifted millions out of poverty within a relatively short period. A salient empirical pattern in the East Asian experience is a large increase in output and factor accumulation (both human and physical capital) despite only a modest increase in TFP, as documented by Young (1992, 1995), Collins and Bosworth (1996) and Kim and Lawrence (1994). This pattern appears to contradict the standard notion that growth is fundamentally driven by productivity improvement. For example, Collins and Bosworth (1996) argue that the main lessons of East Asia's success "come not from identifying which policies best promote TFP growth, but how countries can achieve and sustain high rates of saving and investment". Ventura's model of growth through a high saving rate, rather than through a higher productivity growth, is also motivated by this empirical pattern (Ventura 1997).

In this paper, I propose a simple model of growth and catch-up that offers an alternative explanation for why catching-up economies may experience a large increase in output and factor accumulation despite a small increase in TFP. I will use the model to discuss whether catch-up led by a large increase in factor accumulation is consistent with the standard notion that TFP is the fundamental driver. A novel element of the model is a global education market that allows for the possibility of human capital transfer from frontier to developing economies. In the model, those who received advanced education in frontier economies (such as science and engineering professors trained in the West) can train students in developing economies, provided that the students have sufficient incentives to pay

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for the cost of education.

Using foreign graduates to accumulate domestic human capital is often argued to have played an important role in the technological catch-up of countries like Taiwan, Korea and Japan (Mazzoleni 2008). After the Meji restoration in the late 19th century, Japan relied heavily on foreign scientists to train its domestic students with the ambition to catch-up with the West in science and technology. The entire faculty in Japan's first engineering college, namely the Imperial College of Engineering, consisted of British scientists (Mazzoleni 2008). A large number of 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).

Korea and Taiwan also used foreign graduates (mainly from the US) to provide advanced trainings at their colleges. For example, the Korea Advanced Institute of Science and Technology (KAIST), which primarily focused on supplying skilled workers who were needed to advance the Korean industrial sector, mainly employed foreign-trained professors from the US as a means of transferring technological knowledge to domestic students. Hsieh (1989) reports that the shares of the faculty that received their degree abroad at the two leading universities in Taiwan, National Tsing Hua University and National Taiwan University, were 84% and 74%, respectively. This is also partly reflected in a relatively large presence of Taiwanese students in US colleges (see Figure 1).

In this paper, I present a simple framework to analyze the interaction between catch-up by a developing country and transfer of human capital via import of teachers, as illustrated in the above examples. In the model, output is a function of physical capital, human capital (supplied by skilled workers), raw labor (supplied by unskilled workers) and the level of

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TFP. I assume that the acquisition of human capital involves an investment of time both by the teacher and the student. Teaching is done by skilled individuals who can also engage in the production of goods as skilled workers. The teachers are assumed to be heterogeneous with respect to the level of their human capital (i.e., their quality). Students will then choose from a menu of teachers with different levels of quality. Students taught by high-quality teachers will have a higher level of human capital upon graduation. Although high-quality teachers are preferable to low-quality ones, they are more expensive because the wage a teacher receives from teaching should be weakly higher than her earnings from working in the production sector as a skilled worker. Hence, students face the trade-off between the quality and cost of education.

In addition to domestic graduates, the menu of teachers also includes graduates from the frontier economy so that human capital accumulation is not constrained by the domestic stock of human capital. This assumption allows for possibilities such as graduates from US universities teaching at universities in Taiwan. Thus, the menu of teachers is only constrained by the level of human capital in the frontier economy. A developing economy may then narrow its gap to the frontier economy when individuals in the former have sufficient incentives to pay the cost of importing high-quality teachers from the frontier economy.

The main outcome of the model is that a developing economy may experience a large increase in output in response to a relatively small increase in TFP. It is this prediction of the model that provides a possible explanation for the large increase in output and factor accumulation in catching-up economies, despite a relatively small increase in TFP. By definition, a higher TFP implies a higher level of efficiency in the economy whereby a given stock of human and physical capital results in a higher level of output. Thus, the TFP

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improvements will also increase the productivity of human capital. For the purpose of this discussion (even though it is not necessary), it is intuitive to think of the TFP increase as an outcome of policy/institutional reforms that remove distortions in the economy – factors that Hall and Jones (1999) emphasize as major drivers of productivity differences across countries. Examples of such reforms could be improved tax codes, more secure property rights and a better provision of public infrastructure. The increase in the productivity of human capital (due to the productivity improvement) increases the demand for high-quality education in the developing economy. This will lead to a rise in wages for high-quality teachers. As a result, foreign residents with higher human capital will be induced to come home and teach at domestic universities, leading to an increase in the domestic level of human capital. Since physical capital and human capital are complements, the increase in human capital in turn increases the marginal product of physical capital, which bolsters the accumulation of physical capital. It is due to this chain of complementarity, first from a TFP increase to human capital flows and then to physical capital accumulation, that a small increase in TFP of a catching-up economy leads to a relatively large increase in output.

There is a crucial asymmetry with regard to the impact of TFP increase in a frontier versus a developing economy. Compared to the frontier economy, the developing economy may experience a relatively large increase in output in response to a given TFP increase because the possibility of human capital transfer can have a substantial impact on the human capital stock of the developing economy. Such a transfer of human capital is naturally absent in the frontier economy as it is already at the edge of the knowledge frontier. Hence, a "miraculous" growth in a catching-up economy can be an outcome of the interaction be-

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tween productivity improvements (e.g., due to improved business climates) and the flow of human capital from the frontier economy. Thus, the large increase in output is fundamentally induced by a potentially marginal improvement in TFP, but catalyzed by the transfer of human capital.

Using parameter values from the literature and data, I simulate the model to quantify the extent to which the possibility of human capital transfer amplifies the effect of an exogenous increase in the TFP of a developing economy. As a first step in the calibration exercise, I solve for the balanced growth path (i.e., the long-run equilibrium) of a model with two-countries – a developed and a developing economy. On the balanced growth path, the *relative* levels of TFP, output and human capital between the developing and developed economy remain the same, i.e., both economies grow at the same rate. This is a standard result shared by a large class of multi-country growth models (e.g., Parente and Prescott 1994; Acemoglu and Ventura 2002; Damsgaard and Krusell 2010).

I calibrate the impact of a TFP increase under two scenarios. In the first scenario, the developing economy has access to the global education market whereas in the second scenario, it does not have access. The first scenario implies a higher level of income in the new steady state because the TFP increase induces a human capital transfer. Then, the output difference between the new steady states (after the TFP increase) under the two scenarios is the contribution of human capital transfer in augmenting the TFP impact. In one of the calibrations, I consider a case where the initial income of the developing country is just 8% of the frontier. This roughly corresponds to Taiwan's income relative to that of the US in the early 1950s (or China's relative income in the early 1990s). I then calibrate the steady state impact of a permanent and exogenous increase in the level of the developing

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economy's TFP relative to the frontier. I consider a TFP increase that is large enough so that, in the new steady state and with the possibility of human capital transfer, the developing economy's income becomes 70% of the frontier. Again, this roughly corresponds to the miraculous catch-up experienced by Taiwan in the course of half a century. Then, I re-calibrate the model assuming the same level of TFP increase but *without* the possibility of human capital transfer. Under a set of plausible parameter values, the steady state with the possibility of human capital transfer is found to be twice as large as the scenario without the human capital transfer. This implies that half of the output increase observed in an economy experiencing such a catch-up could plausibly come from the human capital transfer. Under a more conservative choice of parameter values, the contribution of human capital transfer can be about 30% of the total output increase.

The next section presents the related literature. Section 3 describes the environment of the model. Section 4 derives the equilibrium under the assumption of no human capital transaction across the border. In section 5, the equilibrium with human capital trade is analyzed. The final section concludes the paper.

2   Related literature

This paper builds on the existing models of human capital. A common assumption in the existing models of human capital accumulation and growth is that the future levels of human capital depend on the current stock of human capital in the economy (see, e.g., Lucas 1988; Bils and Klenow 2000). This assumption is reasonable to the extent that the knowledge frontier is constrained by the current stock of human capital in the economy, say,

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due to quality of the teachers currently available in the economy. This seems plausible for countries on the knowledge frontier, such as the US, that primarily rely on domestic graduates to train their students. However, countries that are behind the knowledge frontier may instead use foreign graduates with more advanced knowledge to train domestic students. Hence, the current level of human capital may not be the only determinant of the future level of human capital. The contribution of my model is to account for the possibility of such human capital transfer.

Young (1992, 1995) investigates the quantitative contribution of factor accumulation and productivity improvement for the rapid growth of the Asian economies. Young finds that the growth is largely driven by factor accumulation rather than productivity growth. Collins and Bosworth (1996) and Kim and Lawrence (1994) report similar results that emphasize the contribution of factor accumulation as opposed to productivity improvement for the rapid growth of Asian economies. Although Hsieh (2002) and Hsieh (1999) estimate a relatively larger growth in productivity, factor accumulation still accounts for a substantial portion of output growth. This paper is consistent with those empirical findings in the sense that it provides a possible explanation as to why we may observe a large increase in output and factor accumulation along with a potentially small increase in productivity.

