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Abstract

We develop a simple endogenous growth model featuring individuals' choices between general and firm-specific skills, endogenous technological innovation, and a government subsidy for education. General skills are less productive than are specific skills, but they enable workers to operate all technologies in the economy. We show that demand for general skills increases as countries catch up to the world technology frontier. Further, using aggregated data for 12 European OECD counties, we calibrate the model and compare the theoretical prediction with the data. In cross-country comparisons, we find that the returns on general skills and the impact of general education expenditure on GDP are higher in countries with higher total factor productivity. These findings support our theoretical argument of the positive relationship between firms' demand for general skills and countries' stages of development.

Keywords: General and specific skills, Technological uncertainty, Education policy, Distance to world technology frontier

JEL classification: J24, O33, O40, I22

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1 Introduction

Although human capital theory suggests that higher education has a key role in sustained economic growth, countries differ substantially in terms of their schooling and educational structures (see Figure 1). For example, many European countries focus on vocational education that provides highly specialized and job-related "specific skills," whereas the United States emphasizes general education that develops basically and broadly usable "general skills." As Gary Becker notes, there is a trade-off between the two types of skills. Becker (1962) pointed out that specific skills have a stronger relationship to performance of the current job, but that they are difficult to apply across jobs. On the other hand, general skills are less productive than specific skills, but they can be transferred to other jobs. This productivity–transferability trade-off between general and specific skills creates mixed support for general and vocational education and, thus, the differences in the educational structures across countries.

How do these differences in skill composition impact on growth performance of each country? The literature on economic growth has examined this question, focusing on

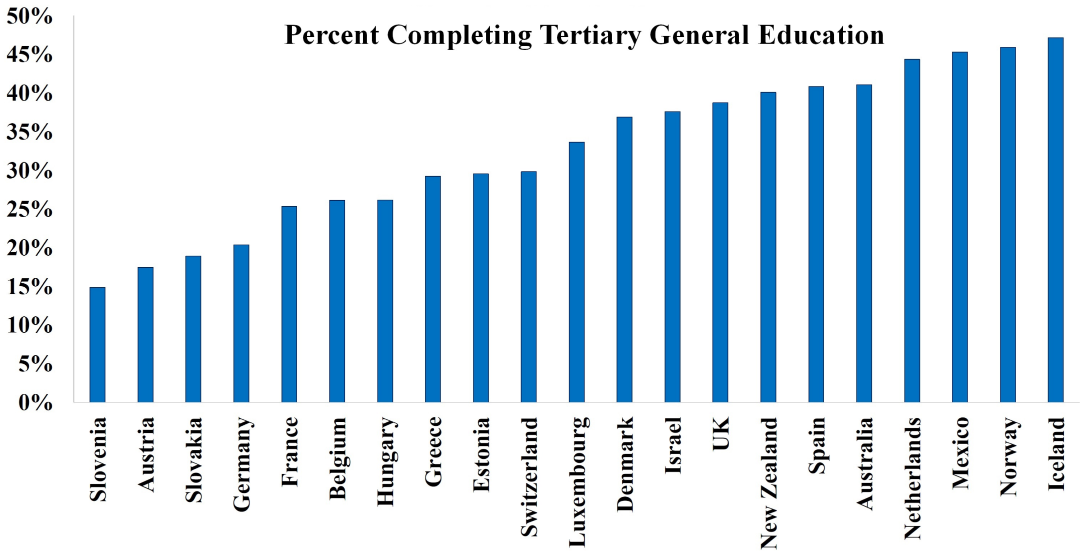


Figure 1: Education type by country

Note: The figure shows the percentage of the tertiary general education graduates among all upper-secondary and tertiary education graduates. We calculate them using data from Education at a Glance (2014, OECD), which provides the general and vocational education population share for both secondary and tertiary education. There are missing data for several countries, including the United States and, thus, we cannot use the data for these countries.

the obsolescence of specific skills caused by the emergence of new technologies. The common argument is that new production technologies replace outdated technologies in innovation processes, and as a result, specific skills become obsolete more quickly than general skills. Krueger and Kumar (2004a, 2004b), for example, argue that the European emphasis on vocational education might have harmed European growth performance relative to that of the United States because specific skills are less able to adapt to technological development. Thus, the Schumpeterian concept of creative destruction has developed a deep understanding of the importance of the skill obsolescence effect underlying long-term economic growth.

However, growth theories have little to say about the difference in skill transferability between general and specific skills. A smooth transition to new or profitable sectors is helpful for the growth of the entire economy, but may be costly for individual workers if their skills are less transferable across jobs. On the other hand, general skills enable workers to deal effectively with unexpected technological breakthroughs. Hence, in this discussion, the key determinant of the skill composition of an economy is the extent of uncertainty about future events, such as changes in industrial structures. Gervais et al. (2008) show that economies with lower uncertainty tend to have a larger share of specialized labor, but that they are more vulnerable to economic turbulence, owing to the inherent difficulty of reallocating workers. Our study also considers the productivity–transferability trade-off between the two skills, and examines the dynamic changes in economic uncertainty and the relative importance of productive and transferable skills. Our main interest is to study how the relative demand for general skills changes in the catching up process of economic development, and how different education systems impact countries' growth performance.

We develop a simple endogenous growth model featuring individuals' choices between general and firm-specific skills, endogenous technological innovation by firms, and government subsidies for general and specific types of education. We assume that firm-specific skills are more productive, but are useful only in the current firm, whereas general skills are less but equally productive in all firms. The dynamic structure of this model is a country's catching up process to the world technology frontier, based on the framework of Acemoglu et al. (2006). Under these assumptions, we analyze the economy's composition of general and specific skills in terms of both transitional dynamics and long-run equilibrium. Three key features of this model are worth noting: (i) general and firm-specific skills are perfectly substitutable; (ii) there is uncertainty in innovation activities; and (iii) firms invest more in innovation activities as their technologies approach the world technology frontier. The assumption of perfect substitution between the two types of skills helps us to identify the market values of productivity and the transferability of skills. Further, innovation activity is a risker task (than imitating existing technologies), so the ex post realization of firms' productivities differ from the ex ante expected productivities. Hence, firms that succeed in innovation may demand additional labor for production. This creates demand for workers with general skills because only general skills can contribute to the ex post labor reallocation across firms. That is, the uncertainty in innovation is the key factor determining the relative demand for, and the equilibrium composition of general skills. The third assumption, which is widely accepted in Schumpeterian growth theory, and is a basic assumption in the distance-to-frontier model, implies that the intensity of firms' innovation activity increases as they approach to the world technology frontier. Therefore, the size of the demand for general skills varies across countries, depending on their stages of development.

The analysis in this paper is divided into two parts. In the first part, in sections 2 and 3, we begin with a simple model that briefly illustrates households' skill choices and no governmental education subsidies. Here, we focus on the change in firms' labor demand for general and specific skills in the catching up process of transition economies. We show that firms' demand for general skills increases as the country approaches the world technology frontier. In relatively less developed countries, firms put less effort into innovation and, thus, place more importance on productivity than on the transferability of workers. Conversely, in countries that are closer to the technology frontier, more general skills are demanded because firms extend their innovative activities and face great uncertainty in production. Additionally, we find that a follower country's technology monotonically converges toward a unique stable steady state, which is less than (or equal to) the world technology frontier. This indicates that, in follower countries with lower initial productivity levels, the demand for general skills increases over time in the process of development.

In the second part, we extend the model of the first part by introducing an elastic labor supply and a governmental education subsidy in section 4. The comparative statistics in the long-run equilibrium show that a higher general education subsidy increases the supply of general skills, enhances firms' innovation investment, and increases the level of technology in the economy. Then, in section 5, we calibrate the model to 12 European countries[1] and quantitatively analyze the effect of a 1% increase in the general education subsidy on the total output of each country. In the multi-country comparison, there is no clear relationship between the population share with a general education and the impact of the general education subsidy on total output. However, we find that the impact is larger in countries with higher total factor productivity (TFP), and that the return on the transferability of general skills is larger in higher TFP countries. These findings support our theoretical argument of the positive relationship between firms' demand for general skill and countries' stages of development. That is, the theoretical and quantitative results indicate that a country's distance to the technology frontier is an important factor in the appropriate composition of general and specific skills.

The present study contributes to the existing theoretical and empirical literature on the trade-off between general and specific skills. The growing demand for general (non-specialized) skills and the resulting lack of workers with such skills, especially in highly developed and industrialized economies, is well documented in the literature. As argued by Goldin (2001), fundamental changes around the turn of the 20th century made formal, general, school-based learning important to the emerging economic leader of the world. Krueger and Kumar (2004a, 2004b) show that general education may contribute to technology adoption and economic growth, especially during times of rapid technological change. From a different perspective, Gervais et al. (2008) construct a model in which economic uncertainty is a key determinant of the skill composition of an economy. The purpose of our study is similar to these studies, but we focus more on the effects of a change of the skill composition on the transitional dynamics. That is, our primary argument is that structural changes in schooling institutions are required as a country approaches the world technology frontier. This result complements the empirical finding of Hanushek (2013), who shows that high-performance skills are more important for growth in developing counties, but that broad basic skills are more relevant in industrialized countries.

[1]We use data for Austria, Belgium, Denmark, France, Germany, Hungary, the Netherlands, Slovakia, Slovenia, Spain, Switzerland, and the United Kingdom.

Outside of the literature on economic growth, numerous studies examine the relationship between skill composition and economic performance. Gould et al. (2001) and Violante (2002) examine the effect of technological changes on the depreciation of specific skills, and show that an increase in the rate of technological progress increases within- and between-group wage inequality, as occurred in the United States during the last three decades of the 20th century.[2] In terms of employment, Wasmer (2006) argues that stringent job protection legislation induces skill specialization and, therefore, less turnover.[3] Hanushek et al. (2017) use microdata for 11 countries to show that the wage and employment advantages of vocational as opposed to general education decrease with age, indicating that specific skills become obsolete too quickly.[4][5]

This study is also related to the rich and growing literature on the role of human capital in technological progress. According to Nelson and Phelps (1966), a major role of human capital is to enable workers to cope with innovation, technological progress, and diffusion. More recently, Galor and Tsiddon (1997), Caselli (1999), Galor and Moav (2000), and Hassler and Rodriguez Mora (2002) examined the effect of a technological transition on the return on human capital. Acemoglu et al. (2006), on which the assumption of technological progress in the present study is based, stressed that as a country catches up with the technology frontier, growth-maximizing governmental policy should evolve in order to increase the intensity of firms' innovation activities and the selection of highly skilled managers. Vandenbussche et al. (2006) also study on countries' catching up processes, and argue the importance of a change in skill composition between basic and higher human capital, according to the stage of development.

[2]See also Kambourov and Manovskii (2009a, b), who emphasize the central importance of occupation-specific human capital to explain the increasing wage inequality in the United States, which occurred simultaneously with an increase in occupational mobility. Dustmann and Meghir (2005) show the sources of wage growth for German workers by estimating returns on experience, sector-specific tenure, and firm-specific tenure. See Sanders and Taber (2012) for a review of the literature on firm-specific human capital, industry- and occupation-specific human capital, and task-specific human capital.

