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Abstract

Human capital plays a key role in fostering technology adoption, the major source of economic growth in developing countries. Consequently, enhancing the level of human capital should be a matter of public concern. The present paper studies public education incentives in an environment in which governments can invest in human capital to facilitate the adoption of new technologies invented abroad or, instead, focus on consumptive public spending. Although human capital is pivotal for growth, the model reveals that incentives to invest in public education vanish if a country is poorly endowed with human capital. Rather, governments of these poorly-endowed countries focus on consumptive public spending. As a result, while their better-endowed counterparts build up human capital thereby promoting technology adoption and growth, the growth process in poorly-endowed countries stagnates.

Keywords: growth, public education, human capital, technology adoption

JEL-Classification: O4, H4, F2

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1 Introduction

Recognizing the importance of human capital for growth, public investment in education has reached high priority in many countries and received increased attention in academic research during the last years. While various justifications for governmental involvement in enhancing human capital exist, a common motivation is the belief that human capital is the key to growth. Thus, public education that facilitates human capital accumulation is viewed as beneficial as it directly promotes the growth process. At the same time, recent endogenous growth theories examining the link between human capital and growth emphasize that human capital fosters growth through the progress in technological knowledge.[1] For most countries and most certainly for developing countries, technological progress hinges on technology adoption, which is the process of imitating and adapting technologies invented abroad.[2] The link between human capital and technology adoption was first highlighted by Nelson and Phelps (1966), who contend that educated workers are better at executing tasks that require adaptation to a changing environment and, thus, adopt new technologies faster. Among others, this technological view of the benefits of human capital receives empirical support by Benhabib and Spiegel (1994, 2005) showing that human capital is an important vehicle for growth through technology diffusion.

Given the crucial role of human capital in promoting growth, one might conjecture that public investment in education constitutes a major aspect of any growth-promoting policy. Especially with respect to developing countries one might expect that governments have incentives to spend on public education in order to foster the process of technology adoption and thereby initiate growth. However, governments these days have to consider many different objectives and provide various other public goods and services that do not directly impact growth but nevertheless contribute to the welfare of residents, such as redistribution and public service delivery. Governments might even try to realize own objectives and divert resources from the public budget for entirely selfish, consumptive purposes. In either way, there appears to exist a trade-off between investing in growth-promoting education and focusing on other consumptive expenditures. This paper analyzes whether and under which conditions governments actually do promote education to foster growth. More precisely, it asks the following question: are governments in developing countries willing to invest in the provision of public education to induce growth or will some countries rather spend on consumptive public goods?

So far, public education has typically been investigated in models in which human capital enters the production function and acts as a direct driver of growth.[3] However, the recent

[1] For instance, models along these lines are: Romer (1990), Aghion and Howitt (1992), Benhabib and Spiegel (1994, 2005), and Howitt and Mayer-Foulkes (2005).

[2] Empirical studies indicate that frontier growth, that is the creation of new technology, is generated in very few, relatively rich countries. For most countries, foreign R&D plays a crucial role. Providing an overview over recent literature on technology diffusion, Keller (2004, p. 776) concludes that "for most countries, foreign sources of technology are of dominant importance (90 percent or more) for productivity growth".

[3] See e.g., Eckstein and Zilcha (1994), Glomm and Ravikumar (1997), Viaene and Zilcha (2002), and Blankenau et al. (2007).

literature on endogenous growth indicates that human capital plays a different role for growth: it widely supports the view that human capital affects growth through technology adoption. This different view might influence governmental incentives to actually supplement private human capital by public education. The present analysis of public education builds on the insights of modern growth theories that view technology adoption as a costly investment process leading to new designs or blueprints of intermediate-input goods. In these models, developing countries benefit from the potential represented by the existing world knowledge only if they exhibit sufficiently high absorptive capabilities, such as the quality of institutions, human capital, and financial development (e.g., Howitt, 2000; Aghion et al., 2005; Benhabib and Spiegel, 2005; Howitt and Mayer-Foulkes, 2005; Sadik, 2008). That is, countries adopt foreign technologies and, hence, catch up with leaders only if they exceed a certain threshold.

Our model integrates some of the recent findings of the theoretical literature as it exhibits a threshold effect with regard to human capital. This is in line with several empirical studies detecting a critical threshold level of human capital that is necessary for successful technology adoption, such as Borensztein et al. (1998), Xu (2000), Benhabib and Spiegel (2005), and Feyrer (2008). Above this level, technology diffusion stimulates growth; countries below this level of human capital lack the capabilities to adopt foreign knowledge.

A number of technology-adoption models featuring threshold effects have concentrated on the specific role of human capital. Examples include models in which human capital is treated as exogenously given (Benhabib and Spiegel, 2005), models in which human capital accumulation results as an unintentional byproduct due to externalities (Howitt and Mayer-Foulkes, 2005), and models in which private households finance education (Berdugo et al., 2005). Although previous studies highlight the importance of human capital in the process of technology adoption, public education has not been investigated within such a framework. The present paper extends the existing technology-adoption literature: it endogenizes the formation of human capital by introducing a public investment decision. Against this background, we analyze whether a government that can enhance human capital through education expenditures and thereby promote growth is actually willing to do so.

This paper studies education policies in an endogenous growth model featuring technology adoption. The analysis considers an open-economy set-up to accommodate the notion that countries are economically highly integrated nowadays and there is a potential for international technology spillovers. In the model, firms can imitate technologies invented abroad. The adoption of new technologies depends on the available human capital in an economy as the latter is associated with the cost to implement a new technology. Firms weigh up the cost of adopting against the prospective return from operating a new technology: the higher the educational attainment, the more likely a country is to advance technologically. The government collects taxes and can chose between investing in growth-promoting public education and engaging in non-productive spending, which can be interpreted as either public service delivery or selfish government consumption. Based on this modeling approach, the paper explores public incentives to provide growth-promoting education.