This study is also related to the literature on cross-country income distribution and endogenous growth models. As noted by Acemoglu and Ventura (2002), a key feature of the endogenous growth models is technological spillover where the global technology frontier is shared by all countries, albeit with some delay (see, e.g., Howitt (2000), Parente and Prescott (1994) and Damsgaard and Krusell (2010)). I consider a specific channel

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for the transfer of technological knowledge from the frontier economy. Those who have the knowledge can engage in "selling" their human capital to residents across the borders as long as there are sufficient incentives. It is this particular channel that enables a relatively small improvement in overall productivity (due to factors such as improved policies and institutions) to have a substantial impact on output. Other studies that incorporate the transfer of knowledge from the old to the young through market transactions include Jovanovic and Nyarko (1995) and Park (1997). Similar to the results in Parente and Prescott (1994), differences in institutions and policies across countries (such as property rights and tax codes) translate into differences in the levels of steady-state output. Moreover, the model in this paper shares the standard result in the endogenous growth models that countries experience the same steady-state growth rates (i.e., a balanced growth path) although they may differ in income level.

I consider a simple learning technology where education involves an opportunity cost of time, as is the case in the standard human capital models (see, e.g., Ben-Porath (1967) and Stokey (1991)). Thus, I abstract from other forms of learning which are potentially important. Park (1997) models on-the-job learning where the old train the young at the job. Hence, learning occurs while producing and it does not necessarily involve an opportunity cost of time. Learning-by-doing is also another means of human capital accumulation which I do not incorporate in this paper [see, e.g., Arrow (1962), Krugman (1987), Lucas (1988), Stokey (1988) and Parente (1994)].

3 Environment of the model

3.1 Demography, preference and endowment

Assume that there are two countries: a developed (frontier) country with a higher level of human capital (i.e., the frontier) and a developing economy. Throughout the analysis, we assume that the markets for goods and physical capital are globalized and countries take the international interest rate as given. Time is discrete and infinite, $t \in \{0, 1, 2, \dots\}$.

We consider an overlapping generations model where current generations care about their offsprings, as in Becker and Barro (1988). Each individual lives for two periods – as young and old. Each country is populated by a continuum of infinitely-lived dynasties of households equal to mass one. Assume, for simplicity, a constant population size with each household having 1 unit of young and 1 unit of old. Denote the consumption of an individual born in period t while young and old, respectively, by c_t^y and c_t^o. The household's utility is given by

$$E_t U_t = E_t \{u_t + \beta U_{t+1}\} \tag{1}$$

where u_t denotes the utility from current consumption by current members of the household. Let the household's total consumption be denoted by $c_t = \left(c_t^y + c_{t-1}^o\right)$. We assume that the household's instantaneous utility, u_t, is logarithmic in c_t,

$$u_t = \log c_t \tag{2}$$

Inserting (2) into (1) and iterating forward (starting from $t = 0$), (1) becomes

$$E_0 U_0 = E_0 \sum_{t=0}^{\infty} \beta^t u_t = E_0 \sum_{t=0}^{\infty} \beta^t \log c_t \tag{3}$$

In each period, each living individual has one unit of labor. Young individuals are born with zero human capital. While young, an individual decides between working and studying. If she studies, she will acquire a positive amount of human capital for the next period (when she becomes old). Note that, at any point in time, it is only the old that have a positive amount of human capital.

Finally, let the period t distribution of human capital in the country be given by $\Gamma_t (\sigma_t)$, a probability measure on $(\Omega_t \cup \{0\}, \mathcal{F}_t)$ where

$$\Omega_t = \{h_{j,t} : h_{j,t} > 0\}$$

and $\mathcal{F}_t$ is the associated Borel σ-algebra. The country's total stock of human capital in period t, denoted by $\bar{H}_t$, is given by

$$\bar{H}_t = \int h d\Gamma_t (h)$$

3.2 Sectors

The economy in each country has two sectors – the production and the human capital sector. In the production sector, output is a function of raw (unskilled) labor, human capital, physical capital and the level of TFP. In addition, the total stock of human capital in the economy may have a positive externality on the productivity of the goods sector. The pos-

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itive externality of aggregate human capital on productivity is also emphasized in previous studies. The externalities may arise due to a complementarity among skills (where skilled individuals are more productive when complemented by other skilled individuals) and/or creating conducive conditions for technology adoption (see, e.g., Lucas 1988; Bils and Klenow 2000; Jones 2011). Following Mankiw, Romer, and Weil (1992), the production function is given by

$$Y_t = F\left(H_t, L_t, \bar{H}_t\right) = A_t K_t^\alpha H_t^\omega L_t^{1-\alpha-\omega} \bar{H}_t^\gamma, \qquad \alpha + \omega \in (0,1); \alpha, \omega, \gamma \geq 0 \quad (4)$$

where H_t and L_t, respectively, denote the total amount of human capital and unskilled labor employed by the representative firm. γ captures the externality effect of the total stock of human capital in the economy. A_t is an exogenously given level of TFP in the economy.

Capital stock evolves according to

$$K_{t+1} = (1 - \delta) K_t + I_t$$

where I_t is investment in period t and δ is the depreciation rate.

In the human capital sector, skilled individuals mentor the young to acquire human capital. The amount of human capital that a young individual acquires depends positively on the quality of her teacher – high-quality teachers produce high-quality graduates. The relationship between the student's human capital, h', and her teacher's human capital, h,

is given by the following function:

$$h' = \eta h^{1-\kappa} \bar{H}^\kappa, \quad \eta > 0, \kappa \in [0,1] \tag{5}$$

where κ measures the externality of aggregate human capital on the productivity of the human capital sector. In the absence of such an externality, $\kappa = 0$. The students-to-teacher ratio is denoted by parameter θ.

Let the tuition fee for acquiring an h level of human capital in period t be given by the function $\zeta_t(h)$. The tuition fee covers the cost of education – both the teacher's wage and the material cost. Denote the wage for a teacher with human capital h by $y_t^e(h)$. From (5), the acquisition of h level of human capital requires having a teacher with $\hat{h}$ level of human capital, where $\hat{h} = \left(h/\left(\bar{H}^\kappa \eta\right)\right)^{\frac{1}{1-\kappa}}$. Denoting the material cost for acquiring h level of human capital by $X_t(h)$, the tuition fee is given by

$$\zeta_t(h) = \frac{1}{\theta} y_t^e(\hat{h}) + X_t(h) \tag{6}$$

All else equal, the tuition fee decreases as a teacher is able to teach more students, i.e., when θ is higher.

We further assume that the material cost is a fixed fraction $v \in (0,1)$ of the total tuition fee:

$$X_t(h) = \nu \zeta_t(h)$$

Combining with (6), $\zeta_t (h)$ becomes a multiple of $y_t^e(\hat{h})$:

$$\zeta_t (h) = \frac{1}{(1 - \nu) \theta} y_t^e(\hat{h}) \tag{7}$$

4 The Balanced Growth Path

In this section, I prove the existence of a balanced growth path (BGP) and characterize it. By the BGP, we mean a long-run equilibrium where the two economies grow at a constant rate. However, there can be a persistent gap in the income levels. The frontier economy can have a persistently higher level of income, human capital and TFP. I show that the output gap is fundamentally determined by the TFP gap. This happens because the TFP gap affects output through two channels: (i) directly via the production function and (ii) indirectly through factor accumulation (both human and physical capital). I will also derive the key equations that will be used for the calibration exercise. As a first step in solving the BGP, in the next sub-section, I solve for the equilibrium for an economy without human capital trade. Then, I will extend the solutions for the scenario where there is trade in human capital.

4.1 Equilibrium in a closed market for human capital

Households

In every period, each young individual chooses whether to work or study. Acquiring human capital is an endeavor requiring an investment of time both by the student and the teacher. Thus, if the young individual chooses to study, she gives up her current wage

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from working as an unskilled worker. Moreover, she incurs a tuition fee to pay for the cost of her education. The tuition fees vary depending on the quality of human capital acquired, which is determined according to equation (5).

We also allow for the possibility that some of the individuals that acquire human capital may not be able to transfer their human capital to the future generation. This friction is meant to capture possibilities such as some of the knowledge acquired during the current generation may become outdated in the future periods. As will be shown latter on, the size of this friction is relevant to the quantitative fit of the model. The friction is modeled by assuming that, when old, each individual is hit by a shock with probability $\psi \in (0,1)$. Skilled individuals who receive the shock can only work in the goods sector whereas those who do not receive the shock can work both in the goods and the human capital sector. Thus, a fraction $\psi \in (0,1)$ of the skilled individuals cannot work as teachers since, for example, there is no demand for their skill by the new generation, i.e., their skills become obsolete upon their death. This is similar in spirit to Mankiw, Romer, and Weil (1992) where they assume a positive depreciation rate for human capital. The shock has no bearing on the career choice of unskilled individuals. Let $\epsilon_t \in \{0, 1\}$ be an indicator variable for whether the individual has received the shock. As will be shown, the value of ψ does not affect the steady-state equilibrium in the closed economy. However, we keep it for notational consistency as it will be an important parameter in the open economy for human capital.