[3]Another interesting study along this line is that of Charlot et al. (2005), who assume that schooling contributes not only to productivity, but also to the adaptability of skills. Then, they show that longer schooling can reduce the unemployment rate, even frictional labor market. On the other hand, Decreuse and Granier (2013), by treating investment in adaptability separately from investment in productivity, model the educational trade-off between general and specific skills.

[4]In addition to the above-mentioned papers, differences in education structures and skill compositions have played a critical role as interrelated factors in sociopolitical development (Bertocchi and Spagat 2004; Malamud and Pop-Eleches 2010), and international trade and labor migration (Kim and Kim 2000; Di Maria and Stryszowski 2009; Guren et al. 2015).

[5]A new insight related to firm-specific human capital is offered by Lazear (2009), who considers that each job requires a slightly different combination of a multiplicity of general skills. See also Silos and Smith (2015), who measure the specificity of human capital using data on college credits across subjects.

2 The Model

2.1 Economic Environment

The economy is composed of a continuum of a unit measure of workers, given exogenously and constant over time. Workers live for one period and spend all of their income on consumption in this period. All workers are equally endowed with one unit of efficient labor, which they supply to the intermediate goods sector inelastically. We assume that labor skills can be of two distinct types: general and sector-specific.

In every period, a unique final good is produced competitively using a continuum of mass one of intermediate goods and any other fixed factor, such as land or natural resources, as inputs. The final good is taken as the numeraire, with its price normalized to 1, and is produced according to the following Cobb–Douglas production function:

$$Y_t = \frac{1}{\alpha} M_t^{1-\alpha} \int_0^1 A_{i,t}^{1-\alpha} y_{i,t}^{\alpha} di, \tag{1}$$

where $A_{i,t}$ is the productivity of firm i, $y_{i,t}$ is the amount of the intermediate good used in the final good production, M_t is the amount of fixed factors, and $\alpha \in (0,1)$. A representative final good producer maximizes the profit

$$\Pi_t = Y_t - \int_0^1 p_{i,t} y_{i,t} di - p_t^M M_t,$$

taking the price of the fixed factors p_t^M and the intermediate good prices $p_{i,t}$ as given. We normalize the total supply of the fixed factors to one. Then, using the first-order condition with respect to $y_{i,t}$, together with $M_t = 1$, the inverse demand function for intermediate good i is given by:

$$p_{i,t} = A_{i,t}^{1-\alpha} y_{i,t}^{\alpha-1}.$$

2.2 Education Choices

At the beginning of their life, workers choose between general and sector-specific skills. Once a worker makes an education choice, it cannot be changed. General skills are less productive than specific skills, while they are equally productive in all sectors. In contrast, skills specific to the i-th sector can only be used in production sector i. We assume that each intermediate good is produced by a single monopoly firm and, thus, the sector-specific skills considered here can be rephrased as being firm specific. In the following analysis, we focus on firms' demand for general skills in economies at different stages of development. Thus, to simplify the argument, we assume that skill acquisition requires no direct expenditure by workers (although we relax this assumption in section 4). Henceforth, we refer to workers with general skills as "G-skill workers" and workers with skills specific to firm i as "S_i-skill workers."

2.3 Firms and Technological Progress

Each intermediate good production is composed of a single monopolistic firm. Further, we assume that each firm is owned by an entrepreneur who, like workers, lives for one period and consumes all of her profit.

Following Acemoglu, Aghion, and Zilibotti (2006) and Vandenbussche, Aghion, and Meghir (2006), henceforth AAZ and VAM, respectively, we assume that the world technology frontier, $\bar{A}_t$, grows exogenously at rate λ, so that

$$\bar{A}_t = (1+\lambda)\bar{A}_{t-1},$$

and characterize the technological innovation process of firm i at time t using the following linear function:

$$A_{i,t} = \phi\bar{A}_{t-1} + \mu_i A_{t-1} x_{i,t}, \tag{2}$$

where $\bar{A}_{t-1}$ is the level of the world technology frontier at time $t-1$, A_{t-1} is the country's local technology level at time $t-1$, $x_{i,t}$ is the level of investment of firm i at time t, and $\phi \in (0,1)$. Here, μ_i represents an idiosyncratic shock to the innovation activity of each firm i, which takes a binary value: $\mu_i \in \{\mu_H, \mu_L\}$, where $\mu_H > \mu_L \geq 0$. We denote by $\pi \in (0,1)$ the probability that each firm draws μ_H. We suppose that the local technology frontier at period $t-1$ in the country becomes common knowledge in period t. Thus, the local technology A_{t-1} in (2) is determined by

$$A_{t-1} = \max\{A_{i,t-1}\}. \tag{3}$$

Further, the cost of investment in innovation takes the following form[6]:

$$c(x) = \frac{\bar{A}_t^{1-\alpha}}{2} x^2.$$

In addition to the innovation activity, each intermediate firm i acts as a monopolist and produces intermediate good i, according to the following production function:

$$y_{i,t} = s_{i,t} + \gamma g_{i,t}, \tag{4}$$

where $s_{i,t}$ and $g_{i,t}$ respectively denote the numbers of S_i-skill and G-skill workers employed by firm i at period t, and $\gamma \in (0, 1)$ represents the relative productivity of general skills. Note that $\gamma < 1$ indicates that the firm i specific skill, as compared to general skills, has a productivity advantage in the production by firm i.

Furthermore, we suppose that, before the shock is realized, firms need to sign wage contracts with workers, which restrict the ability of firms to fire workers or to lower the wages after the realization of the productivity shock. This is relevant in most European countries, where workers are protected against firing by employment protection regulations. This assumption enables workers to invest in relationship-specific skills because it contributes to avoiding the well-known hold-up problem: the returns on firm-specific skills are lost if a firm terminates the relationship.[7] Note that employment protection here plays a key role in guaranteeing the employment and wages of S-skill workers, but is meaningless for G-skill workers because they can move freely across firms, even after the idiosyncratic shock. That is, there is no need for both firms and G-skill workers to limit their ex post reallocation choices by using a contract. Thus, for expositional simplicity, we assume that firms are required to make contracts only with S-skill workers.

2.4 Timing of Events

The timing of events in each period t is as follows. At the beginning of the period, each intermediate firm i decides how many S_i-skill workers to hire, and makes a contract with these workers, that guarantees their payment and employment. We assume that

[6] The assumption that investment cost is proportional to $\bar{A}_t^{1-\alpha}$ ensures balanced growth.

[7] A similar specification is made by Gervais et al. (2008), where firms draw noisy signals about future productivity. Then, after this but before the productivity shock, firms decide how many workers to hire and sign binding contracts with them.

the contract does not depend on the realization of idiosyncratic shocks to the firms. This implies that firms bear the overall risk of holding specific skills. The number of S_i-skill workers, $s_{i,t}$, and the wage paid to them, $W^S_{i,t}$, are determined by the contracts. Because the total number of S-skill workers is determined, the number of G-skill workers is also determined at this time. That is, we suppose that worker's education choices between general and specific skills are made at the same time. Then, each firm i realizes the productivity of innovation process $\mu_i \in \{\mu_H, \mu_L\}$. Based on the realized productivity level, the firm decides on the level of investment $x_{i,t}$ and whether to hire additional G-skill workers. Then, the number of G-skill workers employed in firm i, $g_{i,t}$, their wage, $W^G_{i,t}$, and $x_{i,t}$ are determined.

The important assumption here is that before observing the idiosyncratic shock μ_i, the payments and employment of S-skill workers are guaranteed by contracts. A similar specification of firm specific skills is employed by Gervais et al. (2008). Their specification well describes the productivity–transferability trade-off between specific and general skills. Equation (4) clearly shows that an S_i-skill is more productive than a general skill in the i-th good production and, thus, firms wish to secure a productive labor force. On the other hand, G-skill workers play a complementary role in the ex post efficiency of production by moving to high productive sectors. Note that S-skill workers are protected from outside shocks by long-term contracts. Therefore, it is only firms that face the trade-off in their hiring decisions.

Before presenting the main analysis, several properties of the equilibrium wages are now apparent. First, because intermediate goods firms are ex-ante homogeneous, all firms offer the same wage and hire the same number of S-skill workers, that is, $W^S_{i,t} = W^S_{j,t}$ and $s_{i,t} = s_{j,t}$ hold for all $i \neq j \in [0, 1]$. Second, G-skill workers are hired competitively by firms who seek additional labor. Because G-skill workers are equally productive across firms, if firm i and j demand G-skill workers, $W^G_{i,t} = W^G_{j,t}$ must hold in equilibrium. Finally, because the aggregate state of the economy is not affected by productivity shocks to each firm, workers can perfectly predict the equilibrium wages, W^S_t and W^G_t, when making their education choices. In order for workers to be indifferent between acquiring G-skill and S-skill, both skills must be paid the same wage. That is, we have $W^S_t = W^G_t$ in equilibrium, with positive numbers of G-skill and S-skill workers.

3 Equilibrium

In this section, we study how the share of G-skill workers varies with the economy's distance to the world technology frontier. As discussed in the previous section, even though G-skill workers are less productive than S-skill workers are, and are perfectly substitutable, $W_t^s = W_t^g$ must hold when firms employ G-skill workers in equilibrium. The transferability of general skills is a key determinant of the value of general skills relative to that of firm-specific skills. As we show next, there are two types of equilibrium outcomes: a fraction of workers acquire general skills, or all workers acquire specific skills. These two outcomes are distinguished by parameter values (equation (A1) below), but we focus on the former case. That is, we analyze the equilibrium where both G-skill and S-skill workers emerge and, hence, $W_t^s = W_t^g (\equiv W_t)$ holds.

Further, we find that the ex post realization of firms are either high productivity firms with μ_H, or low productivity firms with μ_L. Hence, they can be distinguished by $i = H, L$. For simplicity, we assume that $\mu_L = 0$ for type-L firms, and denote the productivity of type-H firms as $\mu_H = \mu > 0$.