The analysis reveals that the initial level of human capital plays a crucial role in shaping governmental incentives to invest in education. Since the human capital endowment of individuals increases the productivity of public education, a higher endowment raises the amount spend by the government. The resulting rise in the level of human capital reduces the costs of technology adoption and promotes growth. Countries that are highly endowed with human capital face a pronounced incentive to invest in public education. Conversely, the model implies that countries that are poorly endowed abstain from investing in education. This is due to the fact that for very low endowments of human capital, technology adoption is too costly and firms, thus, abstain from adopting. Although public investments could increase the level of human capital above a threshold such that technology adoption is worthwhile, the government is not willing to do so since the costs of providing the necessary level of public education are too high. Rather, spending on growth-promoting education is replaced by higher expenditures on non-productive public goods. As a result, the growth process in poorly-endowed countries stagnates.

The paper is organized as follows. Section 2 describes the basic model set-up with a special emphasis on the underlying market structure and the process of technology adoption. Section 3 analyzes the optimal education policy a government opts for, while Section 4 discusses the implications of different policies for the growth process. The last section concludes.

2 Theoretical Framework

We explore a discrete-time model of small open follower countries. A follower economy is an economy lagging behind the technology frontier and can, thus, potentially profit from adopting technologies invented in the advanced part of the world. Technological progress resulting from technology adoption is positively affected by the available human capital. The follower country is populated by successive generations with each generation living for one period only. During this period, an individual first acquires human capital and then works and consumes the entire net labor income. Governments raise taxes and can allocate resources to public education or non-productive government spending. While labor is considered immobile, capital moves freely across borders. We analyze optimal education policy of follower economies in an environment, in which countries are economically integrated and growth results from technology adoption. More precisely, optimal policies and growth dynamics are examined, allowing countries to differ with respect to their initial human capital endowment. This section outlines the different aspects of the model.

2.1 Households

Consider successive generations of cohort size $L = 1$. Each worker has one offspring and is, hence, also referred to as a parent. However, children are economically irrelevant until they grow up and enter the working period. Each worker supplies one unit of labor inelastically to firms in the production sector. Residents only live a single period and do not bequeath any resources to their children; inhabitants of follower economies, thus, refrain from saving. Rather, individuals consume their entire wage income net of the proportional labor-income tax τ_w. While there is no intergenerational transmission of financial resources, human capital does spill over from one generation to another. More precisely, every individual born is endowed with e_t, which corresponds to the level of human capital of the previous generation, $e_t = h_{t-1}$. One can think of this as an intergenerational spillover capturing the fact that children inherit knowledge and skills from their parents.

Inherited human capital might be enhanced by public expenditures on education g_t. In this case, at the beginning of every period t and before starting to work, individuals undergo education given their educational endowment e_t. The educational process then determines the overall level of human capital h_t that will be productive in the process of technology adoption

$$h_t = e_t^{1-\gamma} g_t^{\gamma}. \tag{1}$$

Following Galor and Stark (1994), we assume that the level of human capital cannot decline, but only increase if it is combined with public investments. Put differently, inherited knowledge will not get lost in the presence of lacking governmental investment.[4] Whether the government actually provides public education and how much it chooses to invest will be investigated below.

2.2 Market Structure

The research effort of leading economies leads to discoveries and technological improvements, which advance the technology frontier, indexed by $\overline{A}$. Throughout the paper, the frontier is considered as exogenous, and it advances at the rate ε. The follower country imitates and can, thus, only adopt technologies that have already been invented in the advanced part of the world. When modeling the market structure, the paper follows the framework pioneered by Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992).[5] There are three main activities in the economy: a competitive final-good sector produces a homogenous output good; an intermediate-goods sector produces differentiated capital goods and supplies them to final-production firms; and an imitation sector adopts the blueprints for the intermediate goods. In

[4]This implies that public investments in education require some minimum expenditures to actually increase the level of human capital. We show below that the government is always willing to finance these initial investments if it decides to engage in public education.

[5]This framework also forms the basis for a broad range of technology-adoption models, such as Barro and Sala-i Martin (1997), Howitt (2000), and Aghion et al. (2005).

the model, technological progress takes the form of quality improvements of the differentiated capital goods. That is, a new technology corresponds to a new type of intermediate good that increases the efficiency of production in the final-good sector. Implementing a new technology necessitates a fixed cost to be incurred by the adoption sector. In the following, a firm operating in the adoption sector is viewed as the research department of an intermediate-goods firm.

We focus on a number of followers in an open-economy set-up, in which capital is not taxed at all.[6] Followers are assumed to be too small to influence the world interest rate, which can be supported by the view that the bulk of world capital is invested in and flows between advanced countries. Compared to this, flows from and to developing countries are small. Therefore, capital moves freely across borders and can be borrowed at the exogenously given rate $\overline{r}$. To simplify matters, suppose that inhabitants of the follower countries do not save; all capital originates from the advanced part of the world.[7] Consequently, households consume their labor income while all capital income flows to foreign investors.

Final-Good Firms Production of the homogenous final good Y in any period t is given by[8]

$$Y = L^{1-\alpha} \int_0^1 A_j^{1-\alpha} x_j^{\alpha} \, dj, \tag{2}$$

with $0 < \alpha < 1$. x_j denotes the amount of the latest version of the intermediate good j used in the final production while A_j measures the state-of-the-art quality in the follower country associated with that intermediate good. Note that $[0, 1]$ corresponds to the range of industries that produce intermediate goods. L labels inelastic labor supply, which is normalized to 1. Thus, final output Y and per-worker output $\frac{Y}{L}$ coincide.

In each period, firms operating in the final-good sector solve the following profit-maximization problem

$$\max_{L, x_j} L^{1-\alpha} \int_0^1 A_j^{1-\alpha} x_j^{\alpha} \, dj - wL - \int_0^1 p_j x_j \, dj. \tag{3}$$

As can be seen, the final good Y serves as the numéraire good. w is the wage rate paid to workers, and p_j is the rental price for the capital good j. From the viewpoint of the producer, w and p_j are taken as given. The first-order conditions to the maximization problem imply

$$w = (1-\alpha)\frac{Y}{L} = (1-\alpha)Y \tag{4}$$

$$p_j = \alpha L^{1-\alpha} A_j^{1-\alpha} x_j^{\alpha-1} = \alpha A_j^{1-\alpha} x_j^{\alpha-1} \qquad \text{for all } j. \tag{5}$$

[6]This assumption is discussed in detail below when describing the government.