The household chooses optimal paths for consumption c_{t+s}, asset holdings a_{t+s} and human capital investment h_{t+s} to maximize (3). In every period, the household must

satisfy the constraint

$$
\begin{aligned}
& a_t \left(\epsilon_t \right) + y_t \left(h_t | \epsilon_t \right) + y_t \left(0 \right) \left[1 - \mathbf{1}_{h>0} \right] \geq \\
& c_t \left(\epsilon_t \right) + \mathbf{1}_{h>0} \zeta_t \left(h_{t+1} \right) + \sum_{\epsilon_{t+1}} p_t \left(\epsilon_{t+1} \right) a_{t+1} \left(\epsilon_{t+1} \right), \quad \forall \epsilon_t
\end{aligned}
\tag{8}
$$

$\mathbf{1}_{h>0}$ is an indicator function that takes the value of 1 if the young individual in the household decides to acquire a positive amount of human capital and 0 otherwise. $y_t \left(h | \epsilon_t \right)$ is the earning by an individual with human capital h. $y_t \left(h | \epsilon_t \right)$ is contingent on ϵ_t because those who receive the shock can only engage in the goods sector (they cannot work as teachers since, e.g., their skill becomes obsolete in the next period). We have $y_t \left(h | 0 \right) > y_t \left(h | 1 \right)$ because individuals do not earn less by having more career options (as they can always choose the one that pays more). $y_t \left(0 \right)$ equals the wage rate for the unskilled worker. $p_t \left(\epsilon_{t+1} \right)$ is the price of an asset (in terms of period t goods) that pays 1 unit of goods in period $t + 1$ if the state is ϵ_{t+1}.

Each skilled individual, conditional on $\epsilon_t = 0$, chooses between working in the human capital sector (as a teacher) or working in the goods sector (as a skilled worker). Let $\mu_t \in \{0, 1\}$ be an occupational choice variable for the skilled individual where $\mu_t = 1$ if teaching is the chosen occupation. Otherwise, $\mu_t = 0$. The optimal μ_t is chosen to solve

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\max_{\mu_t \in \{0,1\}} = \mu_t y_t^e \left(h \right) + \left(1 - \mu_t \right) y_t^g \left(h \right)
$$

where $y_t^e \left(h \right)$ and $y_t^g \left(h \right)$ are the wage earnings from working in the human capital sector

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and the goods sector, respectively. Thus, we have

$$y_t(h|0) = \max\{y_t^e(h), y_t^g(h)\}$$

$$y_t(h|1) = y_t^g(h)$$

The optimal consumption path satisfies the standard Euler equation

$$c_{t+1}(\epsilon_{t+1}) = \frac{\beta}{p_t(\epsilon_{t+1})} c_t(\epsilon_t)$$

Denote the risk-free rate of return by $R_t = 1 + r_t$. We impose the following no-arbitrage condition between state-contingent assets and the risk-free asset:

$$p_t(1) = \frac{\psi}{R_{t+1}} \tag{9}$$

$$p_t(0) = \frac{1-\psi}{R_{t+1}} \tag{10}$$

While deciding on the level of investment in human capital, the young maximize the present value of their life-time wage earning (net of the tuition fee):

$$\max_h \quad [1 - \mathbf{1}_{h>0}]\left(y_t(0) + \frac{y_{t+1}(0)}{R_{t+1}}\right) + \mathbf{1}_{h>0}\left(\sum_{\epsilon \in \{0,1\}} p_t(\epsilon) y_{t+1}(h|\epsilon) - \zeta_t(h)\right)$$

The firm

We consider a competitive market with a representative firm. Taking wages and the interest rate as given, the firm employs physical capital, human capital and unskilled labor with the objective of maximizing its profit:

$$\max_{H_t, L_t, K_t \geq 0} \pi\left(H_t, L_t, K_t\right) = A_t K_t^{\alpha} H_t^{\omega} L_t^{1-\alpha-\omega} \bar{H}_t^{\gamma} - \left(r_t + \delta\right) K_t - W_t^L L_t - W_t^H H_t \quad (11)$$

W_t^H is the wage for a unit of human capital and W_t^L is the wage rate for a unit of unskilled labor. The firm's first-order conditions are given by

$$K_t : \alpha A_t K_t^{\alpha-1} H_t^{\omega} L_t^{1-\alpha-\omega} \bar{H}_t^{\gamma} = r_t + \delta \quad (12)$$

$$L_t : \left(1-\alpha-\omega\right) A K_t^{\alpha} H_t^{\omega} L_t^{-\alpha} \bar{H}_t^{\gamma} = W_t^L \quad (13)$$

$$H_t : \omega A_t K_t^{\alpha} H_t^{\omega-1} L_t^{1-\alpha-\omega} \bar{H}_t^{\gamma} = W_t^H \quad (14)$$

Rearranging (12) - (14), the demand for unskilled labor, human capital and physical capital is given by

$$L_t = \left(\frac{\left(1-\alpha-\omega\right) A_t K_t^{\alpha} H_t^{\omega} \bar{H}_t^{\gamma}}{w}\right)^{\frac{1}{\alpha+\omega}}$$

$$H_t = \left(\frac{\omega A_t K_t^{\alpha} L_t^{(1-\alpha)\omega} \bar{H}_t^{\gamma}}{W_t}\right)^{\frac{1}{1-\omega}}$$

$$K_t = \left(\frac{\alpha A_t H_t^{\omega} L_t^{1-\alpha-\omega} \bar{H}_t^{\gamma}}{r_t + \delta}\right)^{\frac{1}{1-\alpha}} \quad (15)$$

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Equilibrium

We assume that $R_t = (\beta g_y)^{-1}$, where g_y is the steady state growth rate of output (given below). The equilibrium of this economy is defined as follows.

Definition 1. *The competitive equilibrium is the distribution of c_t, h_t, μ_t and a_t across households, the employment of K_t, L_t and H_t by the firm, and prices $W_t^L, r_t, W_t^H, y_t^e(h)$ and $\zeta_t(h)$ such that, given prices and the distribution,*

- *the households maximize (1) subject to the budget constraint (8),*

- *K_t, L_t and H_t solve the firm's problem (11),*

- *the demand for unskilled workers equals the supply,*

$$L_t = \Gamma_{t+1}(\{0\}) + \Gamma_t(\{0\})$$

- *the demand for teachers equals the supply of teachers,*

- *the demand for human capital in the production sector equals the supply,*

$$H_t = \int_0^1 h_{j,t-1}(1 - \mu_{j,t})\, dj$$

The stationary equilibrium is defined as follows.

Definition 2. *Stationary equilibrium is an equilibrium such that, for all $\sigma_t \in \mathcal{F}_t$ and $\sigma_{t+1} = \{h : h = \eta h_t^{1-\kappa} \bar{H}_t^\kappa \text{ and } h_t \in \sigma_t\}$,*

$$\Gamma_{t+1}(\sigma_{t+1}) = \Gamma_t(\sigma_t) \tag{16}$$

The interpretation of the above definition is that a constant fraction of the skilled individuals from each level of human capital engage in teaching so that the distribution of human capital across households features a stable pattern over time.

Lemma. *If condition (16) is satisfied with $\kappa > 0$, Ω_t converges to a singleton. Moreover, if $\kappa = 0$, Ω_t is a singleton for the stationary equilibrium.*

Proof. See Appendix A. □

Given that Ω_t is either a singleton or must converge to a singleton in the stationary equilibrium, I focus on the equilibrium with a singleton Ω_t. The following proposition states such an equilibrium.

Proposition. *The economy has a stationary equilibrium with singleton Ω_t. In this equilibrium, a constant fraction $\phi \in (0, 1)$ of young individuals invest in human capital in every period where*

$$\phi = \frac{\omega 2 \left[\beta - \frac{1}{(1-\nu)\theta} \right]}{(1 - \alpha - \omega) \left(\frac{\theta - 1}{\theta} \right) (1 + \beta) + \omega 2 \left[\beta - \frac{1}{(1-\nu)\theta} \right]} \tag{17}$$

Moreover, the growth rate of the human capital stock H_t and output Y_t is given by

$$g_h \equiv \frac{h_{t+1}}{h_t} = \eta \phi^\kappa \tag{18}$$

$$g_y \equiv \frac{Y_{t+1}}{Y_t} = g_a^{\frac{1}{1-\alpha}} g_h^{\frac{(\omega+\gamma)\alpha}{1-\alpha}} g_h^{1-\alpha+\gamma} \tag{19}$$

Proof. See Appendix B. □

Growth is driven by a perpetual accumulation of human capital and the TFP growth. Since Ω_t is a singleton, in each period, all old skilled individuals have the same level of

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human capital, i.e., $h_{j,t} = h_t \forall j$. The total stock of human capital in the country is given by

$$\bar{H}_t = \phi h_t$$

A fraction $1/\theta$ of the ϕ individuals who are skilled engage in teaching. The total stock of human capital used for the production of goods is given by

$$H_t = \left(1 - \frac{1}{\theta}\right)\bar{H}_t$$

A constant fraction $1 - \phi$ of young and old individuals work as unskilled workers. The total supply of unskilled labor thus equals $2(1 - \phi)$. Given r_t, we can solve for K_t from equation (15). Equations (13) and (14) then solve for W_t^L and W_t^H:

$$W^L{}_t = B_L A_t^{\frac{1}{1-\alpha}} \bar{H}^{\frac{\gamma+\omega}{1-\alpha}} \tag{20}$$

$$W_t^H = B_H A_t^{\frac{1}{1-\alpha}} \bar{H}^{\frac{\gamma-(1-\omega-\alpha)}{1-\alpha}} \tag{21}$$

where

$$B_L \equiv (1 - \alpha - \omega)\left[\left(\frac{\alpha}{r+\delta}\right)^\alpha \left(\frac{\theta}{L(\theta-1)}\right)^\omega\right]^{\frac{1}{1-\alpha}}$$

$$B_H \equiv \omega \left[\left(\frac{\alpha}{r+\delta}\right)^\alpha \left(\frac{\theta L}{\theta-1}\right)^{(1-\omega-\alpha)}\right]^{\frac{1}{1-\alpha}}$$

Since W_t^H is the wage per unit of human capital, the earning by skilled individuals working

in the goods sector, $y^g(h_t)$, is given by

$$y_t^g(h_t) = h_t W_t^H$$

Moreover, skilled individuals are indifferent between teaching and working in the goods sector, $y_t^g(h_t) = y_t^e(h_t)$.