3.1 Innovation and Demand for General Skills

The firms' problem is divided into two stages: before and after observing the productivity shock. In the second stage, based on the values of μ_i and s_t determined in the first stage, firm i chooses $g_{i,t}$ and $x_{i,t}$ to maximize its profit:

$$\begin{aligned} R(i, s_t) &\equiv p_{i,t} y_{i,t} - W_t g_{i,t} - c(x_{i,t}) \\ &= A_{i,t}^{1-\alpha} y_{i,t}^{\alpha} - W_t g_{i,t} - \frac{1}{2} \bar{A}_t^{1-\alpha} x_{i,t}^2, \end{aligned}$$

Substituting (4) into the above expression yields

$$R(i, s_t) = \left[a_{i,t}^{1-\alpha} (s_t + \gamma g_{i,t})^{\alpha} - w_t g_{i,t} - \frac{1}{2} x_{i,t}^2 \right] \bar{A}_t^{1-\alpha}, \tag{5}$$

where $w_t \equiv W_t / \bar{A}_t^{1-\alpha}$ and $a_{i,t} \equiv A_{i,t}/\bar{A}_t$. Further, define $a_t \equiv A_t/\bar{A}_t \in (0, 1]$ as an inverse measure of the country's distance to the world technology frontier. Therefore, the innovation process (2) can be rewritten as

$$a_{i,t} = \frac{1}{1+\lambda}\big(\phi + \mu_i a_{t-1} x_{i,t}\big). \tag{6}$$

From (5) and (6), the second-stage problem of firm i can be expressed as follows:

$$\max_{g_{i,t}, x_{i,t}} \left(\frac{1}{1+\lambda}\right)^{1-\alpha} \big(\phi + \mu_i a_{t-1} x_{i,t}\big)^{1-\alpha} (s_t + \gamma g_{i,t})^{\alpha} - w_t g_{i,t} - \frac{1}{2} x_{i,t}^2.$$

Assuming interior solutions, the first-order conditions with respect to $g_{i,t}$ and $x_{i,t}$ are, respectively,

$$g_{i,t} = \frac{1}{\gamma}\left[-s_t + \left(\frac{\gamma\alpha}{w_t}\right)^{\frac{1}{1-\alpha}} a_{i,t}\right] \tag{7}$$

and

$$x_{i,t} = \frac{(1-\alpha)\mu_i}{1+\lambda}(s_t + \gamma g_{i,t})^{\alpha} a_{i,t}^{-\alpha} a_{t-1}. \tag{8}$$

Substituting (7) into (8), we obtain

$$x_{i,t} = \frac{(1-\alpha)\mu_i}{1+\lambda}\left(\frac{\gamma\alpha}{w_t}\right)^{\frac{\alpha}{1-\alpha}} a_{t-1}. \tag{9}$$

From (9), we have that $x_{i,t}$ increases in a_{t-1}. That is, as in AAZ and VAM, the firms enhance their innovation activities as the country approaches the world technology frontier. On the other hand, type-L firms choose $x_{L,t} = 0$ because they gain no benefit from investing in innovation activity. Therefore, the technology levels of type-H and type-L firms are

$$a_{H,t} = \frac{1}{1+\lambda}\left[\phi + \frac{(1-\alpha)\mu^2}{1+\lambda}\left(\frac{\gamma\alpha}{w_t}\right)^{\frac{\alpha}{1-\alpha}} a_{t-1}^2\right], \tag{10}$$

$$a_{L,t} = \frac{\phi}{1+\lambda}. \tag{11}$$

Clearly, we have that $a_{H,t} > a_{L,t}$. In other words, type-H firms can develop and employ more advanced technology than type-L firms can. Further, from (3), we have that $a_{H,t} = a_t$ holds in period $t+1$ because the type-H firms are the local technology frontier in each period. Thus, the law of motion of the (inverse) measure of the country's distance to the frontier, a_t, can be derived using (10) (see section 3.4).

Even though we focus on the equilibrium in which both general and specific skills are demanded, type-L firms never hire G-skill workers (see Appendix A for a formal proof). Intuitively, because type-H firms enjoy higher productivity, they produce more goods and demand more labor than type-L firms do. Because S-skill workers are more productive than G-skill workers, firms in the first stage hire sufficient S-skill workers so that they do not have to hire G-skill workers, even in the case of being type-L. At the same time, type-H firms seek additional labor and, thus, hire G-skill workers to cope with the labor shortage in the second stage.[8] Therefore, we have

$$g_{H,t} = \frac{1}{\gamma}\left[-s_t + \left(\frac{\gamma\alpha}{w_t}\right)^{\frac{1}{1-\alpha}} a_{H,t}\right] \tag{12}$$

and $g_{L,t} = 0$.

3.2 Demand for Specific Skills

Before the shock is realized, firms in the first stage decide how many S-skill workers to hire so as to maximize their expected profits. Substituting (12) and $g_{L,t} = 0$ into (5), we derive the revenues of type-H and type-L firms as functions of s_t, as follows:

$$R(H, s_t) = \left[(1-\alpha)\left(\frac{\gamma\alpha}{w_t}\right)^{\frac{\alpha}{1-\alpha}} a_{H,t} + \frac{1}{\gamma}w_t s_t - \frac{1}{2}x_{H,t}^2\right]\bar{A}_t^{1-\alpha},$$

$$R(L, s_t) = a_{L,t}^{1-\alpha} s_t^{\alpha} \bar{A}_t^{1-\alpha}.$$

The firms' problem in their first stage can be written as

$$\max_{s_t} \ \pi R(H, s_t) + (1-\pi)R(L, s_t) - w_t s_t \bar{A}_t^{1-\alpha}$$

$$\Leftrightarrow \quad \max_{s_t} \ \pi\left\{(1-\alpha)\left(\frac{\gamma\alpha}{w_t}\right)^{\frac{\alpha}{1-\alpha}} a_{H,t} + \frac{1}{\gamma}w_t s_t - \frac{1}{2}x_{H,t}^2\right\} + (1-\pi)a_{L,t}^{1-\alpha}s_t^{\alpha} - w_t s_t.$$

We see from the above maximization problem that the existence of an interior solution of s_t requires that $\pi/\gamma < 1$. Alternatively, $g_{H,t} = g_{L,t} = 0$ is realized. Intuitively, $1/\gamma$ units of G-skill workers can be replaced with a single unit of S-skill workers. That is, by hiring an additional single unit of S-skill workers in the first stage, firms can reduce, as

[8] Note that $g_{L,t} = 0$ is not derived from the assumption that $\mu_L = 0$. As long as $\mu_H > \mu_L$ holds, the result remains unchanged, even if we allow μ_L to be strictly positive.

expected, $\frac{\pi}{\gamma}w_t$ of payments for G-skill workers. If this is always higher than the marginal cost from hiring a single unit of S-skill workers, w_t, firms never employ G-skill workers. However, a world with no general skills seems unrealistic and, hence, we assume in the subsequent analysis that

$$\pi < \gamma. \tag{A1}$$

Under assumption (A1), the interior solution of s_t is given by:

$$s_t = \left(\frac{(1-\pi)\gamma\alpha}{(\gamma-\pi)w_t} \right)^{\frac{1}{1-\alpha}} a_{L,t}. \tag{13}$$

Finally, denote by $\mathcal{G}_t$ and $\mathcal{S}_t$ the aggregate demand for G-skill and S-skill workers, respectively. From (12) and (13), we have

$$\begin{aligned} \mathcal{G}_t &= \pi g_{H,t} \\ &= \frac{\pi}{\gamma} \left[\left(\frac{\gamma\alpha}{w_t} \right)^{\frac{1}{1-\alpha}} a_{H,t} - \left(\frac{(1-\pi)\gamma\alpha}{(\gamma-\pi)w_t} \right)^{\frac{1}{1-\alpha}} a_{L,t} \right], \end{aligned} \tag{14}$$

$$\begin{aligned} \mathcal{S}_t &= s_t \\ &= \left(\frac{(1-\pi)\gamma\alpha}{(\gamma-\pi)w_t} \right)^{\frac{1}{1-\alpha}} a_{L,t}. \end{aligned} \tag{15}$$

Further, from (14) and (15), the relative demand for G-skill workers can be expressed as

$$\frac{\mathcal{G}_t}{\mathcal{S}_t} = \frac{\pi}{\gamma} \left[\left(\frac{\gamma-\pi}{1-\pi} \right)^{\frac{1}{1-\alpha}} \widetilde{a}_t - 1 \right], \tag{16}$$

where $\widetilde{a}_t = a_{H,t}/a_{L,t}$ represents the technology gap between type-H and type-L firms. Here, (16) shows that the relative demand for G-skill workers increases in the technology gap, and is the key factor in firms' demands for general skills. The technology gap $\widetilde{a}_t$ can be interpreted as the measure of uncertainty that firms face about future productivity. That is, firms tend to place more importance on transferable skills than they do on productive skills as the uncertainty about future technology increases. Therefore, firms demand more general skills as the technology gap between the success and failure of innovation increases.

The feature of this model is that the uncertainty $\widetilde{a}_t$ is determined endogenously. Our next step is to examine how a change in the distance to the frontier affects the technology gap and the relative demand for general skills.

3.3 Labor Market Equilibrium

In this section, we analyze the equilibrium composition of the labor force between the two types of skills. Because we suppose that the total labor supply is fixed at 1, labor market clearing requires $\mathcal{G}_t + \mathcal{S}_t = 1$. Substituting (14) and (15) into the labor market clearing condition yields the market clearing wage:

$$\left(\frac{\gamma\alpha}{w_t}\right)^{\frac{1}{1-\alpha}} = \left[\frac{\pi}{\gamma}a_{H,t} + \frac{(\gamma-\pi)}{\gamma}\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}} a_{L,t}\right]^{-1}. \tag{17}$$

Combining (17) with (10) and (11), we find that the equilibrium level of $\widetilde{a}_t$ satisfies the following equation:

$$(\widetilde{a}_t - 1)\left[\frac{\pi}{\gamma}\widetilde{a}_t + \frac{\gamma-\pi}{\gamma}\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}}\right]^{\alpha} = \frac{(1-\alpha)\mu^2 a_{t-1}^2}{(1+\lambda)^{1-\alpha}\phi^{1+\alpha}}. \tag{18}$$

The equilibrium composition of skills is determined by (16) and (18). We see from (18) that $\widetilde{a}_t$ increases in a_{t-1}. The positive relation between $\widetilde{a}_t$ and a_{t-1} stems from the size of the technological spillover from the world technology frontier. As seen from (2), when a country is a long way from the world technology frontier, the major determinant of firms' technologies is the spillover of the frontier technology. That is, firms' innovation does not contribute significantly to their technologies in the early stages of development. However, the closer the economy is to the frontier, the higher is the importance of innovation as a determinant of firms' technologies and, thus, the technology gap between type-H and type-L firms increases.

However, note that an increase in a_{t-1} does not always expand the demand for general skills. Equation (16) indicates that we have $\mathcal{G}_t = 0$ for small values of $\widetilde{a}_t$, that is, for small values of a_{t-1}. In other words, there exist $\widehat{a}$ such that the number of G-skill workers is zero when $a_{t-1} < \widehat{a}$. The next lemma shows the existence of the threshold value, $\widehat{a} \in (0, 1)$.

Lemma 1. *Let*

$$\widehat{\mu} \equiv \left[\frac{(1+\lambda)^{1-\alpha}\phi^{1+\alpha}}{1-\alpha}\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{\alpha}{1-\alpha}}\left\{\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}}-1\right\}\right]^{\frac{1}{2}},$$

and suppose that (A1) *and* $\mu > \widehat{\mu}$ *hold. Then, there exists* $\widehat{a} \in (0,1)$*, such that for all* $a_{t-1} \in (\widehat{a}, 1]$*, the number of workers with general skills is strictly positive.*

Lemma 1 is proved in Appendix B. It implies that general skills are beneficial for economies that are closer to the frontier, that is, for more developed countries. As shown in Appendix B, $\mu > \widehat{\mu}$ guarantees the existence of $\widehat{a} \in (0,1)$. From the above discussion, together with Lemma 1, we have the following proposition.

Proposition 1. *Suppose that* (A1) *and* $\mu > \widehat{\mu}$ *hold. Further, assume that* $\widehat{a} < a_{t-1} < 1$*. Then, firms' relative demand for workers with general skills,* $\mathcal{G}_t/\mathcal{S}_t$*, is higher when* a_{t-1} *is higher (i.e., when the economy is closer to the world technology frontier).*

Proposition 1 is obtained directly from (16), (18), and Lemma 1. It argues that the relative importance of general skills increases as the country approaches the world technology frontier. The driving force behind the growing demand for general skills is the increase in $\widetilde{a}_t$. As discussed above, when the country is closer to the frontier, firms gain relatively less from the frontier technology, but gain more from the local technology. Hence, type-H firms increase their investment in innovation. This leads to large technological uncertainty for firms and, thus, transferable skills become more important than technical expertise.