[7]The form of capital holding could easily be altered by introducing a savings rate. Since capital is perfectly mobile across countries and not taxed in the follower economies, extending the model in this direction would not change the results.

[8]Time subscripts are suppressed for the moment.

The optimality conditions reveal that final-good producers choose input quantities such that the marginal products equal input prices. The final-good production function along with the profit-maximizing behavior imply that labor income in the economy totals $wL = (1-\alpha)Y$ and that the compensation stream to the intermediate-goods sector sums up to $\int_j p_j x_j \, dj = \alpha Y$. Moreover, equation (5) expresses the inverse demand function for capital good j, which intermediate-goods firms take as given.

Intermediate-Goods Firms Each intermediate-goods firm produces a particular type of capital good. Suppose that a firm incurred the fixed cost required to adopt a certain quality. This incumbent subsequently acts as a monopolist and collects profits from operating the new technology. If there were no gains to be realized in the intermediate-goods sector, no firm would be willing to run a business because of the start-up investment. Once the firm incurred the fixed set-up cost and, thus, knows the blueprint for an intermediate good, each unit of a specific capital good x_j can be exchanged for one unit of raw capital[9] borrowed on the world capital market. Let us denote raw capital by $K = \int_0^1 x_j \, dj$, indicating that the total amount of intermediate goods corresponds to overall capital or raw capital K in the economy.

In each period, intermediate-goods monopolists maximize

$$\max_{x_j} \pi_j = p_j(x_j)x_j - \overline{r}x_j. \tag{6}$$

π_j labels per-period profit of firm j; $\overline{r}$ represents the rental price of raw capital K. As mentioned above, the monopolist takes the inverse demand function for capital good j, $p_j(x_j)$, as given. Solving yields $p_j'(x_j)x_j + p_j(x_j) = \overline{r}$ and can be rearranged to

$$p_j = \frac{1}{\alpha}\overline{r}. \tag{7}$$

Thus, the intermediate-goods monopolist chooses a price that equals a markup times the rental cost of capital. Equation (7) indicates that all monopolists sell their capital goods for the same price: $p = p_j$ for all j. Moreover, symmetry with respect to quality $A = A_j$ across sectors[10] implies that $x = x_j$ for all j. As the production function of the intermediate-goods sector involves $K = \int_0^1 x_j \, dj = x$, final output can be rewritten into the standard neoclassical production function

$$Y = K^\alpha A^{1-\alpha} = \widetilde{k}^\alpha A, \quad \text{with } \widetilde{k} \equiv \frac{K}{A}. \tag{8}$$

[9]Similarly, Jones (1995), Howitt (2000), and Kumar (2003) assume interchangeability of raw capital and specific capital goods.

[10]Symmetry can be sustained for the following reason: it is standard in the literature to assume that the leader's knowledge $\overline{A}_j$ is the same across sectors j at any point in time and that the follower's initial technology level $A_{j,t=0}$ is independent of the sector j. This implies that each firm in the follower country faces the same decision problem and, accordingly, implements the same quality level. Symmetry, thus, results as firms face the same adoption decision and as there is no uncertainty in the technology-adoption process.

Since total proceeds to the intermediate-goods sector equal $\int_0^1 p_j x_j \, dj = \alpha K^\alpha A^{1-\alpha}$, equation (7) can be rearranged to express the relation between the domestic and the world interest rate as

$$\bar{r} = \alpha^2 \left(\frac{A}{K}\right)^{1-\alpha} = \alpha \frac{\partial Y}{\partial K}. \tag{9}$$

Note the interest rate is lower than the marginal product of capital as entrepreneurs have to be compensated for setting up a firm. For future reference, note that $\widetilde{k} = \frac{K}{A} = \left(\frac{\alpha^2}{\bar{r}}\right)^{\frac{1}{1-\alpha}}$, which is a constant.

Considering the price that intermediate-goods monopolists set and the production costs they encounter, profits earned by each firm in a given period can be stated as

$$\pi_j = \alpha(1-\alpha)Y = \alpha(1-\alpha)\widetilde{k}^\alpha A_j \qquad \text{for all } j, \tag{10}$$

where $A = A_j$ is the same across sectors due to symmetry. j subscripts are henceforth suppressed. Using the definition $\widetilde{\pi} \equiv \frac{\pi}{A}$, it follows from (10) that $\widetilde{\pi} = \alpha(1-\alpha)\widetilde{k}^\alpha$, with $\widetilde{\pi}$ being a constant.

The Process of Technology Adoption Consider a single intermediate-goods firm that seeks to acquire the blueprint for a specific technology. Implementing a newer, better technology requires a non-recurring outlay $\widetilde{f}$ undertaken by the adoption department of an intermediate-goods firm, where $\widetilde{f}$ stands for the technology-adjusted quantity devoted to technology adoption.[11] These one-time expenses are necessary in order to adapt the technology to the present environment. Specifically, the technology-adoption cost of a follower country that wishes to implement the quality level A_t, at a given point in time, is of the form

$$\widetilde{f}_t = \frac{1}{\widetilde{h}_t^\beta} \left(\frac{A_t}{\bar{A}_t}\right)^\sigma, \tag{11}$$

with $\beta > 0$ and $\sigma > 0$. On the one hand, this formulation reflects the fact that it is more difficult and, thus, more expensive to imitate technologies that are more sophisticated relative to the technology frontier. The ratio representing relative technology captures the idea that the costs of copying increase as the follower country approaches the global technology frontier. On the other hand, an increasing level of effective human capital in the economy counteracts the latter cost increase because a better educated workers can handle new and more complex technologies more easily. The notion that effective human capital lowers the cost of adoption is captured by the term $\widetilde{h}$, which is defined by $\widetilde{h} \equiv \frac{h}{A}$. The term is indicative for the absorptive capacity of a country and translates into lower costs of adopting.

[11] Following the standard assumption for technology-adoption models featuring quality improvements in intermediate goods, $\widetilde{f}$ reflects the technology-adjusted cost required in the adoption process, meaning that $\widetilde{f}$ corresponds to total adoption expenditure divided by A. This assumption is taken in Howitt (2000), Aghion et al. (2005), and Howitt and Mayer-Foulkes (2005), for instance, and accommodates the force of increasing complexity: as the technology level in an economy advances, the required outlays for further improvements increase.