Inserting (15) into (4) and using $L = 2(1 - \phi)$,

$$Y_t = B_y A_t^{\frac{1}{1-\alpha}} \bar{H}^{\frac{\gamma+\omega}{1-\alpha}} \tag{22}$$

where

$$B_y = \left[\left(\frac{\alpha}{r+\delta} \right)^\alpha (2(1-\phi))^{1-\alpha-\omega} \left(\frac{\theta-1}{\theta} \right)^{-\omega} \right]^{\frac{1}{1-\alpha}}$$

4.2 Equilibrium in an open market for human capital

We now allow for the possibility that graduates in the frontier economy may transfer human capital to the low human capital economy. This is done by assuming that the developing economy can import teachers from the frontier economy.

We consider a stationary equilibrium with one level of human capital in each country. We will use the subscript f to denote variables of the frontier economy. Let $h_{f,t}$ and h_t denote the level of human capital by graduates in the frontier and the low human capital economy, respectively. We allow for the two economies to be potentially different in two key parameters: the level of human capital and the level of overall productivity (TFP). The frontier economy is assumed to have higher levels of both human capital and TFP, $h_{f,t} > h_t$ and $A_{f,t} > A_t$. To simplify the analysis, we further assume that the developing economy is

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a small economy so that the flow of graduates from the frontier to the developing economy does not affect the total stock of the frontier's human capital. Given this assumption, we take as given the fact that the frontier is in a stationary equilibrium.

If a young individual decides to acquire h_{t+1} level of human capital, the present value of her next period income, denoted by $V_t(h_{t+1})$, is given by

$$V_t(h_{t+1}) = \sum_{\epsilon} p_t(\epsilon)\, y_{t+1}(h_{t+1}|\epsilon) \tag{23}$$

Definition 3. *With an open market for human capital, the developing economy is said to be in equilibrium if, in addition to the conditions stated in the above definition (Definition 2), the following condition is satisfied:*

$$V_t(\tilde{h}_{t+1}) - \zeta_t\left(\tilde{h}_{t+1}\right) = V_t(h_{t+1}) - \zeta_t(h_{t+1}) \tag{24}$$

where $\tilde{h}_{t+1} = \eta h_{f,t}^{1-\kappa} \bar{H}_t^{\kappa}$ and $h_{t+1} = \eta h_t^{1-\kappa} \bar{H}_t^{\kappa}$.

Since $\tilde{h}_{t+1} > h_{t+1}$, having teachers who graduated in the frontier economy leads to higher earnings (i.e. $V_t(\tilde{h}_{t+1}) > V_t(h_{t+1})$). On other hand, the tuition fee is higher for high-quality teachers, $\zeta_t\left(\tilde{h}_{t+1}\right) > \zeta_t(h_{t+1})$. Thus, individuals investing in human capital face the trade-off between quality and cost. The above condition states that, in equilibrium, they should be indifferent.

Inserting (7) into (24),

$$V_t(\tilde{h}_{t+1}) - \frac{\theta}{1-\nu} y_t^e(h_{a,t}) = V_t(h_{t+1}) - \frac{\theta}{1-\nu} y_t^e(h_t)$$

Note that the level of human capital in the closed economy equilibrium is determined by the initial condition. However, in the open economy equilibrium, for a given $h_{f,t}$, the level of human capital is determined by the condition (24). Otherwise, the equilibrium of the open economy is similar to that of the closed one. A constant fraction ϕ, given by equation (17), of individuals invest in human capital. Skilled individuals earn the same amount from teaching and working in the production sector, $y_t^e(h_t) = W_t^H h_t$. Since we assume that country f is also in stationary equilibrium, $y_t^e(h_{a,t}) = W_{f,t}^H h_{f,t}$ where

$$W_{f,t}^H = B_H A_{f,t}^{\frac{1}{1-\alpha}} \bar{H}_{f,t}^{\frac{\gamma-(1-\omega-\alpha)}{1-\alpha}} \tag{25}$$

Moreover, $V_t(h_{t+1})$ is the discounted value of the next period wage earning for the skilled worker, $\left(h_{t+1}W_{t+1}^H\right)/R_{t+1}$. Inserting these values into (24) and rearranging,

$$y_t^e(h_{a,t}) = W_t^H h_t + \frac{1-\nu}{\theta}\left(V_t(\tilde{h}_{t+1}) - \frac{W_{t+1}^H h_{t+1}}{R_{t+1}}\right) \tag{26}$$

Combining (26) with (23), iterating forward, and using (10) and (9) for asset prices, we get

$$V_t\left(\tilde{h}_{t+1}\right) = V_t(h_{t+1}) Q(h_{f,t}, h_t) \tag{27}$$

where

$$Q\left(h_{f,t}, h_t\right) \equiv \sum_{s=0}^{\infty} q^s \left\{ \psi \left(\left[\frac{h_{f,t}}{h_t} \right]^{1-\kappa} \right)^{s+1} + \Phi \right\}$$

$$q \equiv \frac{1-\psi}{R} \frac{1-\nu}{\theta} g_y$$

$$\Phi \equiv (1-\psi) \frac{R\theta - (1-\nu) g_y}{R\theta}$$

$V_t\left(\tilde{h}_{t+1}\right)$ exceeds $V_t\left(h_{t+1}\right)$ by a factor of $Q\left(h_{f,t}, h_t\right)$. Thus, $Q\left(h_{f,t}, h_t\right)$ is the value of having teachers that are foreign graduates *relative* to home graduates. For $h_{f,t} = h_t$, $Q\left(h_{f,t}, h_t\right) = 1$ so that home graduate teachers are equally valued as foreign graduates since they have the same level of human capital.[1] $Q\left(h_{f,t}, h_t\right)$ is increasing in $h_{f,t}$.

The infinite summation captures the fact that the value of acquired human capital depends on the returns that future generations receive as human capital is transferred from one generation to the other. The discount factor q is lower the higher is the rate of knowledge decay ψ (since a lower number of skilled individuals are able to transfer human capital to future generations). q is also decreasing in the cost of transferring knowledge from one generation to the other, $1/\left[\theta(1-\nu)\right]$. Note that the tuition fee is increasing in this term (see equation (7)).

Inserting (27) into (26):

$$y_t^e\left(h_{a,t}\right) = W_t h_t + \frac{1-\nu}{\theta}\left(V_t\left(h_{t+1}\right) Q\left(h_{a,t}, h_t\right) - \frac{W_{t+1} h_{t+1}}{R}\right)$$

Note that $V_t\left(h_{t+1}\right) = W_{t+1} h_{t+1}/R_{t+1}$. From the steady state growth rates, we have

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[1] $Q(1,1) = \sum_{s=0}^{\infty} q^s \{\psi + \Sigma\} = \frac{\psi + \Sigma}{1-q} = \frac{1-q}{1-q} = 1.$

$W_{t+1}h_{t+1} = g_y W_t h_t$ (see equations (18), (19) and (21)). Using $y_t^e (h_{a,t}) = W_{a,t} h_{a,t}$, the above equation becomes

$$W_{a,t} h_{a,t} = W_t h_t \left[1 + \frac{1 - \nu}{\theta} \frac{g_h}{R} \left[(Q(h_{a,t}, h_t) - 1) \right] \right] \tag{28}$$

Using the values for W_t and $W_{f,t}$ from equations (21) and (25), we can rewrite (28) as

$$\left(\frac{\bar{H}_{f,t}}{\bar{H}_t} \right)^{\frac{\gamma + \omega}{1 - \alpha}} \left\{ \frac{g}{R} \left[Q \left(\frac{\bar{H}_{f,t}}{\bar{H}_t} \right) - 1 \right] + \frac{1}{(1 - \nu)\theta} \right\} = \frac{1}{(1 - \nu)\theta} \left(\frac{A_t}{A_{f,t}} \right)^{\frac{-1}{1 - \alpha}} \tag{29}$$

From (22), the steady state output ratios are given by

$$\frac{Y_t}{Y_{f,t}} = \left(\frac{A_t}{A_{f,t}} \right)^{\frac{1}{1 - \alpha}} \left(\frac{\bar{H}_{f,t}}{\bar{H}_t} \right)^{\frac{\gamma + \omega}{1 - \alpha}} \tag{30}$$

An appealingly simple feature of the model is that, given the parameter values, equations (28) and (29) can be used to back-out the steady-state levels of relative productivity (A/A_f) and relative human capital $\bar{H}/\bar{H}_f$ implied by a given level of output gap.