The result shown in Proposition 1 complements an emerging body of literature that emphasizes the importance of basic knowledge through general education, especially during times of rapid technological progress.[9] The heart of their critique is that specific skills become obsolete more quickly with the emergence of new technology and, thus, the need for general skills grows. Furthermore, from (16) and (18) we have that an increase in innovation efficiency (μ) increases the demand for general skills. However, we focus

[9] See Krueger and Kumar (2004a, 2004b), Hanushek and Woessman (2012), and Hanushek et al. (2017).

not on skill obsolescence, but on the change in firms' demand for skill transferability. The relative productivity of specific skills compared to that of general skills ($1/\gamma$) is fixed and assumed to be greater than 1. In spite of this, accelerating innovative activities increases the importance of labor flexibility to unpredictable changes in industrial structure and, hence, increases the demand for workers with general skills.

3.4 Equilibrium Dynamics

In the comparative statics analysis of the previous subsection, we showed that the number of G-skill workers increases as the country approaches to the technology frontier. We now explore the dynamics of a_t. Substituting (17), (11), and $a_{H,t} = a_t$ into (10) yields

$$a_t = \frac{\phi}{1+\lambda} + \frac{(1-\alpha)\mu^2}{(1+\lambda)^2}\left[\frac{\pi}{\gamma}a_t + \frac{\phi(\gamma-\pi)}{\gamma(1+\lambda)}\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}}\right]^{-\alpha} a_{t-1}^2. \quad (19)$$

We assume that the follower countries do not overtake the frontier; that is, we suppose that the steady-state value a^* satisfies $a^* \leq 1$. In the next proposition, we summarize some of the properties of the transitional dynamics and the steady state of a_t.

Proposition 2. *Let*

$$\bar{\mu} \equiv \left[\frac{(1+\lambda)(1+\lambda-\phi)}{1-\alpha}\left\{\frac{\pi}{\gamma} + \frac{\phi(\gamma-\pi)}{\gamma(1+\lambda)}\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}}\right\}^{\alpha}\right]^{\frac{1}{2}},$$

and suppose $\widehat{\mu} < \mu \leq \bar{\mu}$ holds. Then, the economy with initial state $a_o \in (\widehat{a}, 1]$ converges monotonically to the unique stable steady state, where its distance to the world technology frontier is weakly positive (i.e., $a^* \leq 1$).

As shown in Appendix C, a sufficiently large value of $\gamma \in (\pi, 1)$ guarantees the existence of the non-empty interval $[\widehat{\mu}, \bar{\mu}]$. Here, $\mu \leq \bar{\mu}$ guarantees a unique and stable steady state, where the value of a^* is weakly less than 1. Figure 2 depicts the equilibrium dynamics. It follows from Propositions 1 and 2 that if $a_0 \in (\widehat{a}, a^*)$, then the economy starts with a larger stock of specific skills, increases the ratio of workers with general skills over time, and approaches the world technology frontier.

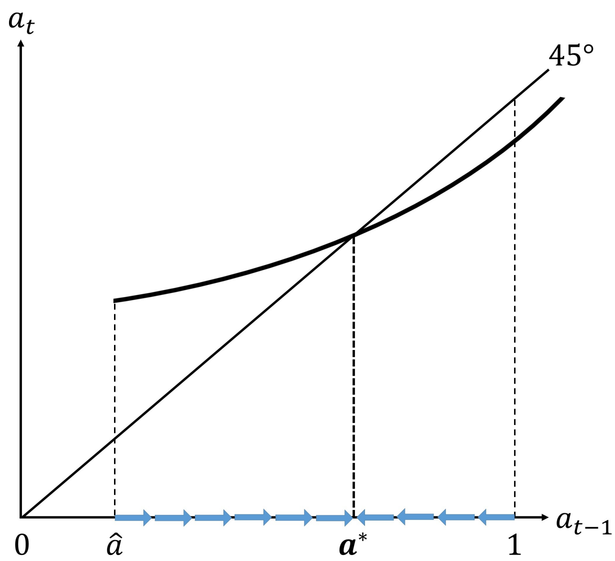


Figure 2: Equilibrium dynamics of a_t

4 Extensions and Policy Analyses

The analysis so far has established a simple theoretical framework for understanding the importance of the transferability of labor skills in more developed countries. Contrary to the theoretical prediction, countries have actually adopted very different schooling structures, even in the most advanced nations. However, the previous model is not directly applicable to the analysis of educational policies in each country because we did not pay much attention to households' educational choices. To address this problem, we extend the previous model to a more general setting in which workers with different initial abilities choose between general and specific types of education. With this extension, the equilibrium wages are different between education groups, as is consistent with the widely observed wage premium for general education graduates.[10] The extension also allows us to relax the theoretical assumption of $\gamma < 1$, which indicates that individuals with a vocational education are more productive than those with a general education.

[10] For example, OECD data show that, on average, individuals who have completed a general education earn 34% more than those with a vocational education do within the group of tertiary graduates. See Education at a Glance (2012, Table A6.1a).

Further, we examine the impact of a change in the education policy, which is captured by the change in the relative subsidies for general and specific types of education. In th following analysis, we focus on the steady-state equilibrium of the model economies.

We first introduce workers' preferences, following the work of Krueger and Kumar (2004b). There is a utility cost, $C(\theta) = 1/\theta$, of obtaining a general education, which depends on a worker's innate ability $\theta \in [0, 1]$. We assume that θ is uniformly distributed across the population, and that the the ability is irrelevant to workers' productivity. The heterogeneity of workers' ability yields the wage differentials between education groups; that is, W_t^g does not coincide with W_t^s in equilibrium. We suppose that workers' preferences are represented by the utility

$$U^g = \log W_t^g - \log \frac{1}{\theta} + \log \nu S_g,$$

when the worker chooses general skills. On the other hand,

$$U^s = \log W_t^s + \log S_s,$$

when the worker chooses specific skills. Here, S_g and S_s represent the government subsidies for general and specific types of education, respectively, and $\nu > 0$ denotes the relative efficiency of the education subsidy for general education.[11] Then, we identify the worker, $\bar{\theta}$, who is indifferent between acquiring general and specific skills, as follows

$$\bar{\theta} = \frac{w_t^s S_s}{\nu w_t^g S_g}.$$

All workers indexed by $\theta \in [0, \bar{\theta}]$ receive a specific education, while workers with $(\bar{\theta}, 1]$ receive a general education. Denoting as $\bar{g}$ the total supply of G-skill workers, the above

[11]We assume, for simplicity, that the subsidy yields utility directly. One justification for this specification is that it is the reduced form of the simple educational choice model. Suppose that a policy-maker sets educational standards E_g and E_s, and individuals choose their effort in response to these standards. Individuals are endowed with a unit of time and need to spend a fraction e of their time on education, and the rest on labor. Then, the budget constraint is given by $C = W_t(1 - e)$. We assume that educational attainment is determined by the function $(\theta S_g)/(1-e)$ for a general education and $S_s/(1-e)$ for a specific education. Then, to meet the standards, individuals must exert effort $e = 1 - \theta S_g/E_g$ to achieve a general type education, and $e = 1 - S_s/E_s$ to achieve a specific education. Finally, the assumption of logarithmic utility, $\log C$, together with $E_g = 1/\nu$ and $E_s = 1$, yields the above specifications of the utility function.

expression can be rewritten as follows:

$$1 - \bar{g} = \frac{w_t^s S_s}{\nu w_t^g S_g}. \tag{20}$$

We continue our analysis on the equilibrium, where there are strictly positive numbers of G-skill and S-skill workers, as in the previous section. However, note that the equilibrium wages in the present model must satisfy

$$w_t^s < \frac{w_t^g}{\gamma}, \tag{21}$$

indicating that the wage per unit of labor is higher for G-skill workers than it is for S-skill workers. Rewriting (21) yields $\gamma < wp$ ($\equiv w_t^g / w_t^s$). This means that the wage premium for general skills, wp, is higher than the relative productivity of general skills, γ, because the G-skill wage includes payment for their skill transferability. Because the transferability wage premium is strictly positive, $\gamma < wp$ must be satisfied in equilibrium with a positive number of G-skill workers. Further, using this relation, we can estimate the size of the transferability wage premium from the gap between wp and γ. We return to this issue in section 5. A further important point is that γ in the present model does not have to be lower than 1. Even if general skills are more productive than specific skills, S-skills remain valuable to firms as long as (21) holds.

We relegate the technical derivation of the firms' profit maximizing decisions to Appendix D, because they are much the same as the previous derivation. As shown in Appendix D, the total demand for G-skill workers in the steady state can be represented by

$$\mathcal{G} = \frac{\pi}{\gamma} \left[-s + \left(\frac{\gamma \alpha}{w^g} \right)^{\frac{1}{1-\alpha}} a^* \right], \tag{22}$$

and the total demand for S-skill workers is

$$\mathcal{S} = \frac{\phi}{1+\lambda} \left(\frac{(1-\pi)\gamma\alpha}{\gamma w^s - \pi w^g} \right)^{\frac{1}{1-\alpha}}. \tag{23}$$

Because we analyze a stationary equilibrium, we drop the time subscript from all variables. The labor market clearing conditions are $\bar{g} = \mathcal{G}$ for G-skill workers, and $1 - \bar{g} = \mathcal{S}$ for S-skill workers. Let us denote by g^* the steady-state equilibrium value of the number of G-skill workers. Dividing both sides of (22) by (23), and using these market-clearing conditions yields

$$\frac{g^*}{1-g^*} = \frac{\pi}{\gamma}\left[-1 + \frac{1+\lambda}{\phi}\left(\frac{\gamma\frac{w^s}{w^g} - \pi}{1-\pi}\right)^{\frac{1}{1-\alpha}} a^*\right]. \tag{24}$$

Moreover, by substituting w^s/w^g of (20) into (24), we have

$$\frac{g^*}{1-g^*} = \frac{\pi}{\gamma}\left[-1 + \frac{1+\lambda}{\phi}\left(\frac{\gamma\nu\widetilde{S}(1-g^*) - \pi}{1-\pi}\right)^{\frac{1}{1-\alpha}} a^*\right], \tag{25}$$

where $\widetilde{S} = S_g/S_s$. Finally, the dynamic equation (33) in Appendix D, evaluated at the steady state, is represented by

$$a^* = \frac{1}{1+\lambda}\left[\phi + \frac{(1-\alpha)\mu^2}{1+\lambda}\left(\frac{\gamma\alpha}{w^g}\right)^{\frac{\alpha}{1-\alpha}}(a^*)^2\right]. \tag{26}$$

Further, substituting w^g of (22), together with $\mathcal{G} = g^*$ and $s = 1 - g^*$, into (26), we obtain

$$(1+\lambda)a^* - \phi = \frac{(1-\alpha)\mu^2}{1+\lambda}\left(1 + \frac{\gamma-\pi}{\pi}g^*\right)^{\alpha}(a^*)^{2-\alpha}. \tag{27}$$

Here, g^* and a^* in the steady-state equilibrium are determined from (25) and (27). Appendix E shows that the dynamic structure of a_t is much the same as that in the previous section. The results of the comparative statics with respect to the relative education subsidies, $\widetilde{S}$, are summarized in the following proposition.