It is worth highlighting that the imposed type of cost function is consistent with balanced growth. Further, note that in the model, human capital is solely productive in the adoption sector but not in the final-goods sector. This corresponds to the idea suggested by Nelson and Phelps (1966) that an educated labor force copes more easily in a dynamic and technologically progressive environment and is, therefore, better at adopting new technologies. According to their view, human capital has a positive effect in the economy only if technology is continuously improving, meaning that human capital should not enter the final production function directly.[12]

After the firm incurred the set-up cost, it henceforth knows how to convert a unit of raw capital into a specific capital good and collects monopoly profits π_t. As firms have no initial resources, the funds to finance the start-up investment originate from the world capital market. Consequently, technology adoption is only worthwhile if the profits are large enough to cover the initial adoption costs plus interest payments. Firms wish to expand the technology level if profits can be realized at the beginning of a period, which gives rise to the following technology-adoption condition

$$\widetilde{\pi}_t \geq (1+\overline{r}) \cdot \widetilde{f}\left(A_{t-1}, \overline{A}_t, \tilde{h}_t\right), \tag{12}$$

where A_{t-1} corresponds to the initial technology level an economy possesses at the beginning of a new period. Note that profits relevant for the valuation of a specific project last for one period only. After this period, a new process of technology adoption might start implying that a new technique is implemented, which renders the old technology obsolete. If this is not the case, that is in the event of no technology adoption in sector j in the following period, it is presumed that control of the incumbent firm falls randomly to a foreign investor of the next generation.[13]

The crucial point concerning the adoption process is whether the technology-adoption condition is satisfied or not for a given level of human capital in a certain period. If it is, the economy has an incentive to advance the technology level. Otherwise, the laggard country's technology level stagnates at $A_t = A_{t-1}$. As pointed out above, a higher absorptive capacity makes the adoption condition more likely to hold. This implies that there exists a threshold level of human capital above which it is worthwhile for firms to incur technology-investment costs. This threshold level h_t^{TA} is the level of human capital for which the technology-adoption condition is just satisfied. More precisely, at h_t^{TA} the adoption condition (12) holds with equality for given values of $\overline{A}_t$ and A_{t-1}. Hence, the threshold level is determined by

$$h_t^{TA} = \left(\frac{A_{t-1}^{\beta+\sigma}}{\overline{A}_t^{\sigma}} \frac{1+\overline{r}}{\alpha(1-\alpha)\tilde{k}^{\alpha}}\right)^{\frac{1}{\beta}}. \tag{13}$$

If the human capital stock is above this level, the economy adopts new qualities and grows. Clearly, this threshold level depends negatively on the technology level available in the frontier

[12]For empirical support of this idea, see Benhabib and Spiegel (1994, 2005).
[13]A similar assumption can be found in Aghion et al. (2006).

economies, $\overline{A}_t$. Since $\overline{A}_t$ increases over time, technology adoption becomes less costly. Consequently, the level of human capital required to render technology adoption beneficial declines. The model, hence, predicts that with time, more and more countries face the incentive to engage in technology adoption and start catching up with leading economies.

In what follows, we briefly outline what happens in the two possible scenarios $h_t \leq h_t^{TA}$ and $h_t > h_t^{TA}$. It is worth pointing out that the findings discussed in the following correspond to the decisions taken by private firms for a given level of h_t. We illustrate below how the government chooses to influence the level of human capital in the economy by investing in public education.

No-Technology-Adoption State Suppose the technology-adoption condition is violated, and the economy encounters $h_t \leq h_t^{TA}$. Consequently, it is not worthwhile for firms to copy new, but yet unimplemented technologies. The different intermediate-goods firms in period t, therefore, prefer to stay at their initial technology level A_{t-1}. Output in the economy then totals $Y_t = \widetilde{k}^{\alpha} A_t = \widetilde{k}^{\alpha} A_{t-1}$. In this case, there are some potential avenues for the follower to escape from technological stagnation: since the frontier $\overline{A}_t$ advances with time, the cost of technology adoption for a given (constant) level of human capital an eventually drop below the gains from adopting. Thus, at some point in time, it becomes worthwhile to implement new technologies. Put differently, the threshold level of human capital declines with time. Other potential channels include changes that raise the level of human capital as this would improve the absorptive capacity of a receiving country, thereby stimulating technology adoption.

Technology-Adoption State Suppose $h_t > h_t^{TA}$; that is, potential profits are high enough to finance the necessary set-up costs. These potential profits induce intermediate-goods firms to incur the set-up cost to start operating. We make the standard assumption that there is free-entry into the intermediate-goods market, which results in the elimination of profits in a present-value sense. This implies that the quality level increases until the following research-arbitrage condition holds

$$\widetilde{\pi}_t = \alpha(1-\alpha)\widetilde{k}^{\alpha} = (1+\overline{r}) \cdot \widetilde{f}\left(A_t, \overline{A}_t, \tilde{h}_t\right). \tag{14}$$

Given the underlying cost function, the no-arbitrage condition (14) can be solved for the new technology level

$$A_t = \left(\frac{\alpha(1-\alpha)\widetilde{k}^{\alpha}}{1+\overline{r}} h_t^{\beta} \overline{A}_t^{\sigma}\right)^{\frac{1}{\beta+\sigma}}, \tag{15}$$

that results in case technology adoption is worthwhile. Consequently, if there are profits to be realized at the beginning of a period (meaning that the technology-adoption condition is satisfied), firms start expanding the level of technological sophistication up to the quality level stated in equation (15). However, whether technology adoption is worthwhile from the perspective of a firm depends on the exact parameter and variable combination, the distance to the technology frontier, and the level of human capital that is available in the economy. From the point of view of an intermediate-goods firm, the level of human capital h_t is given. Yet, recall that the current stock of human capital h_t depends positively on the educational endowment e_t and the effort on the part of the government g_t. This implies that the level of technology ultimately hinges on the domestic variables e_t and g_t as well as on the technology level of the frontier, $A_t = A(e_t, g_t, \overline{A}_t)$.