5 Calibration

This section presents the calibration exercise. Using parameter values from the literature and data, I simulate the model to quantify the extent to which the possibility of human capital transfer amplifies the effect of an exogenous increase in the TFP of a developing economy. Such a TFP increase can be considered as an outcome of a large scale institutional/policy reform that arguably improves the efficiency of resource use in the economy.

An example of such a reform could be China's decision to open up its economy for the private sector in early 1980s that triggered the later growth.

5.1 Choice of parameter values

The choice of parameters is as follows. Using a similar two-period OLG model of human capital investment, Mayr and Peri (2008) consider a total working life of 40 years so that each period represents 20 years, which I follow in this exercise. In the literature, the standard annualized value for the discount factor β is 0.98. The share of capital, α, is set to one-third. Among the 1,311 higher education institutions that provided data to *U.S. News* in 2010, the average faculty-to-student ratio, θ, is 14.8 (U.S.News 2011). Estimates by Acemoglu and Angrist (2000) suggest a 2% externality of aggregate human capital, implying $\gamma = 0.02$. A similar value is assumed for the externality parameter in the human capital sector, $\kappa = 0.02$. Based on the evidence by the U.S. Department of Education (1996) and Kendrick (1976), Bils and Klenow (2000) argue that students' and teachers' time constitutes 90% of the cost of education, the remaining 10% being the cost for material. This jointly implies that $\nu = 0.4$ and $\phi = 0.42$. The US per capita GDP grew by an average of 2.27% per year over the period $1960 - 1990$ (Heston, Summers, and Aten 2012)[2]. To match the calibrated steady-state growth with that of the long-run US growth, η is set to 1.52. Following Mankiw, Romer, and Weil (1992), we experiment the calibration for ω in the interval between a third and one-half.

$$TableHere$$

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[2]The growth rate I use here is the slope of log GDP on time, i.e., $\log Y_t = 0.0227 \times year + constant$.

We are left with the parameter for the friction in the inter-generational transfer of human capital, ψ. The value of ψ is chosen so that the relationship between the output gap and the human capital gap predicted by the model closely matches the data. Figure C plots the relative values of human capital against relative output levels. The human capital stock data is from Bils and Klenow (2000). The estimation of the human capital stock in Bils and Klenow (2000) involves two steps. First, the average earnings for different groups of workers (categorized by their education level) is estimated. Then, the aggregate stock of human capital is estimated by summing the groups with each group weighted by the number of its members and the group's relative earnings. In Figure C, the predicted relationship between the output gap and the human capital stock gap is plotted for three values of ψ. Lower values of ψ imply higher values of the human capital stock. This relationship follows from the fact that a decrease in ψ implies an increase in the value of human capital. This is the case because when ψ is lower, knowledge can be sold to the future generation with a higher probability. This effect is captured in the expression for Q where an increase ψ increases the discount factor, q. We observed that the value of ψ that produces a closer match to the data is 0.93. I use this value in the calibrations. Table 1 summarizes the parameter values and the sources.

5.2   Human capital transfer and amplification of a TFP increase

Given the above parameter values, we now turn to the calibration exercise to quantitatively assess the extent to which the possibility of human capital transfer amplifies the impact of a TFP increase. We assume two initial conditions: (i) the developing economy has an initial level of TFP, human capital and income that are lower than the frontier, and (ii) the initial

level of the developing economy's human capital is such that the students in the developing economy are indifferent between importing teachers or not. An interpretation of the latter condition is that the developing economy has had access to the education market and it is already on the balanced growth path. However, it is not necessary that there has been trade in human capital. The calibration results hold if the developing economy happens to have such a level of human capital without human capital import. This assumption is needed to net out the impact of human capital transfer in amplifying the impact of a TFP increase because, given this condition, there will not be any import of human capital without a TFP increase. All of the human capital transfer has to be induced by the TFP increase. In terms of the figure below, the assumption about the initial level of the developing economy's human capital is such that the output in scenarios II and IV is the same. The amount by which output in scenario I exceeds output in scenario III will be the contribution of human capital transfer in amplifying the impact of TFP.

		Change in relative TFP	
		Increase	No change
Possibility of HC transfer	Yes	I	II
	No	III	IV

Figure 2 illustrates the dynamics of output under the four scenarios. Until period t_0, the two economies are on the balanced growth path. The output of the frontier economy, y_f, remains above that of the developing economy (y_0) while both economies grow at the same rate. The relative level of TFP also remains the same. We can consider the four scenarios at period t_0. In case there is a shift in the relative level of the developing economy's TFP (scenarios I and III), we assume that the economy will have returned to the

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balanced growth path in period t_1. The graph y_0 captures scenarios II and IV. The graphs y_1 and y_1' capture, respectively, scenarios I and III. The difference between y_1 and y_1' on the new balanced growth path is the contribution of human capital transfer to the steady state level of output.

Let us consider the case where the initial income of the developing country is just 8% of the frontier economy. This roughly corresponds to Taiwan's income relative to that of the US in the early 1950s (or China's relative income in the early 1990s). For the students in this economy to be indifferent between importing teachers or not, the condition given by equation (24) has to be satisfied. This will be the case, given the parameter values and the relative output level, if the relative levels of TFP and human capital of the developing economy are 0.31 and 0.36, respectively. Now, assume that there is a permanent and exogenous increase in the level of the developing economy's TFP relative to the frontier. Consider a TFP increase that is large enough so that in the new steady state and with the possibility of human capital transfer (i.e., scenario I), the developing economy's income becomes 70% of the frontier economy. Again, this roughly corresponds to the miraculous catch-up experienced by Taiwan in the course of half a century.

$$FigureHere$$

The first row in Table 2 shows the sources of this increase in the developing economy's relative output. The first procedure in the calibration exercise is to back out the relative levels of TFP and human capital stock on the new balanced growth path with the developing economy having a relative income of 70%. A shift the relative output in the steady state from 8% to 70% implies an increase in the developing economy's output by a factor

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of 8.8. The new steady-state is achieved by an increase in the relative TFP and the human capital transfer that is induced by the TFP increase. Following this procedure, the relative TFP level that is required to achieve the new steady-state is calibrated to be 0.94. Then, we ask: what would be the new output level if we had the TFP increase but shut down the human capital transfer? This output level, reported in the last column, is 33.6%, implying that the relative output without a human capital transfer would have increased by a factor of only 4.2 (instead of 8.8). Thus, the human capital transfer contributes a factor of 2.1. Assuming a period of 50 years and a 2.08% steady state growth rate in the frontier economy, the contribution of human capital transfer for the increase in the absolute (instead of the relative) level of output would be 52%. This implies that half of the output increase observed in this economy comes from the human capital transfer.

$$TableHere$$

The second row in 2 presents a similar exercise for an economy that starts out with an initial relative income of 10% and moves to a new steady state with a relative income of 60%, experiencing a six-fold increase in relative income. This roughly corresponds to the level of increase experienced by South Korea over the last fifty years. In this case, the contribution the TFP increase and the human capital transfer is a factor of 3.3 and 1.8, respectively. Again, considering a 50 year period with a 2.08% annual growth rate in the frontier economy, about 45% of the increase in the absolute level of output is due to the human capital transfer.

The extent to which a TFP increase is amplified by the human capital transfer depends on the initial conditions. Figure C shows this non-linearity. On the horizontal axis, we

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have the initial level of relative TFP. We assume that the economy is on the balanced growth path so that the TFP gaps translate into gaps in output and the human capital stock. On the vertical axis, we have the contribution of human capital transfer if the economy experiences a 10 percentage point increase in the relative TFP. As the economy gets closer to the frontier, this contribution falls consistently. This non-linearity is the fundamental reason why a developing economy may experience a disproportionate effect from a TFP increase. All else equal, countries that are further behind the frontier will experience a higher level of increase in output and factor accumulation for a given level of TFP increase. This result is consistent with the fact that the TFP increases observed by the East Asian economies are not exceptionally high compared to those experienced by relatively more industrialized countries such as Italy. However, the observed increase in output and factor accumulation is much higher in the East Asian economies (Young 1995).

$$FigureHere$$

Table 3 presents the sensitivity of the results to ω. The calibration is done for the economy that experienced a shift from 8% of initial output to 70%. When ω is half, the contribution of human capital transfer is about 52%. As ω falls, the human capital transfer contribution also decreases. This follows from the fact that lower values of ω imply that human capital is less important in the production function. When ω is set to one-third, the lowest value that Mankiw, Romer, and Weil (1992) consider, the contribution of human capital transfer is about 40%. The contribution will fall to about 32% if I we further lower

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ω to a quarter, a relatively conservative value.

$$TableHere$$

6 Concluding remarks

Why do emerging economies experience a very rapid growth? Building on Lucas (1988), this paper provides an alternative framework to analyze the mechanics of catch-up in per capita income. This is done by taking into account the possibility that knowledge transfer from frontier economies may play an important role. In particular, I endogenize the possibility that foreign residents with a higher level of human capital may play a crucial role in knowledge transfer, thereby facilitating catch-up.