Proposition 3. *The number of workers with general skills, g^*, and the level of technology, a^*, increase in $\widetilde{S}(= S_g/S_s)$.*

The formal proof of Proposition 3 is given in Appendix E. The first key finding in this proposition is that, although it may be obvious, the number of G-skill workers increases as the subsidy for general education increases. This is because a higher general education subsidy makes workers more willing to supply general skills for a lower wage premium and, thus, makes the threshold ability $\bar{\theta}$ lower. On the other hand, the positive relation between a^* and $\widetilde{S}$ is non-trivial. It indicates that an increase in the general education subsidy improves the steady-state level of technology. Therefore, the present model shows that an increase in the supply of G-skill workers enhances the innovation activities of firms, and thus, improves the technology level.

Although there is no fundamental change in the dynamic system from that described in section 3, we cannot rule out the possibility of the existence of multiple steady states in our analytical work. In the numerical study in the next section, however, we confirm the uniqueness of the stable steady state using the data for the sample countries.[12] Thus, in the following analysis, we suppose that economies are located at the stable steady state.

5 Quantitative Analysis

In this section, we explore how the total output of the economies are affected by the education subsidy on general education. Although Proposition 3 shows that a^* increases in $\widetilde{S}$, we cannot conclude that a higher general education subsidy always increases the gross domestic product of the economy. This is because if general skills are less productive than specific skill, an increase in G-skill workers decreases the total labor supply of the economy. Thus, it is meaningful to explore whether and how an emphasis on a general education subsidy contributes to countries' GDP. Our final goal is to estimate the effect of the marginal increase in $\widetilde{S}$ on GDP.

The system of (20), (24), and (27) contains 11 variables. Using the available data set for 12 European countries, namely, Austria, Belgium, Denmark, France, Germany, Hungary, the Netherlands, Slovakia, Slovenia, Spain, Switzerland, and the United Kingdom[13], we first determine the values of (g^*, w_s/w_g, $\widetilde{S}$, a^*) for each country. The parameters describing the production technology, (λ, ϕ, α, π), are chosen to satisfy broadly observable empirical evidence. The remaining three parameters, (γ, ν, μ), which are model-specific parameters, are derived from the three equations, (20), (24), and (27),

[12]Under the parameter values estimated in section 5, there are two steady-state points, where that with a lower value is stable and the other is unstable, as is the case of the dynamics of a_t in section 3 (see Appendix C). Thus, we should expect economies to locate at the lower value. However, we cannot rule out the possibility of more complex structures of the dynamic system of a_t in our analytical work.

[13]We initially attempted to use all available EU countries from the OECD data set (22 countries), but we exclude 10 countries for the following two reasons. First, we need data on attainment and per student expenditure per education type (general/specific), but these data are missing for nine countries (Czech Republic, Estonia, Greece, Ireland, Italy, Luxembourg, Poland, Portugal, and Sweden). Second, because we regard the United States as the frontier country, we cannot use data for countries whose total factor productivity is higher than the United States. For this reason, we exclude Norway.

Table 1: Four key observations from the data

	AUT	BEL	DNK	FRA	DEU	HUN	NLD	SVL	SVN	ESP	CHE	GBR
wp	1.29	1.23	1.11	1.34	1.25	1.64	1.08	1.39	1.32	1.47	1.17	1.26
$\widetilde{S}$	1.09	1.31	1.94	1.38	1.63	2.01	1.45	1.66	1.22	1.37	1.44	1.47
g^*	0.17	0.27	0.38	0.26	0.22	0.27	0.45	0.19	0.17	0.42	0.32	0.40
a^*	0.82	0.86	0.91	0.95	0.93	0.57	0.96	0.66	0.60	0.81	0.96	0.72

Note: $wp = w^g/w^s$ *and* $\widetilde{S} = S_g/S_s$. *The country codes are AUT=Austria, BEL=Belgium, DNK=Denmark, FRA=France, DEU=Germany, HUN=Hungary, NLD=Netherlands, SVK=Slovakia, SVN=Slovenia, ESP=Spain , CHE=Switzerland, GBR=United Kingdom.*

and the eight predetermined variables. Then, we estimate the impact of a 1% increase in $\widetilde{S}$ on the GDP of each country.

5.1 Data

Our primary data source is the Education at a Glance series: OECD indicators, which provides a rich description of education indicators per education type (general/vocational). Education at a Glance (2014) provides the relative earnings of workers aged 25–64 (normalizing the income of adults with upper secondary education to 100). These are given for university and non-university tertiary categories[14] and, thus, we regard the former as the general type of education and the latter as the specific (vocational) type of education. Although the OECD also classifies secondary education into the same two categories for some data, we cannot obtain the wage gap between secondary general and vocational education graduates. Thus, we use the tertiary wage gap as a proxy for w_g/w_s. As such, we obtain a general education wage premium $wp \equiv w_g/w_s = 185/143 \simeq 1.29$ for Austria, for example.

The data for the relative education subsidy $\widetilde{S}$ for each country is also extracted from Education at a Glance (2014), which provides the annual expenditure per student by educational institution. Although it makes sense to use data on tertiary education to

[14]The OECD discriminates university-level education from non-university tertiary education; the OECD calls the former "tertiary-type A" and the latter "tertiary type B." The general pattern of tertiary type A education is to offer programs that are broader and more general in orientation. Tertiary type A institutions are known as universities in most countries. On the other hand, tertiary type B education offers shorter vocational programs and do not lead to the baccalaureate. Tertiary type B institutions are known as further education colleges in the United Kingdom, community or two-year colleges in the United States and vocational education and training institutions in Australia.

ensure consistency with the wage data, some countries have no data on tertiary education expenditure by general/vocational category. Thus, following Kruger and Kumar (2004b), we use governmental expenditure on all secondary education as a proxy for S_s, and expenditure on all tertiary education as a proxy for S_g.[15] Then, the relative subsidy for Austria, for example, is calculated as $\widetilde{S} = 14895/13607 \simeq 1.09$.

Education at a Glance (2014) also provides data on the educational attainment of the labor force for OECD countries. It provides information on the share of the population aged 25–64 having completed general or vocational education, at both the secondary and the tertiary levels. However, in addition to tertiary type B graduates, we regard all upper secondary graduates as S-skill workers. Then, for example, 60.0% of population in Austria are regarded as having specific skills, and 12.7% have general skills. Thus, we obtain the number of G-skill workers as $g^* = 12.7/72.7 \simeq 0.17$ for Austria, and g^* of the other countries are determined in the same way.

Finally, a proxy for the inverse measure of the distance to the frontier, a^*, is defined as the total factor productivity (TFP) of each country divided by the TFP of the United States. We use the Penn World Table (PWT) 9.0 data set, which gives the TFP levels in 2014 for several countries at current purchasing power parity relative to the United States. The values of (g^*, wp, $\widetilde{S}$, a^*) for 12 countries are summarized in Table 1.

5.2 Predetermined Parameters

Next, we choose the values of the technological parameters, (λ, ϕ, α, π). The majority of studies employing the distance-to-frontier model take the United States as the frontier country and, thus, we regard λ as the US TFP growth rate. Let us suppose that one model period corresponds to 15 years. The Penn World Table 9.0 data set shows that the average US TFP growth rate (at constant national prices, 2011 = 1) is 0.763% per year for the period 2000–2014. Thus, the growth rate of the frontier economy is set to $\lambda = (1 + 0.00763)^{15} - 1 \simeq 0.1208$.

The share parameter α in the production function is set to 0.7. Because α represents the labor share of the final product (the sum of workers' income and entrepreneurs' profits) and, thus, a choice of $\alpha = 0.7$ seems reasonable, as is commonly used. In the

[15] Seven countries, Austria, France, Germany Hungary, the Netherlands, Spain, and Switzerland, have data on annual expenditure per student for both Tertiary type A (mainly university) and type B (non-university); the other five countries do not.

Table 2: Parameters assumed to be common across countries

Parameter	λ	α	ϕ	π
value	0.12	0.70	0.64	0.78

latter part of this section, we examine the sensitivity of our results to different values of α.

The values of the spillover parameter ϕ and the share of type-H firms π are determined simultaneously from (2). We see from the expression that, in the frontier economy, the TFP of the type-L sector, $\bar{A}_{L,t}$, grows at rate ϕ; that is,

$$\frac{\bar{A}_{L,t}}{\bar{A}_{t-1}} = \phi. \tag{28}$$

On the other hand, the growth of the frontier economy is driven by innovation activities of the type-H sector in the frontier economy. Hence, we have

$$\frac{\bar{A}_{H,t}}{\bar{A}_{t-1}} = \frac{\bar{A}_{t}}{\bar{A}_{t-1}} = 1 + \lambda. \tag{29}$$

For information on the US industries' TFP performance, we use the Bureau of Labor Statistics data set (US Department of Labor), which provides US output per employee data for 157 four-digit manufacturing and non-manufacturing industries. We calculate the average TFP growth rate for the period 2000–2014 for each sector, and then rank them based on the growth rate. Here, we regard the top π ratio of industries as the type-H sector, and define the lowest value as $\bar{A}_{H,t}/\bar{A}_{t-1}$. Similarly, we define the lowest TFP growth rate among the bottom $1 - \pi$ industries as $\bar{A}_{L,t}/\bar{A}_{t-1}$. To ensure consistency with (29), the lowest value of the top π ratio of industry groups must be consistent with $1 + \lambda$. The closest value is obtained by setting the top 122 industries as type-H. Then, we have $A_{H,t}/A_{t-1} = 1.1222$ (the actual value of $1 + \lambda$ is 1.1208). Thus, we set $\pi = 122/157$. Then, the lowest TFP growth rate of the bottom 35 industries is obtained as 0.6384, which is used as the value of ϕ, according to (28).

Table 3: Estimation results

	AUT	BEL	DNK	FRA	DEU	HUN	NLD	SVL	SVN	ESP	CHE	GBR
γ	1.24	1.18	1.07	1.29	1.20	1.63	1.06	1.35	1.29	1.45	1.13	1.25
ν	0.86	0.84	0.74	0.73	0.63	0.41	1.15	0.53	0.75	0.85	0.87	0.89
μ	3.06	3.05	3.06	3.05	3.10	2.65	3.06	2.90	2.84	2.84	3.08	2.88
$\frac{wp-\gamma}{wp}$	4.3%	3.7%	3.1%	4.2%	4.6%	0.5%	2.6%	2.8%	2.5%	1.0%	3.9%	1.0%

5.3 Calibration

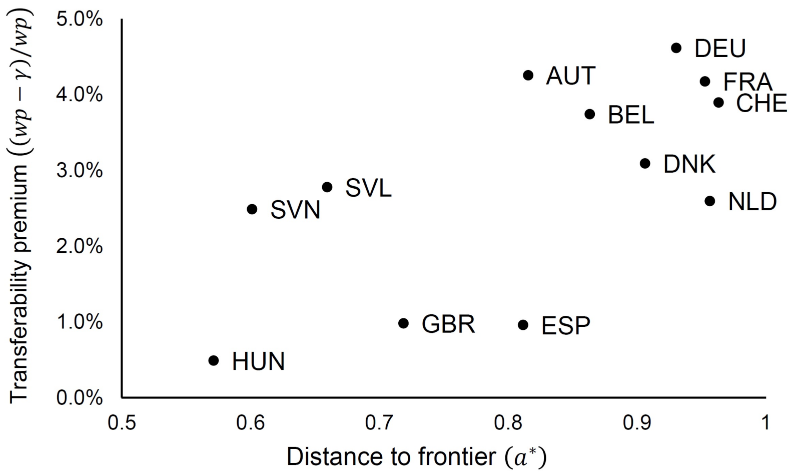
Now, we calibrate the set of parameters (γ, ν, μ) by matching the above key statistics from the data to the steady-state characteristic of the model in section 4. The estimates of ν, γ, and μ are derived from (20), (24), and (27), respectively. The estimation results are listed in Table 3.