2.3 Government

Consider a government or a politician that is in office for a single period only.[14] The government collects taxes levied on wage income whereas mobile capital is not taxed.[15] The tax revenue can be spend on non-productive government spending or on public education, which determines the level of human capital that enters the technology-adoption process. The government anticipates this effect on technology adoption when deciding on the optimal level of public education. The payoff function of the government is formalized as

$$(1 - \tau_w)(1 - \alpha)Y_t + \lambda c_t^G, \tag{16}$$

where τ_w denotes the income-tax rate, $(1-\tau_w)(1-\alpha)Y_t$ corresponds to private consumption and c_t^G to unproductive government spending. The governmental payoff function can be interpreted in two ways allowing us to encompass different views of the government in a single modeling framework. First, one can think of a situation in which residents not only value private consumption, but to some extent λ also benefit from the provision of public consumption goods and services. In this case, the government would be benevolent in the sense that it aims at maximizing the utility of its residents. The above-stated payoff function then reflects the utility of a country's inhabitants. In contrast, the payoff function of the government can also be interpreted as one of a Leviathan. In this case, c_t^G denotes the amount of rent extraction of a selfish politician. The degree of selfishness depends on the parameter λ. For illustration, if λ approaches infinity, the government is purely selfish and cares no longer about private consumption.[16]

When deciding on the amount of public education, the government has to respect the public budget constraint

$$\tau_w w_t = \tau_w(1 - \alpha)Y_t = c_t^G + g_t. \tag{17}$$

Substituting the budget constraint into the government's payoff function yields a reduced form

[14]This ensures that the elected politician and the single household face an identical time horizon. Section 3 discusses the implications of an infinite time horizon of the government.

[15]The assumption that governments only tax immobile labor and abstain from taxing capital is also taken in Viaene and Zilcha (2002), for instance. It can be justified by the inefficiency of the taxation of internationally mobile capital, a well-known result of the literature on optimal taxation that has first been derived by Gordon (1986) in a static set-up, but was later extended to dynamic frameworks as well (see e.g., Razin and Yuen, 1999).

[16]The idea of integrating both benevolent as well as Leviathan objectives in a single objective function is due to Edwards and Keen (1996). In the present model, we follow the approach suggested by Cai and Treisman (2005).

of the governments optimization problem

$$\max_{g_t} (1-\tau_w)(1-\alpha)Y_t + \lambda\left(\tau_w(1-\alpha)Y_t - g_t\right) = \max_{g_t} \tau(1-\alpha)Y_t - \lambda g_t, \tag{18}$$

with $\tau \equiv 1-\tau_w(1-\lambda)$. The income-tax rate is assumed to be exogenously given. This ensures that the government cannot increase the tax rate on labor to finance growth-promoting education while holding the level of unproductive spending constant. Rather, a true trade-off between productive and consumptive government spending arises.[17]

Since in the presence of internationally mobile capital the production function can be written as $Y_t = (1-\alpha)\widetilde{k}^\alpha A_t$, the government's optimization problem becomes

$$\max_{g_t} \tau(1-\alpha)Y_t - \lambda g_t = \max_{g_t} \tau(1-\alpha)\widetilde{k}^\alpha A_t - \lambda g_t. \tag{19}$$

When solving the optimization problem, we first hypothetically assume that technology adoption actually takes place. Accordingly, the technology level A_t is endogenously determined by the level of public education, the human capital endowment, and the world's frontier knowledge, $A_t = A(e_t, g_t, \overline{A}_t)$. Whether technology adoption takes place and which optimal public policies are actually undertaken will be discussed in the subsequent section.

Given the endogenous level of technology $A_t = A(e_t, g_t, \overline{A}_t)$, maximization yields the level of public education provision,

$$g_t^* = g^*(e_t, \overline{A}_t) = \left(\Omega \overline{A}_t^\sigma e_t^{\beta(1-\gamma)}\right)^{\frac{1}{(1-\gamma)\beta+\sigma}}, \tag{20}$$

where $\Omega \equiv \left(\frac{\tau(1-\alpha)\widetilde{k}^\alpha}{\lambda}\frac{\gamma\beta}{\beta+\sigma}\right)^{\beta+\sigma}\frac{\alpha(1-\alpha)\widetilde{k}^\alpha}{1+\overline{r}}$ summarizes the exogenous variables and parameters influencing educational spending g_t^*. Since the variable Ω negatively depends on the valuation of non-productive government spending, public expenditures on education are lower whenever the benefit from alternative investments is high, that is if λ is large.

It is important to point out that the initial level of human capital positively affects the amount of public education: the chosen level of educational spending is higher if the human capital endowment is higher. Moreover, the level of productive public good provision increases with the technology available in the frontier economies, $\overline{A}_t$. Recall that the amount of spending g_t^* derived above relies on the hypothetical presumption that adoption actually takes place. Yet, this need not be the case. The next section examines more closely the decisions taken by the government under different scenarios.

[17]It is important to point out that one can easily endogenize the tax rate by eliminating unproductive government spending from the model. In this case, the budget constraint reduces to $\tau_w(1-\alpha)Y_t = g_t$, and the payoff function can be formalized as $(1-\alpha)Y_t - g_t$. Comparing the payoff function with equation (18) reveals that the results of this model specification coincide with our solution when setting $\tau = 1$ and $\lambda = 1$. Consequently, the present modeling approach is more general and encompasses different versions of the problem. Additionally, it allows to analyze the trade-off between productive and consumptive government spending.

3 Optimal Public Policies

To analyze the optimal policy from the viewpoint of a small open economy, one needs to distinguish between different scenarios that might occur in the model. First of all, it is not clear whether technology adoption is worthwhile and economic growth indeed occurs. Countries at an early stage of development with a level of human capital endowment $e_t \leq h_t^{TA}$ will not engage in technology adoption and will, consequently, not grow at all. Yet, the government can induce technology adoption and initiate growth by investing in public education to raise the level of human capital above the threshold level h_t^{TA}. Clearly, the government is only willing to do so if the payoff from providing growth-promoting education exceeds the payoff from abstaining. Consequently, the optimal policy can be derived by comparing the relevant payoff functions.