A novel result of the model is that a relatively small improvement in the overall productivity of the economy, e.g., due to institutional reforms such as more efficient trade policies and more secure property rights, may lead to a substantial increase in output. The reforms may result in small changes in measured overall productivity (such as TFP measures). However, with the possibility of human capital transfer, the impact of such relatively small productivity improvements on output could be extremely large. The model in this paper thus provides a framework that is consistent with the empirical observation that the Asian miracle happened with a relatively modest increase in overall productivity along with a large increase in factor accumulation (Young 1995).

Modern production activities involve sophisticated knowledge. The sphere of such knowledge ranges from technical skills on the specifics of producing a particular good to

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skills in the organization and management of firms. The diffusion of such knowledge occurs via various forms of learning and is influenced by the incentives for learning. In this paper, I considered a simple learning technology – teachers teach students and are paid for that. I abstracted from other forms of learning which could potentially be very important. Thus, exploring the various channels by which human capital flows across borders, and the incentives that shape the flow, is a promising research avenue to understand the phenomenon of rapid growth in emerging economies. An example in this direction is Alvarez, Buera, and Lucas (2011) who study the cross-border flow of ideas as a by-product of the interaction in international trade.

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A Proof of Lemma ..

When $\kappa > 0$

Suppose that $h_{t,i} \in \Omega_t$. Then, by definition of the stationary equilibrium, $h_{t+1,i} \in \Omega_{t+1}$ where

$$h_{t+1,i} = \eta h_{t,i}^{1-\kappa} \bar{H}_t^{\kappa}$$

Iterating forward,

$$h_{t+T,i} = h_{t,i}^{(1-\kappa)^T} \prod_{n=0}^{T-1} \eta^{(1-\kappa)^n} \bar{H}_{t+n}^{\kappa(1-\kappa)^n}$$

If $\kappa \in (0,1)$, $\lim_{T\to\infty} (1-\kappa)^T = 0$. Hence, for any $h_{t,i} > 0$,

$$\lim_{T\to\infty} h_{t,i}^{(1-\kappa)^T} = 1$$

This means that, for any $h_{t,i} \in \Omega_t$, the limit of $h_{t+T,i}$ in the above expression is independent of $h_{t,i}$ and converges to $\prod_{n=0}^{T-1} \left(\eta^{(1-\kappa)^n} \bar{H}_{t+n}^{\kappa(1-\kappa)^n} \right)$. Thus, Ω converges to a singleton.

When $\kappa = 0$

When $\kappa = 0$, Ω_t is a singleton for the stationary equilibrium. We prove this by contradiction.

Take any $h_t, \bar{h}_t \in \Omega_t$ with $\bar{h}_t > h_t$. In the stationary equilibrium, individuals should be

indifferent between having the two levels of human capital:

$$\frac{W_{t+1}\bar{h}_{t+1}}{R} - \frac{1}{(1-\nu)\,\theta}W_t\bar{h}_t = \frac{W_{t+1}h_{t+1}}{R} - \frac{1}{(1-\nu)\,\theta}W_th_t$$

where $\bar{h}_{t+1} = \eta\bar{h}_t$ and $h_{t+1} = \eta h_t$. Combining with $W_{t+1}h_{t+1}/(W_th_t) = g_y$,

$$W_t\bar{h}_t\left(\frac{g_y}{R} - \frac{1}{(1-\nu)\,\theta}\right) = W_th_t\left(\frac{g_y}{R} - \frac{1}{(1-\nu)\,\theta}\right)$$

which is a contradiction (since $\bar{h}_t > h_t$)

B   Proof of proposition ..

We conjecture the stationary equilibrium stated in proposition () and proof that it is true.

The present value of life-time income by the unskilled worker equals $w_t + w_{t+1}/R$. Net of the tuition fee, the skilled worker earns $W_{t+1}h_{t+1} - \zeta_t(h_t)$. Given ϕ, we prove the proposition by verifying that the young individual is indifferent between the two:

$$w_t + \frac{w_{t+1}}{R} = \frac{W_{t+1}h_{t+1}}{R} - \zeta_t(h_t) \tag{31}$$

Given that a constant fraction ϕ of the young invest in human capital every period, w_t and W_t are given by equations (20) and (21), respectively. Using these values along with (31) and (7),

$$B\left(1-\theta\right)\bar{H}_t^{\left(\frac{\gamma+1-\alpha}{1-\alpha}\right)} + \left(\tfrac{1}{R}\right)B\left(1-\theta\right)\bar{H}_{t+1}^{\left(\frac{\gamma+1-\alpha}{1-\alpha}\right)} =$$
$$\left(\tfrac{1}{R}\right)B2\left(1-\phi\right)\bar{H}_{t+1}^{\left(\frac{\gamma}{1-\alpha}\right)}h_{t+1} - \tfrac{\theta}{1-\nu}B2\left(1-\phi\right)\bar{H}_t^{\left(\frac{\gamma}{1-\alpha}\right)}h_t \tag{32}$$

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Substituting for $\bar{H}_t$ in (5),

$$h_{t+1} = \eta h_t^{(1-\kappa)} (\phi h_t)^\kappa$$

The growth rate of human capital is thus given by

$$g_h \equiv \frac{h_{t+1}}{h_t} = \eta \phi^\kappa$$

Combining this with (32), we get

$$(1-\theta) \bar{H}_t^{\left(\frac{\gamma+1-\alpha}{1-\alpha}\right)} \left[1 + \left(\frac{1}{R}\right) g_h^{\left(\frac{\gamma+1-\alpha}{1-\alpha}\right)}\right] =$$
$$2(1-\phi) \left[\left(\frac{1}{R}\right) \bar{H}_{t+1}^{\left(\frac{\gamma}{1-\alpha}\right)} h_{t+1} - \frac{\theta}{1-\nu} \bar{H}_t^{\left(\frac{\gamma}{1-\alpha}\right)} h_t\right]$$

$$\implies (1-\theta) \left[1 + \left(\frac{1}{R}\right) g_h^{\left(\frac{\gamma+1-\alpha}{1-\alpha}\right)}\right] = 2 \frac{(1-\phi)}{\phi} \left[\left(\frac{1}{R}\right) g_h^{\left(\frac{\gamma+1-\alpha}{1-\alpha}\right)} - \frac{\theta}{1-\nu}\right]$$

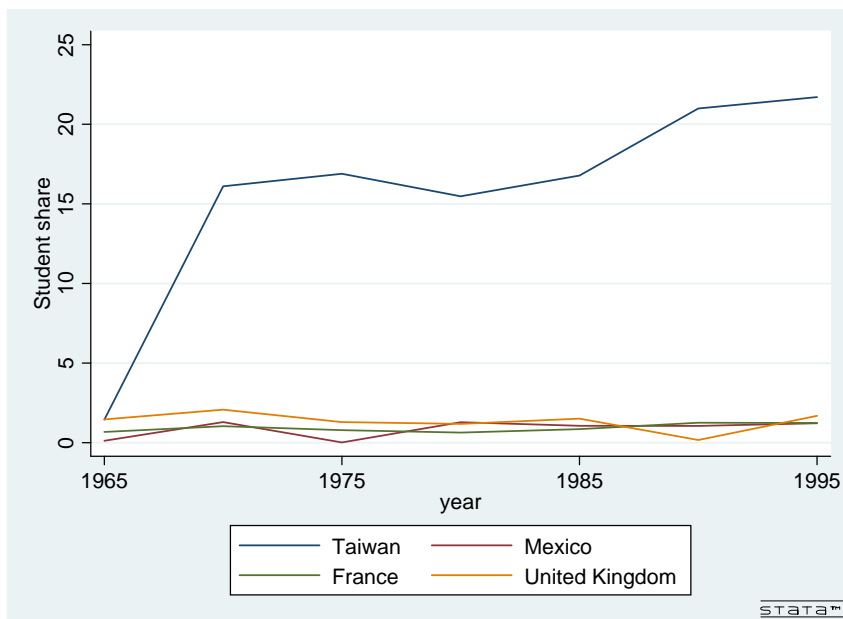Equation (19) follows from the production function (22). Replacing g_y for g_h,