As expected, the estimated values of γ are strictly greater than one for all countries. They range from 1.06 for Netherlands to 1.63 for Hungary. That is, the estimates show that general education graduates are more productive than vocational education graduates. The superiority of general skills is well discussed in the literature on the argument that specific skills become obsolete over time.[16] However, the estimates of γ in Table 3 may be overestimated, because we set wp using the wage differentials of tertiary graduates, which will higher than that of upper-secondary or secondary graduates.

Importantly, our estimates satisfy $\gamma < wp$; that is, the wage gap between G- and S-skill workers is greater than their productivity gap. In other words, a positive transferability premium on the wage of general skills is observed for all countries. The final row of Table 3 gives the transferability premium's share of the wage differentials, which is highest in Germany (4.6%) and lowest in Hungary (0.5%). Further, as shown in Figure 3, we find a positive relation between $(wp - \gamma)/wp$ and a^*. This observation leads to the hypothesis that in countries closer to the frontier, the supply of general skills is insufficient to meet firms' needs for a transferable labor force. We test the hypothesis by examining the impact of an increase in the supply of general skills on GDP in the

[16] For instance, Hanushek et al. (2017) show using the German Microcensus data set that general-education individuals earn less at a younger age, but at an older age, earn more than vocational-education individuals. Although we use earning data on employed individuals aged 25–64, our data show that the general/specific wage differential is lower in cohorts aged 25–34, but is higher in cohorts aged 55–64. Thus, the skill obsolescence of vocational-education individuals is also observed in our data.

Figure 3: Distance to frontier and transferability premium



next subsection.

5.4 Impacts of an Education Subsidy on GDP

Now, we examine impact of an educational policy on the economy. Our primary interest here is to examine how an increase in transferable skills contributes to GDP. Note, however, that the above estimates of $\gamma > 1$ mean that G-skill workers have a higher productive skill than that of S-skill workers. That is, an increase in the number of G-skill workers increases the GDP, not only by improving transferability, but also by reinforcing the total labor input in the economy. Here, we focus on the former effect and, hence, we use the output per effective unit of labor $\mathcal{Y}_t \equiv Y_t/(s^* + \gamma g^*)$ as an objective measure in our analysis of the impact of a general education subsidy. Rewriting the definition of final good production in (1), together with $s^* = 1 - g^*$, yields,

$$\mathcal{Y}_t = \frac{1}{\alpha} M^{1-\alpha} \bar{A}_t^{1-\alpha} \frac{\pi a_H^{1-\alpha} y_H^{\alpha} + (1-\pi) a_L^{1-\alpha} y_L^{\alpha}}{1 + (\gamma - 1) g^*}. \tag{30}$$

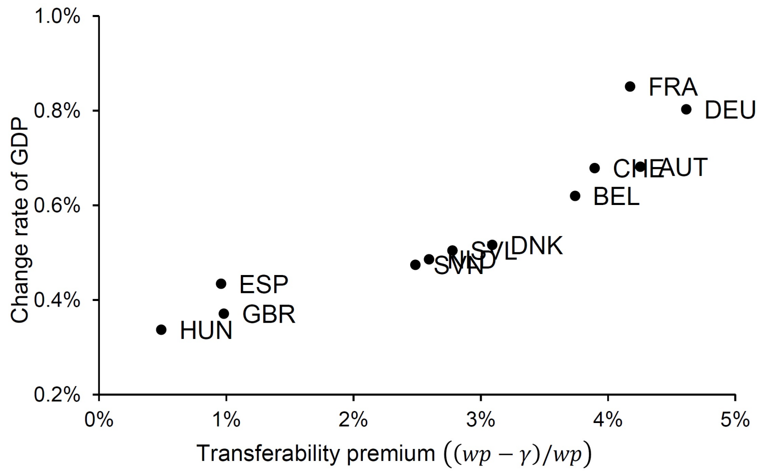
Four steady-state variables in (30), g^*, a_H, y_H, and y_L, are affected by the increase in $\widetilde{S}$: the former three variables increase in $\widetilde{S}$, while y_L decreases in $\widetilde{S}$.

We calculate the changes in g^* and $\mathcal{Y}_t$ caused by a 1% increase in $\widetilde{S}$. The results are summarized in Table 4. As shown theoretically in Proposition 3, the results in Table 4 show positive impacts of $\widetilde{S}$ on g^*. Furthermore, we find that the change rate of g^* is negatively related to g^* in Table 1. The result in Table 4 also shows that a 1% increase in $\widetilde{S}$ increases $\mathcal{Y}_t$ in all countries in our sample. Surprisingly, we cannot find

Table 4: Change rates of g^* and $\mathcal{Y}_t$ by 1% increase in $\widetilde{S}$

	AUT	BEL	DNK	FRA	DEU	HUN
Change rate of g^*	4.59%	2.67%	1.60%	2.87%	3.60%	2.55%
Change rate of $\mathcal{Y}_t$	0.68%	0.62%	0.52%	0.85%	0.80%	0.34%
	NLD	**SVL**	**SVN**	**ESP**	**CHE**	**GBR**
Change rate of g^*	1.19%	4.05%	4.46%	1.35%	2.09%	1.43%
Change rate of $\mathcal{Y}_t$	0.49%	0.50%	0.47%	0.43%	0.68%	0.37%

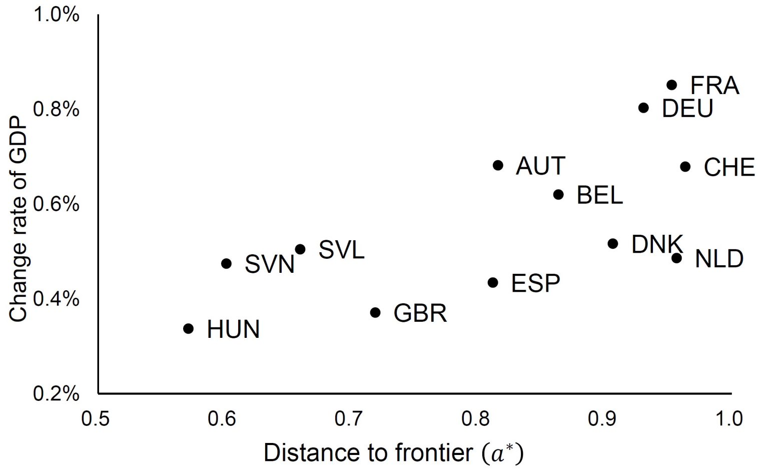
Figure 4: Transferability premium and change rate of $\mathcal{Y}_t$



clear relations between the values of g^* or the change rate of g^* and the change rate of $\mathcal{Y}_t$. Hungary, Slovakia, and Slovenia have a relatively small share of general education graduates. Thus, a marginal increase in a general education subsidy increases the general education share in these countries significantly. However, despite the higher change rates of g^*, the general education subsidy has less impact on $\mathcal{Y}_t$ in these countries. On the other hand, as shown in Figure 4, there is a strong and positive relation between the change rate of $\mathcal{Y}_t$ and the transferability premium $((wp-\gamma)/wp)$. These observations indicate that a key determinant of the effect of the general education subsidy on $\mathcal{Y}_t$ is not the absolute size of the general education share, but rather the size of firms' relative demand for general skills.

In addition, Figure 5 shows that change rate of $\mathcal{Y}_t$ is higher in countries that are closer to the frontier (i.e., countries with higher a^*). The reasoning behind this observation is

Figure 5: Distance to frontier and change rate of $\mathcal{Y}_t$



given in Figure 3. The figure suggests the possibility of a short supply of general skills in relatively high TFP countries, such as Germany, France, and Switzerland. In fact, a relative increase in the general education subsidy has a significant impact on the change of $\mathcal{Y}_t$ in these countries. Conversely, in relatively low TFP country, such as Hungary, the demand for general skills is not as large and, hence, the subsidy for general education has less impact on $\mathcal{Y}_t$.

5.5 Sensitivity Analysis

In section 5.2, we set $\alpha = 0.7$ as a benchmark by considering that α represents the labor share of the final product. The rationale behind this assumption is that the revenue of each intermediate firm is divided between workers and the entrepreneurs and, thus, α is equal to the labor share of total output. However, the final good production function is defined as the relation between the quantity of inputs of intermediate goods, y_i, the fixed factor, M, and the quantity of outputs, Y_t. Thus, the value of the share parameter α will vary according to what M represents (however, note that the results in Table 4 are not affected by the value of M). Rather than defining M, we check the sensitivity of the results to other values of α.

In Table 5 and Table 6, we report the results of the sensitivity analysis for $\alpha = 0.6$ and $\alpha = 0.8$, respectively. The tables show that our argument, thus far, does not depend on the value of α. That is, even at $\alpha = 0.6$ and $\alpha = 0.8$, we still observe positive impacts of a general education subsidy on GDP for all countries, and find especially large values for countries with a higher transferability premium and that are closer to the frontier.

Table 5: Results for $\alpha = 0.6$

	AUT	BEL	DNK	FRA	DEU	HUN
$\frac{wp-\gamma}{wp}$	5.51%	4.87%	4.06%	5.42%	5.96%	0.66%
Change rate of g^*	4.68%	2.76%	1.66%	3.86%	4.14%	2.49%
Change rate of $\mathcal{Y}_t$	0.84%	0.85%	0.76%	3.01%	1.75%	0.29%
	NLD	SVL	SVN	ESP	CHE	GBR
$\frac{wp-\gamma}{wp}$	3.42%	3.64%	3.27%	1.29%	5.07%	1.31%
Change rate of g^*	1.29%	4.00%	4.39%	1.38%	2.60%	1.42%
Change rate of $\mathcal{Y}_t$	0.99%	0.49%	0.43%	0.57%	2.14%	0.38%

Table 6: Results for $\alpha = 0.8$

	AUT	BEL	DNK	FRA	DEU	HUN
$\frac{wp-\gamma}{wp}$	2.92%	2.55%	2.09%	2.86%	3.18%	0.32%
Change rate of g^*	4.59%	2.66%	1.61%	2.79%	3.54%	2.60%
Change rate of $\mathcal{Y}_t$	0.63%	0.56%	0.47%	0.63%	0.65%	0.38%
	NLD	SVL	SVN	ESP	CHE	GBR
$\frac{wp-\gamma}{wp}$	1.75%	1.88%	1.68%	0.64%	2.66%	0.65%
Change rate of g^*	1.19%	4.10%	4.54%	1.36%	2.06%	1.45%
Change rate of $\mathcal{Y}_t$	0.42%	0.53%	0.52%	0.39%	0.55%	0.38%

6 Conclusion

In this paper, we have proposed a growth model where the composition of general and specific skills changes during a country's catching up process to the world technology frontier. The key element underlying the growing importance of general skills in the development process is the increasing uncertainty about private sector productivity. Given the assumption that firms' innovation activities are riskier than copying and adopting existing technology, more developed countries, which have to put greater effort into innovation, face a higher productivity risk. This results in firms' precautionary demand for transferable workers who are adaptable to the unexpected sectoral changes. Thus, the proposed model predicts that firms place more importance on transferability than they do on productivity for labor skills, and that their demand for general skills increases as the country approaches the world technology frontier.