In general, the payoff function of the government is given by its objective function $P(g_t) = \tau(1-\alpha)\widetilde{k}^{\alpha} A_t - \lambda g_t$. If the government abstains from investing in public education, it saves the costs of provision ($g_t = 0$), but at the same time it forgoes the growth-promoting aspects of education. Since the level of human capital h_t will remain at $e_t \leq h_t^{TA}$, technology adoption at this early stage of development is too costly and the level of technology remains at $A_t = A_{t-1}$. The payoff is, therefore, given by $P(g_t = 0) = \tau(1-\alpha)\widetilde{k}^{\alpha} A_{t-1}$. In contrast, if the government decides to provide public education to initiate technology adoption, it will choose a level of provision of $g^*(e_t, \overline{A}_t)$ and the payoff becomes $P(g_t^*) = \tau(1-\alpha)\widetilde{k}^{\alpha} A(e_t, g_t^*) - \lambda g_t^*$. Comparing the different payoff functions, investment in growth-promoting infrastructure will occur whenever

$$\tau(1-\alpha)\widetilde{k}^{\alpha} A(e_t, g_t^*, \overline{A}_t) - \lambda g_t^* > \tau(1-\alpha)\widetilde{k}^{\alpha} A_{t-1}, \tag{21}$$

with $g_t^* = g^*(e_t, \overline{A}_t)$.[18] Since the optimal amount of public spending depends positively on the endowment level and, moreover, the level of technology is rising as a response to both higher human capital endowment and public education, the payoff associated with investing is an increasing function of the endowment level,

$$\tau(1-\alpha)\widetilde{k}^{\alpha} A(e_t, g_t^*, \overline{A}_t) - \lambda g_t^* = \lambda \frac{\beta(1-\gamma)+\sigma}{\beta\gamma} \left(\Omega \overline{A}_t^{\sigma} e_t^{\beta(1-\gamma)}\right)^{\frac{1}{(1-\gamma)\beta+\sigma}}. \tag{22}$$

In contrast, the payoff of not-investing is constant and independent of e_t. This implies that there exists a critical endowment level e_t^{crit} above which the government gains a higher payoff if it engages in growth-promoting public spending

$$e_t^{crit} = \left[\frac{\Delta}{\Omega \overline{A}_t^{\sigma}}\right]^{\frac{1}{(1-\gamma)\beta}}, \tag{23}$$

[18] Obviously, investments in public education will only take place if they increase the technology level enough to compensate for the costs of provision. This implies that the amount of public education needs to be sufficiently high to actually increase the level of human capital. As a consequence, it is guaranteed that if the government chooses to invest after comparing the relevant payoffs according to equation (21), it will always finance the minimum expenditures needed to raise the level of human capital.

where $\Delta \equiv \left(\frac{\tau(1-\alpha)\widetilde{k}^{\alpha}}{\lambda} \frac{\gamma\beta}{(1-\gamma)\beta+\sigma} A_{t-1}\right)^{(1-\gamma)\beta+\sigma}$ comprises all exogenously given parameters. One can easily show that the critical endowment level is larger if non-productive public goods are highly appreciated: as the valuation of consumptive spending λ increases, it becomes more difficult to generate the same utility gain by facilitating technology adoption. Accordingly, the critical endowment level above which productive public spending becomes attractive rises. Moreover, the critical endowment level depends negatively on the technology frontier $\overline{A}_t$: as $\overline{A}_t$ increases with time, technology adoption becomes less costly and starts at a lower threshold of human capital h_t^{TA}. Consequently, it becomes cheaper for the government to lift the economy above this threshold and induce growth. The model, hence, predicts that with time, more and more countries face the incentive to invest in education and, thus, start growing.[19]

Figure 1 illustrates the different payoff functions for the two cases, holding $\overline{A}_t$ constant for the moment. The bold line represents the payoff the government can obtain if it does not invest in public education. Since the level of human capital is too low to make technology adoption worthwhile, A_t resembles the level of technology already acquired in the previous period, A_{t-1}. The payoff of the government in this case can be represented by a straight, constant line. The dashed curves display the payoff function in case the government does invest in education and is based on the assumption that the level of technology is given by the endogenous level $A(e_t, g_t, \overline{A}_t)$. Since the payoff function depends positively on the human capital endowment, the shape of the curves depicted in Figure 1 vary for different levels of human capital endowment e_t.

The lowest dashed line is drawn for a rather low human capital endowment e_t^{low}. It illustrates a combination in which the payoff is below $P(g_t = 0)$, even at the point of maximization. This indicates that if the human capital endowment is very low, the government prefers the higher payoff associated with $g_t = 0$ (bold line). Therefore, if e_t is too low, the government does not care about education and spends the entire tax revenue on consumptive government expenditures. Any incentive to invest in human capital vanishes and the economy stays at A_{t-1}. In contrast, the upper dashed line depicts a situation in which the government is inclined to enhance the level of human capital and with it the technology level since the respective payoff is clearly above $P(g_t = 0)$. The government will, therefore, spend the amount g_t^* on public education. Furthermore, Figure 1 visualizes that there exists a critical endowment level, that is a minimum human capital endowment e_t^{crit} above which the government starts to care about public education. This critical endowment level is given by the payoff function that is tangent to the payoff in the no-investment case.

Summarizing, at low initial human capital endowments the government has no incentives to invest in education and, thus, chooses to refrain from providing any public education, $g_t = 0$. In this case, both the level of human capital and the available technology remain constant, that is

[19] Note that from the point of view of the government, sustaining this catch-up process in the long run is only beneficial if the gains involved are large enough to compensate for the costs of public good provision. To ensure this, we assume that the rate of frontier growth is sufficiently high with $1 + \varepsilon > \left(\frac{\beta+\sigma}{(1-\gamma)\beta+\sigma}\right)^{(\beta+\sigma)/\beta}$.