$$(1-\theta) \left[1 + \left(\frac{1}{R}\right) g_y\right] = 2 \frac{(1-\phi)}{\phi} \left[\left(\frac{1}{R}\right) g_y - \frac{\theta}{1-\nu}\right]$$
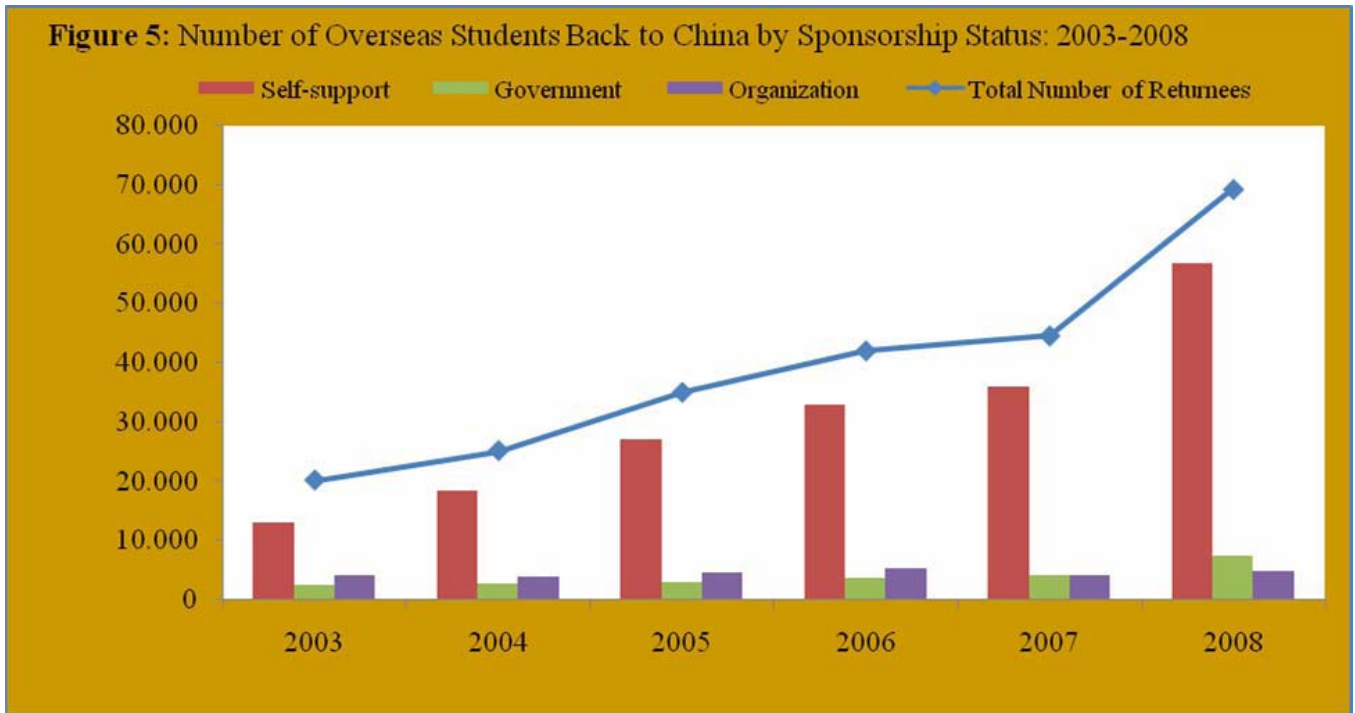
Given that $g_y = \beta R$, we have

$$\phi = \frac{2\left(\beta - \frac{\theta}{1-\nu}\right)}{(1-\theta)(1+\beta) + 2\left(\beta - \frac{\theta}{1-\nu}\right)}$$

C Figures

Figure 1: Share of foreign students in US colleges (pop. weighted)

Figure 5: Number of Overseas Students Back to China by Sponsorship Status: 2003-2008

Source: Figure 5 in Constant et al. (2011)

Human capital and output gap: data vs model
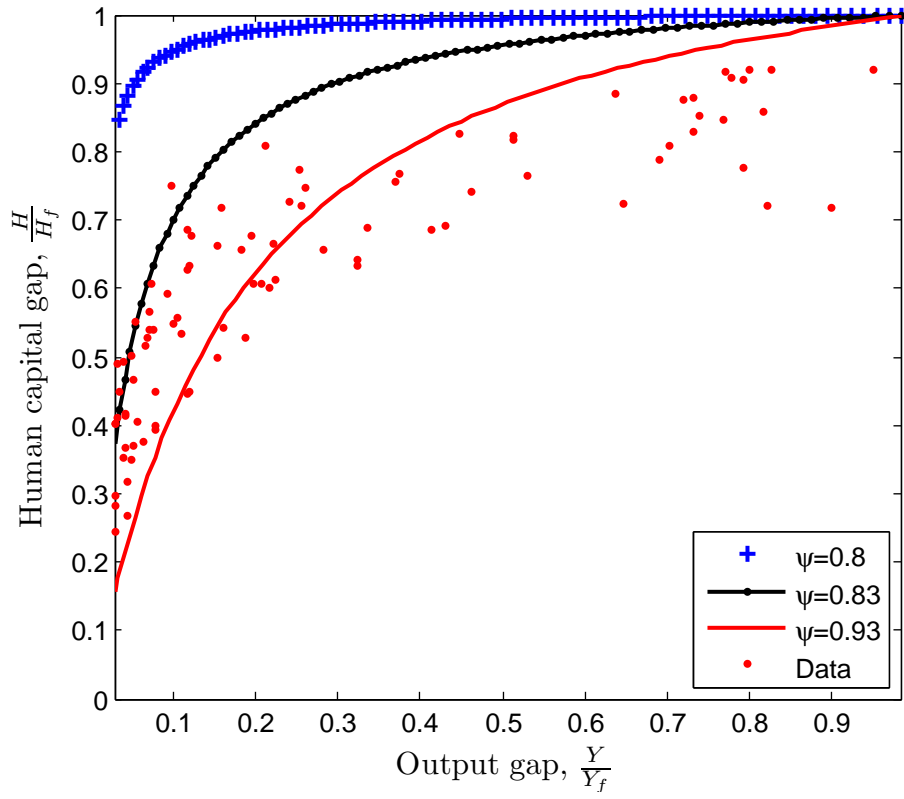
Table 1: Parameter values

Parameter	value	Note
α	0.33	Match captial share to one-third
β	0.98	Annualized value
γ, κ	0.02	Acemoglu and Angrist (2000)
ν	0.1	Bils and Klenow (2000)
η	1.52	Match U.S. growth
θ	0.068	U.S.News 2011

Figure 2: Impact of a TFP increase with and without human capital transfer

$y = \log Y$

y_f

y_1

y_1'

y_0

t_0 t_1 t
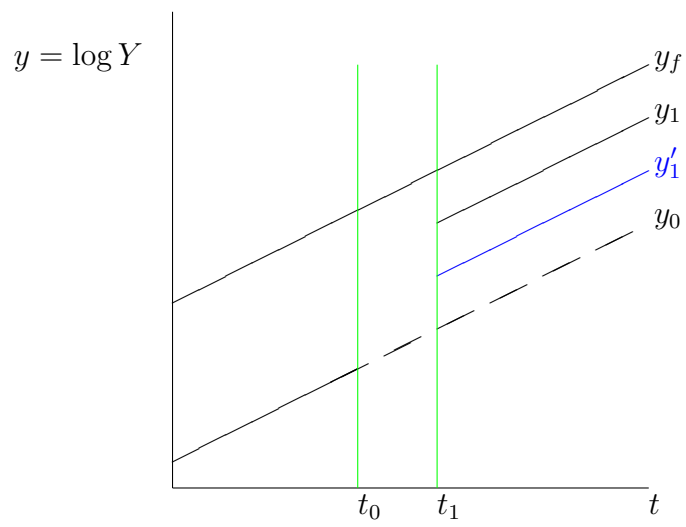
Table 2: Contributions of productivity increase and human capital transfer

| | Output rise | The contribution of: | | Counter-factual $\frac{Y}{Y_f} \times 100$ |
		Productivity increase	Human cap. transfer	
(A)	8% → 70% (↑ by 8.8×)	4.2	2.1	33.6%
(B)	10% → 60% (↑ by 6×)	3.3	1.8	33.0%