However, contrary to the models' prediction, many of most developed and industrialized countries in Europe have a small share of general education. A number of studies have examined the European educational composition and, in some cases, find a need for an expansion of general education. To the best of our knowledge, this study serves first attempt to examine the relationship between the educational composition and growth performance of the economy by focusing on the productivity–transferability trade-off between general and specific types of education. Our numerical analysis shows that a marginal increase in general education expenditure increases the steady-state GDP for all 12 European countries in our data. Interestingly, the cross-country comparison does not show a clear relationship between countries' initial share of the general education population and the impact of general education expenditure on GDP. On the other hand, the results show that the demand relative to the supply of general skills is larger in higher TFP countries, and that the impact of general education expenditure is positively related to countries' TFP levels. These findings suggest that the distance to the world technology frontier is relevant to the debate on secondary and tertiary schooling structures. The results also indicate the possibility of an over-specialization in skills in countries at higher stages of development.

The arguments on cross-country comparisons in this study can be extended to cross-industry comparisons. Although the present model ignores sectoral differences in the distance to the frontier, the cross-industry variance of sectoral TFP levels within a country might be not small. Thus, there may exist large differences in the demand for general skills between industries, in which case, general skills will be more required in well-developed and/or highly innovative industries.

Appendix

Appendix A: Proof of $g_{L,t} = 0$

In this appendix, we prove that $g_{L,t} = 0$ holds for any equilibrium. Conversely, we assume that $g_{H,t} > 0$ and $g_{L,t} > 0$. Then, firms' demand for general skilled workers is obtained as follows:

$$
\begin{aligned}
g_{H,t} &= \frac{1}{\gamma}\left[-s_t + \left(\frac{\gamma\alpha}{w_t}\right)^{\frac{1}{1-\alpha}} a_{H,t}\right], \\
g_{L,t} &= \frac{1}{\gamma}\left[-s_t + \left(\frac{\gamma\alpha}{w_t}\right)^{\frac{1}{1-\alpha}} a_{L,t}\right].
\end{aligned}
$$

Using these expressions, the firms' problem in the first stage can be expressed as follows:

$$
\begin{aligned}
\max_{s_t} \ & \left[\pi\left\{(1-\alpha)\left(\frac{\gamma\alpha}{w_t}\right)^{\frac{\alpha}{1-\alpha}} a_{H,t} + \frac{1}{\gamma}w_t s_t - \frac{1}{2}x_{H,t}^2\right\}\right. \\
& \left. + (1-\pi)\left\{(1-\alpha)\left(\frac{\gamma\alpha}{w_t}\right)^{\frac{\alpha}{1-\alpha}} a_{L,t} + \frac{1}{\gamma}w_t s_t\right\} - w_t s_t\right].
\end{aligned}
$$

The maximization problem is linear in s_t and, hence, the non-negative constraint $g_{L,t} \geq 0$ has to be binding. Thus, we have $g_{L,t} = 0$.

Appendix B: Proofs of Lemma 1 and Proposition 1

From (16), we have that $\mathcal{G}_t/\mathcal{S}_t > 0$ requires that

$$
\widetilde{a}_t > \left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}}. \tag{31}
$$

Combining (31) and (18), we have that a_{t-1} must satisfy the following inequality:

$$
\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{\alpha}{1-\alpha}}\left(\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}} - 1\right) < \frac{(1-\alpha)\mu^2 a_{t-1}^2}{(1+\lambda)^{1-\alpha}\phi^{1+\alpha}}.
$$

Solving the above inequality with respect to a_{t-1} yields

$$a_{t-1} > \left[\frac{(1+\lambda)^{1-\alpha}\phi^{1+\alpha}}{(1-\alpha)\mu^2}\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{\alpha}{1-\alpha}}\left\{\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}}-1\right\}\right]^{\frac{1}{2}} \equiv \widehat{a}.$$

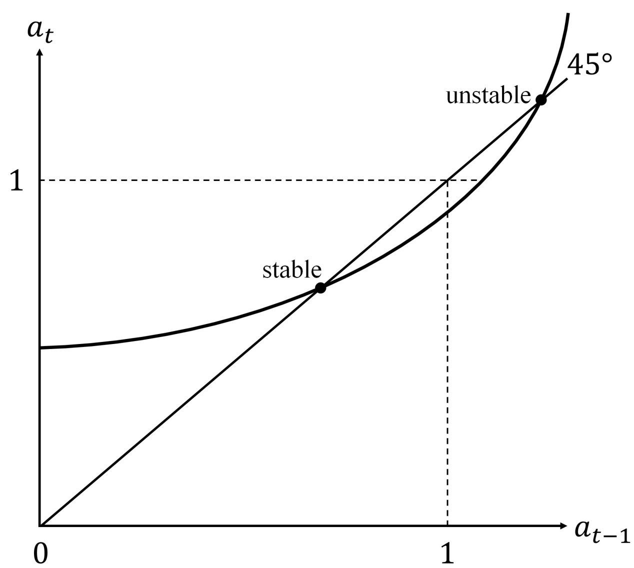
Further, in order to guarantee the existence of general skills, $\widehat{a} < 1$ must hold. Rearranging the condition yields

$$\mu > \left[\frac{(1+\lambda)^{1-\alpha}\phi^{1+\alpha}}{1-\alpha}\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{\alpha}{1-\alpha}}\left\{\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}}-1\right\}\right]^{\frac{1}{2}} \equiv \widehat{\mu}.$$

Appendix C: Proof of Proposition 2

From (19), we have that the dynamics of a_t satisfy $da_t/da_{t-1} > 0$, $d^2a_t/da_{t-1}^2 > 0$, and that $a_t = \frac{\phi}{1+\lambda} > 0$ when $a_{t-1} = 0$. That is, a_t is increasing and convex in a_{t-1}, and has a positive intercept. Thus, the dynamics of a_t have at most two steady-state points. As shown in the figure below, if two steady-state points exist, the one with a lower value is stable and the larger one is unstable. A condition for the existence of a unique and stable steady state in the interval $(0,1]$ is that $a_{t-1} \geq 1$ at $a_t = 1$. Substituting this condition into (19), and rearranging, yields

$$\mu \leq \left[\frac{(1+\lambda)(1+\lambda-\phi)}{1-\alpha}\left\{\frac{\pi}{\gamma}+\frac{\phi(\gamma-\pi)}{\gamma(1+\lambda)}\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}}\right\}^{\alpha}\right]^{\frac{1}{2}} \equiv \bar{\mu}.$$



Finally, because μ must satisfy $\mu \in (\widehat{\mu}, \bar{\mu})$, we have to check whether $\widehat{\mu} < \bar{\mu}$ holds. Substituting $\widehat{\mu}$ and $\bar{\mu}$ into $\widehat{\mu} < \bar{\mu}$, and rewriting, yields

$$\phi^{1+\alpha}\left\{\left(\frac{1-\pi}{\gamma-\pi}\right)^{\frac{1}{1-\alpha}} - 1\right\} < (1+\lambda)^{\alpha}(1+\lambda-\phi)\left\{\frac{\pi}{\gamma}\left(\frac{\gamma-\pi}{1-\pi}\right)^{\frac{1}{1-\alpha}} + \frac{\phi(\gamma-\pi)}{\gamma(1+\lambda)}\right\}^{\alpha}.$$

The left-hand side of the above inequality decreases in γ and is equal to 0 when $\gamma \to 1$. On the other hand, the right-hand side increases in γ and is equal to 0 when $\gamma \to \pi$. That is, γ has to be large enough to ensure that $\widehat{\mu} < \bar{\mu}$. From the above discussion, there exists $\widehat{\gamma} \in (\pi, 1)$, such that $\widehat{\mu} < \bar{\mu}$ holds for $\gamma \in (\widehat{\gamma}, 1)$.

Appendix D

First, we return to the second-stage problem of firms, and resolve $g_{H,t}$ and $x_{i,t}$. The second-stage problem of type-H firms is as follows:

$$\max_{g_{H,t}, x_{i,t}} \left(\frac{1}{1+\lambda}\right)^{1-\alpha} (\phi + \mu a_{t-1} x_{i,t})^{1-\alpha} (s_t + \gamma g_{H,t})^{\alpha} - w_t^g g_{H,t} - \frac{1}{2} x_{i,t}^2.$$

The first-order conditions with respect to $g_{H,t}$ and $x_{H,t}$ are, respectively,

$$g_{H,t} = \frac{1}{\gamma}\left[-s_t + \left(\frac{\gamma\alpha}{w_t^g}\right)^{\frac{1}{1-\alpha}} a_{H,t}\right] \tag{32}$$

and

$$x_{i,t} = \frac{(1-\alpha)\mu}{1+\lambda}(s_t + \gamma g_{H,t})^{\alpha} a_{H,t}^{-\alpha} a_{t-1}.$$

Using the above two first-order conditions, we obtain

$$x_{i,t} = \frac{(1-\alpha)\mu}{1+\lambda}\left(\frac{\gamma\alpha}{w_t^g}\right)^{\frac{\alpha}{1-\alpha}} a_{t-1}.$$

Then, we have the technology level of type-H firms as

$$a_{H,t} = \frac{1}{1+\lambda}\left[\phi + \frac{(1-\alpha)\mu^2}{1+\lambda}\left(\frac{\gamma\alpha}{w_t^g}\right)^{\frac{\alpha}{1-\alpha}} a_{t-1}^2\right]. \tag{33}$$

Next, the first-stage problem of firms can be written as

$$\max_{s_t} \ \pi \left\{ (1-\alpha)\left(\frac{\gamma\alpha}{w_t^g}\right)^{\frac{\alpha}{1-\alpha}} a_{H,t} + \frac{1}{\gamma} w_t^g s_t - \frac{1}{2} x_{H,t}^2 \right\} + (1-\pi) a_{L,t}^{1-\alpha} s_t^{\alpha} - w_t^s s_t.$$

Note that $\pi w_t^g/\gamma < w_t^s$ is required for the existence of an interior solution, that is, for the existence of G-skill workers. Combining this condition with (21), we have

$$\gamma < \frac{w_t^g}{w_t^s} < \frac{\gamma}{\pi}. \tag{34}$$

We focus on the equilibrium that satisfies the condition given in (34), in which both G-skill and S-skill workers exist. Section 5 showed that all estimates obtained from our calibration satisfy (34). Finally, the first-order condition of this problem yields

$$s_t = \left(\frac{(1-\pi)\gamma\alpha}{\gamma w_t^s - \pi w_t^g}\right)^{\frac{1}{1-\alpha}} a_{L,t}. \tag{35}$$

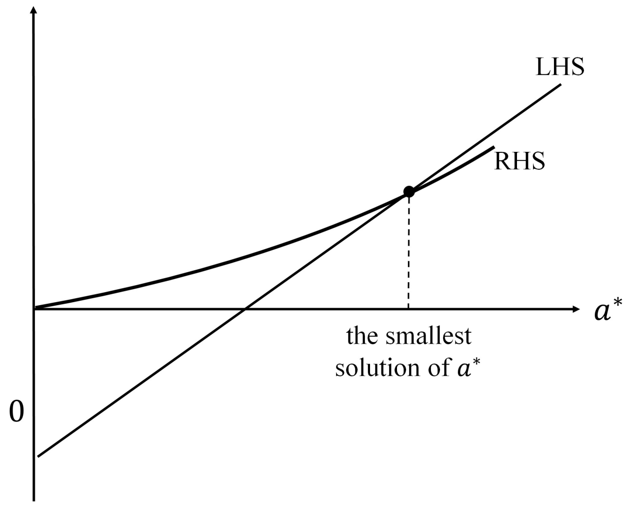
Rearranging (32) and (35) by evaluating at the steady state and substituting $a_{L,t} = \phi/(1+\lambda)$ yields (22) and (23).