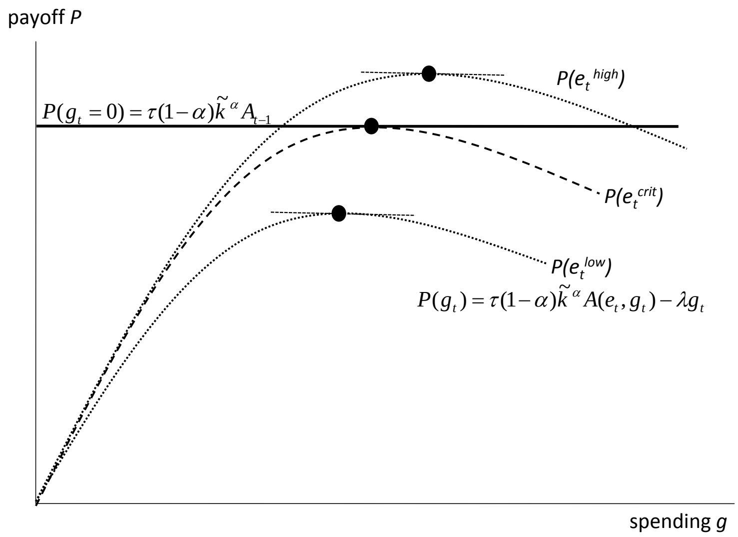

Figure 1: Payoffs for various e_t

$h_t = e_t$ and $A_t = A_{t-1}$, meaning that the economy stagnates. Conversely, for sufficiently high initial endowments $e_t > e_t^{crit}$, the government opts for enhancing the available human capital in the economy by investing $g^*(e_t, \overline{A}_t)$. When the economy faces $e_t > e_t^{crit}$, the outcomes are, thus, defined by the solution to the maximization problem that relied on the assumption that technology adoption is worthwhile.

The results indicate that, although human capital is the key for a country's economic prosperity, this is no guarantee that governments actually choose to invest in education by supplying this growth-enhancing public good. This is due to the fact that lifting the level of human capital above the threshold such that technology adoption becomes beneficial can be extremely costly for the government. Consequently, at early stages of development where the human capital endowment is very low, it is more attractive to simply consume the entire tax revenue. It is worth noting that this is independent of the underlying view of the government. Even an entirely benevolent government that acts in the best interest of its residents will refrain from investing in education at very low stages of development: since residents value non-productive public goods and services, it is more attractive to focus on consumptive spending than to incur very high costs for a negligible technological progress.

Further, a remark regarding the time horizon of the government might be in order. Recall that, in our model, the government lives for one period only. The horizon of the government is of the same length as the one of the private agents to accommodate the notion that members of the government are of the same type as the economically active individuals or that the government has to receive electoral support from its inhabitants. We deem treating the government and the households symmetric with respect to the time horizon most convincing. Yet, since the government only takes into account the current period in its optimization problem, it can be considered as myopic. A forward-looking government would take into account the positive effect of current educational investment on future generations and, thus, incentives to invest in human capital would be higher. However, it should be emphasized that our results continue to hold under a forward-looking government, even if it values future discounted payoffs with an infinite horizon. A forward looking government recognizes the direct positive effect of investments on the level of human capital plus the indirect effect of a higher productivity of public investments in the next period that results from a rise in next period's human capital endowment. Yet, while the benefits of public good provision increase, the potential payoff continues to depend on the initial endowment level implying that there still exists a critical threshold of human capital endowment below which the government finds it optimal not to invest in a certain period. A very low human capital endowment level severely constrains the government's possibilities and creates a strong disincentive to invest caused by the cost g, which can be so profound that the government abstains from investing in education. Of course, with a forward-looking government, the critical level of human capital endowment is lower, but it continues to exist.

4 Growth Analysis

The findings concerning the optimal educational investment from the viewpoint of the government have important repercussions on the growth prospects of developing countries. This section explores the interplay between education policies and growth. It first focuses on the implications on the accumulation of human capital over time and then transfers these insights to the analysis of growth in output.

As discussed before, the government abstains from enhancing human capital if the human capital endowment is below the critical level e_t^{crit}. In this case, human capital remains constant, and the ratio $\frac{h_t}{h_{t-1}}$ equals 1. On the other hand, if the economy is above the threshold, the human capital evolution obeys

$$\frac{h_t^*}{h_{t-1}} = \frac{g_t^{*\gamma} e_t^{1-\gamma}}{e_t} = \left(\frac{g_t^*}{e_t}\right)^{\gamma} = \left(\Omega\left(\frac{\overline{A}_t}{e_t}\right)^{\sigma}\right)^{\frac{\gamma}{(1-\gamma)\beta+\sigma}}. \tag{24}$$

Figure 2 visualizes the outcomes from the payoff considerations and the analysis of the ratio $\frac{h_t}{h_{t-1}}$. It illustrates the finding that below a critical endowment level, human capital remains at the inherited level. Above the critical level, policies and the ratio $\frac{h_t}{h_{t-1}}$ are determined by the optimization behavior of the government, that is by (24). Figure 2 allows for two ways of interpreting.[20] On the one hand, the illustration can be seen as a snapshot image of a world

[20]As shown below, the model predicts that the level of domestic knowledge A grows at the rate of the frontier

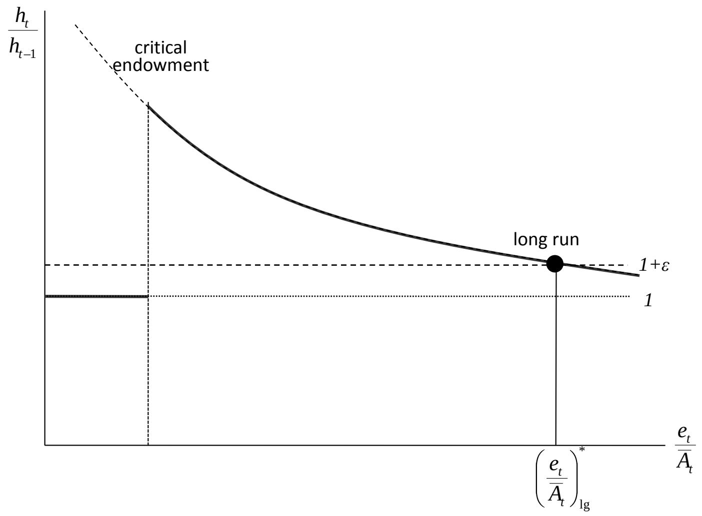

Figure 2: Outcomes for various e_t

consisting of a number of small followers that solely differ with respect to their educational endowment e_t; otherwise, they are treated identical in the graph. Figure 2 depicts a specific period t in which $\overline{A}_t$ is given. Countries that are located below the critical level e_t^{crit} display zero human capital growth whereas countries above the critical level build up human capital. Consider now those economies that exceed the critical endowment level. As can be seen, human capital growth in countries at lower stages of development, corresponding to moderate levels of e_t, is more pronounced than the progress in more developed followers. This property gives rise to catch-up behavior of less developed economies.