Table 3: Sensitivity to ω

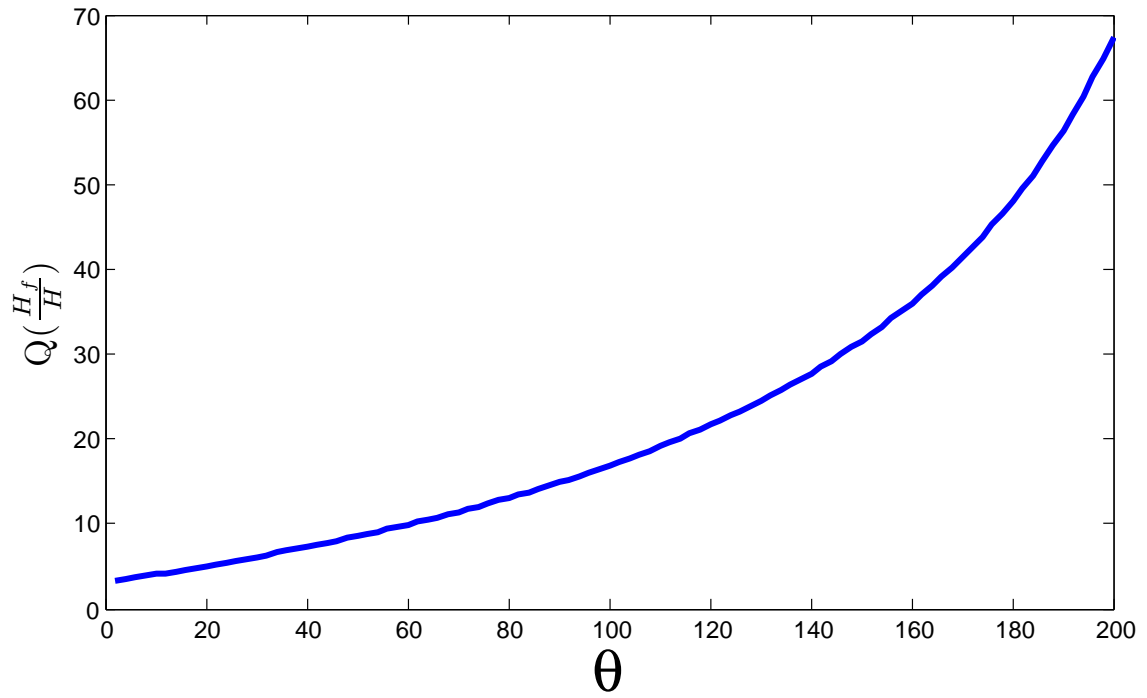| ω	Contribution of human capital transfer to output gain (percent)
$\frac{1}{2}$	52.2
$\frac{1}{3}$	39.5
$\frac{1}{4}$	31.8

Contribution of human capital transfer in response to a 10 pp $\uparrow$ in $\frac{A}{A_f}$
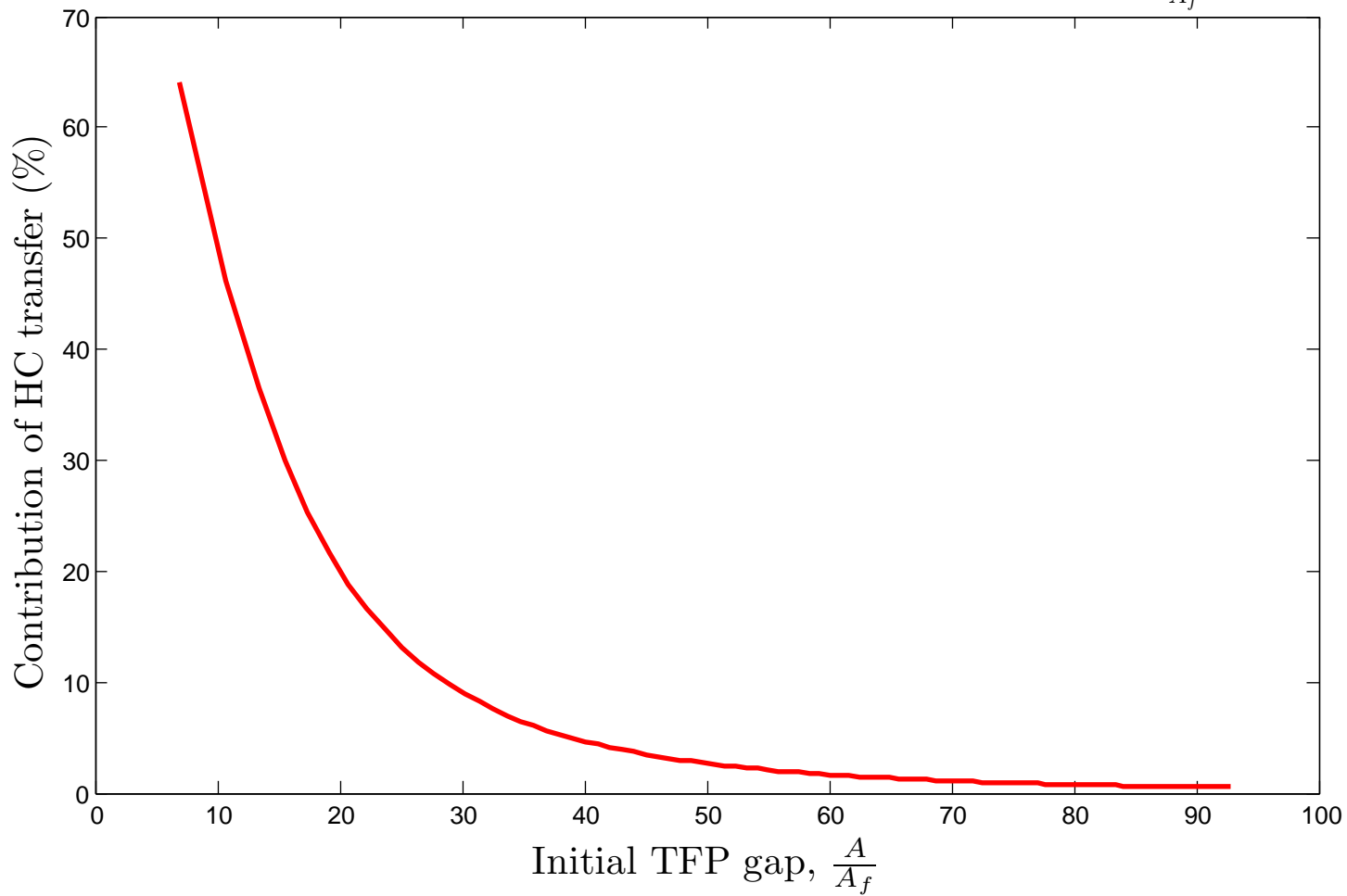
Education technology and human capital.
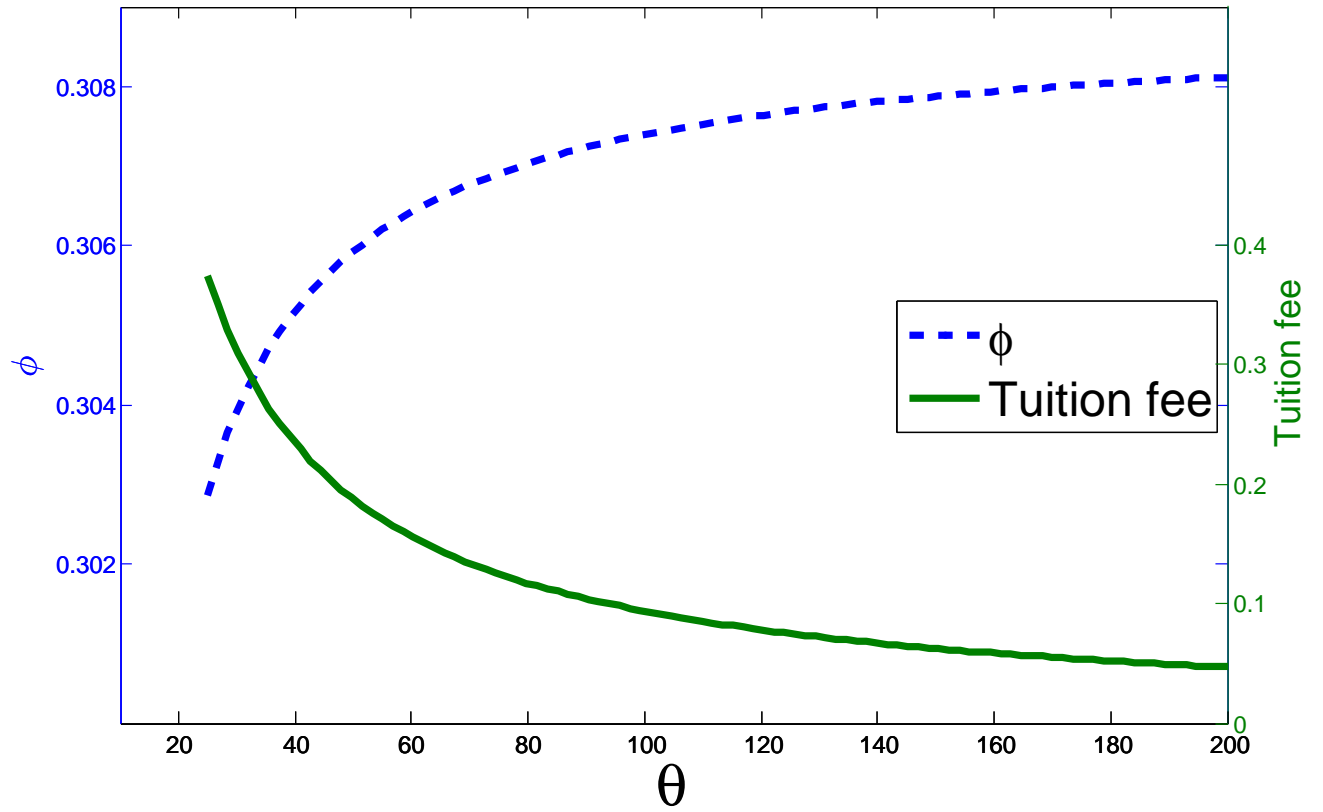
The value of foreign education vs. θ ($\frac{H}{H_f}$=30%)

Human capital and output gap vs. θ ($\frac{A}{A_f}$=28%)