Appendix E: Proof of Proposition 3

In this appendix, we examine the steady-state characteristics using the system given in (25) and (27). We first show that the steady-state values, g^* and a^*, increase in $\widetilde{S}$. Let us denote as $g(\widetilde{S}, a^*)$ the solution of (25) with respect to g^*, as a function of a^* and $\widetilde{S}$. From (25), we have that $g(\widetilde{S}, a^*)$ increases in both $\widetilde{S}$ and a^*. Substituting $g^* = g(\widetilde{S}, a^*)$ into (27) yields

$$(1+\lambda)a^* - \phi = \frac{(1-\alpha)\mu^2}{1+\lambda}\left(1 + \frac{\gamma-\pi}{\pi} g(\widetilde{S}, a^*)\right)^{\alpha} (a^*)^{2-\alpha}.$$

Here, a^* is determined from the above expression. The left-hand side (LHS) of the above expression is increasing and is a linear function of a^* with a negative intercept. At the same time, the right-hand side (RHS) increases in a^*, and passes through the origin. However, we cannot examine the number of intersections between the LHS and RHS curves because very little is known about the shape of the RHS function. However, we have that if the LHS and the RHS curves have one or more intersections, the value of the smallest steady-state increases in $\widetilde{S}$. This means that the smallest steady-state point of a increases in $\widetilde{S}$ and, thus, it becomes clear that $g^* = g(\widetilde{S}, a^*)$ increases in $\widetilde{S}$. The steady-state point is described in the figure below.



Next, we investigate the stability of the steady state corresponding to the smallest solution of a^*. Let us denote as g_t the total number of G-skill workers in equilibrium, but not in the steady state. Then, substituting $\pi g_{H,t} = g_t$, $s_t = 1 - g_t$, and $a_{H,t} = a_t$ into (32) and (33) yields

$$g_t = \frac{\pi}{\gamma}\left[-(1-g_t) + \left(\frac{\gamma\alpha}{w_t^g}\right)^{\frac{1}{1-\alpha}} a_t\right], \tag{32'}$$

and

$$a_t = \frac{1}{1+\lambda}\left[\phi + \frac{(1-\alpha)\mu^2}{1+\lambda}\left(\frac{\gamma\alpha}{w_t^g}\right)^{\frac{\alpha}{1-\alpha}} a_{t-1}^2\right]. \tag{33'}$$

Moreover, using (20) together with $s_t = 1 - g_t$ and $a_{L,t} = \frac{1}{1+\lambda}[a_{t-1} + \phi(1 - a_{t-1})]$, (35) can be rewritten as

$$(1 - g_t) = \left(\frac{1-\pi}{\gamma\nu\widetilde{S}(1-g_t) - \pi}\right)^{\frac{1}{1-\alpha}}\left(\frac{\gamma\alpha}{w_t^g}\right)^{\frac{1}{1-\alpha}}\frac{\phi}{1+\lambda}. \tag{35'}$$

The three endogenous variables, g_t, a_t, and w_t^g, are determined by (32′), (33′), and (35′). These equations show $da_t/da_{t-1} > 0$ for $a_{t-1} \in [0, 1]$, and that $a_t > 0$ when $a_{t-1} = 0$.[17]

[17]By eliminating a_t and w_t^g from (32′), (33′), and (35′), we can see the positive relation between g_t and a_{t-1}. From this observation, we have from (33′) and (35′) that a_t increases in a_{t-1}.

Therefore, the steady state determined by the first intersection of the dynamic equation of a_t and the 45-degree line is stable, indicating that the dynamics are much the same as those described in section 3 and in the figure in Appendix C. In the subsequent discussion, we continued the analysis by supposing that economies are on this stable steady state, although we did not prove its uniqueness. Instead of deriving the parameter conditions for the existence and uniqueness of the stable steady state, we confirmed them in the quantitative analysis in section 5.

References

[1] Acemoglu, D. (1998). "Why do new technologies complement skills? Directed technical change and wage inequality." Quarterly Journal of Economics, vol. 113, issue 4, pp. 1055–1089.

[2] Acemoglu, D., Aghion, P., Zilibotti, F. (2006). "Distance to frontier selection and economic growth." Journal of the European Economic Association, vol. 4, issue 1, pp. 37–74.

[3] Becker, G. (1962). "Investment in Human Capital: A Theoretical Analysis." Journal of Political Economy. vol. 70, issue 5, pp. 9–49.

[4] Bertocchi, G., M. Spagat, (2004). "The Evolution of Modern Educational Systems: Technical vs. General Education, Distributional Conflict, and Growth." Journal of Development Economics, Vol. 73, issue 2, pp. 559–582.

[5] Caselli, F. (1999). "Technological Revolutions." American Economic Review, vol. 89, issue 1, pp. 78–102.

[6] Charlot, O., Decreuse, B., Granier, P. (2005). "Adaptability, productivity, and educational incentives in a matching model." European Economic Review, Vol. 49, issue 4, pp. 1007–1032.

[7] Decreuse, B., Granier, P. (2013). "Unemployment benefits, job protection, and the nature of educational investment." Labour Economics, Vol. 23, pp. 20–29.

[8] Di Maria, C., Stryszowski, P. (2009). "Migration, human capital accumulation and economic development." Journal of Development Economics, Vol. 90, issue 2, pp. 306–313.

[9] Dustmann, C. and C. Meghir (2005). "Wages, experience and seniority." Review of Economic Studies, Vol. 72, issue 1, pp. 77–108.

[10] Galor, O., Moav, O. (2000). "Ability-Based Technological Transition, Wage Inequality, and Economic Growth." Quarterly Journal of Economics, vol. 115, issue 2, pp. 469–497.

[11] Galor, O., Tsiddon, D. (1997). "Technological progress, mobility, and economic growth." The American Economic Review. vol. 87, issue 3, pp. 363–382.

[12] Gervais, M., Livshits, I., Meh, C. (2008). "Uncertainty and the specificity of human capital." Journal of Economic Theory. vol. 143, issue 1, pp. 469–498.

[13] Goldin, C. (2001), "The Human Capital Century and American Leadership: Virtues of the Past." Journal of Economic History, Vol. 61, issue 2, pp. 263–292.

[14] Guren, A., Hemous, D., Olsen, M. (2015). "Trade Dynamics with Sector-Specific Human Capital." Journal of International Economics, Vol. 97, issue 1, pp. 126–147.

[15] Gould, E., Moav, O. Weinverg, B. (2001). "Precautionary demand for education, inequality, and technological progress." Journal of Economic Growth. vol. 6, issue 4, pp. 285–315.

[16] Hanushek, E.A., Woessmann, L. (2012). "Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation." Journal of Economic Growth, Vol. 17, issue 4, pp. 267–321.

[17] Hanushek, E.A., (2013). "Economic growth in developing countries: the role of human capital." Economics of Education Review, vol. 37, pp. 204–212.

[18] Hanushek, E.A., Schwerdt, G., Woessmann, L., Zhang, L. (2017). "General Education, Vocational Education, and Labor Market Outcomes over the Lifecycle." Journal of Human Resources, Vol. 52, issue 1, pp. 48–87.

[19] Hassler, J., J.V. Rodriguez Mora (2000). "Intelligence, Social Mobility, and Growth." American Economic Review, vol. 90, issue 4, pp. 888–908.

[20] Kambourov, G., I. Manovskii, (2009a). "Occupational Specificity of Human Capital." International Economic Review, vol. 50, issue 1, pp. 63–115.

[21] Kambourov, G., I. Manovskii, (2009b). "Occupational Mobility and Wage Inequlality." Review of Economic Studies, vol. 76, issue 2, pp. 731–759.

[22] Kim, S. J., Y. Kim, (2000). "Growth Gains from Trade and Education." Journal of International Economics, Vol. 50, issue 2, pp. 519–545.

[23] Krueger, D., and K. B. Kumar. (2004a). "Skill-Specific Rather than General Education: A reason for US-Europe Growth Differences?" Journal of Economic Growth 9, no. 2: 167–207.

[24] Krueger, D., and K. B. Kumar. (2004b). "US-Europe Differences in Technology-Driven Growth: Quantifying the Role of Education." Journal of Monetary Economics, vol. 51, issue 1, pp. 161–190.

[25] Lazear, E. P. (2009). "Firm-specific human capital: A skill-weights approach." Journal of Political Economy, Vol. 117, issue 5, pp. 914–940.

[26] Malamud, O., C. Pop-Eleches. (2010). "General education versus vocational training: Evidence from an economy in transition." Review of Economics and Statistics, Vol. 92, issue 1, pp. 43–60.

[27] Nelson, R., S. Phelps, (1966). "Investment in Humans, Technological Diffusion, and Economic Growth." American Economic Review, vol. 56, issue 1, pp. 69–75.

[28] OECD. (2014). "Education at a Glance: OECD Indicators 2014". OECD, Paris.

[29] Sanders, C., and C. Taber (2012). "Life-Cycle Wage Growth and Heterogeneous Human Capital," Annual Review of Economics, Vol. 4, pp. 399–425.

[30] Silos, P., E. Smith (2015). "Human capital portfolios." Review of Economic Dynamics, Vol. 18, issue 3, pp. 635–652.

[31] Vandenbussche, J., Aghion, P., Meghir, C. (2006). "Growth, distance to frontier and composition of human capital." Journal of Economic Growth. vol. 11, issue 2, pp. 97–127.

[32] Violante, G. (2002). "Technological acceleration, skill transferability, and the rise in residual inequality." Quarterly Journal of Economics. CXVII, pp. 297–338.

[33] Wasmer, E. (2006). "General versus Specific Skills in Labor Markets with Search Frictions and Firing Costs" American Economic Review, vol. 96, issue 3, pp. 811–831.