On the other hand, Figure 2 can be interpreted in a dynamic way. For this purpose, consider a single economy evolving through time. First, note that in the long run, an economy exhibits balanced growth. From $\frac{h_t^*}{h_{t-1}}$ stated in (24), it is obvious that, under balanced growth, human capital advances at the rate of the technology frontier ε. Thus, in the long-run equilibrium, the term $\frac{h_t}{h_{t-1}}$ equals $1+\varepsilon$, and the ratio $\frac{\overline{A}_t}{e_t}$ is constant (marked by $\left(\frac{\overline{A}_t}{e_t}\right)^*_{lg}$ in Figure 2). To illustrate the evolution of an economy through time, consider a poorly-endowed economy that is initially below the critical endowment level. As discussed above, the expanding level of frontier knowledge $\overline{A}_t$ shifts the required critical level e_t^{crit} gradually down, corresponding to a leftward movement of the line labeled 'critical endowment'. At some point, the economy surpasses the critical value. The government then starts to invest in public education, and the economy's law of motion is governed by $\frac{h_t^*}{h_{t-1}}$, that is by the curved line. Given that the curved line is clearly above $1+\varepsilon$

$\overline{A}$ in the long run, which implies that the ratio $\left(\frac{A}{\overline{A}}\right)^*_{lg}$ is constant under balanced growth. The figure implicitly presumes that the initial value of A_{t-1} is below its balanced-growth relationship.

at intermediate levels of initial human capital, this indicates that human capital grows faster than the technology frontier although at a declining rate. This corresponds to a rightward slide along the curved line. From period to period, the economy accumulates human capital faster than the frontier expands and, thus, catches up until it reaches the long-run equilibrium. In this equilibrium, human capital grows at the same pace as the technology frontier. To summarize, our model implies that more and more countries grow with time and, additionally, it suggests that late starters grow more rapidly than countries that started their pursuit of leaders earlier on.

The analysis above has focused on the evolution of the human capital stock. Yet, one can easily transfer the insights to growth in output and technology. From the production function $Y_t = \widetilde{k}^{\alpha} A_t$, it is apparent that growth rates of final production Y_t and technological knowledge A_t coincide: $\frac{Y_t}{Y_{t-1}} = \frac{A_t}{A_{t-1}}$. As noted above, countries that lie below the critical human capital endowment level stagnate economically, involving $A_t = A_{t-1}$ and $Y_t = Y_{t-1}$. For all other economies, growth in production and technology is given by

$$\frac{A_t^*}{A_{t-1}} = \left((1+\varepsilon)^{\sigma} \left(\Omega \left(\frac{\overline{A}_t}{e_t} \right)^{\sigma} \right)^{\frac{\beta\gamma}{(1-\gamma)\beta+\sigma}} \right)^{\frac{1}{\beta+\sigma}} = \left(\left(\frac{\overline{A}_t}{\overline{A}_{t-1}} \right)^{\sigma} \left(\frac{h_t^*}{h_{t-1}} \right)^{\beta} \right)^{\frac{1}{\beta+\sigma}}, \qquad (25)$$

which arises from analyzing the level of technology of two consecutive periods. As the stock of human capital under balanced-growth progresses at the frontier growth rate ε, it is obvious that the growth rate of domestic technology is constant in the long run and corresponds to ε as well. Depicting $\frac{A_t}{A_{t-1}}$ would yield a similar picture as the one for human capital: analogously, at intermediate levels of development, that is for economies just above the critical threshold, growth in technology and, accordingly, output exceeds the progress in world frontier knowledge. Again, this suggests that a follower economy catches up with growth in more advanced countries and gains substantially once it has surmounted the critical threshold level. Conversely, poorly-endowed countries do not grow at all.

5 Conclusion

In view of the substantial role of human capital in promoting economic growth, the present paper studies whether governments in developing countries are actually willing to invest in the provision of public education to enhance the growth process or, rather, engage in unproductive public spending. To account for the high relevance of technology adoption, the major driver for growth in developing countries, the paper puts forward a growth model in which follower countries can adopt more advanced technologies from the rest of the world. The costs that arise when firms aim at implementing new and more complex technologies crucially impact the process of technology adoption. Human capital is conducive to technology adoption as it plays a critical role in reducing these costs. Therefore, by providing public education that enhances the level of human capital, governments can influence the process of technology adoption and, thus, stimulate economic growth. Against this background, the paper analyzes whether governments are actually willing to provide public education or whether they alternatively prefer to engage in consumptive public spending.

The results contrast with the common belief that governments wish to engage in public education in any circumstance once the technological view of the benefits of human capital and the role of initial endowments are taken into account. Even though human capital plays a key role in economic development via its positive effect on technology adoption, governments do not necessarily engage in the provision of public education. Only if the human capital endowment exceeds a certain threshold, governments opt for building up human capital, thereby fostering the acquisition of technological knowledge and promoting growth. For poorly-endowed economies incentives to invest in human capital might be absent. That is, governments in such economies might refrain from investing in growth-enhancing public education. This is due to the fact that lifting the level of human capital above a threshold such that technology adoption becomes beneficial is extremely costly for the government. Instead, governments maximize their payoff by focusing on consumptive public spending. Yet, abstaining from human-capital enhancement to engage in other, consumptive public expenditures implies that the process of technology adoption receives no boost. Consequently, poorly endowed regions fail to adopt new technologies and their growth process stagnates.

As the model can account for the observed convergence among growing economies as well as the divergence between these countries and the poor, stagnating economies, it is consistent with the well-documented convergence-club feature of the world income distribution. While recent technology-diffusion models exhibiting a threshold effect also generate the convergence-club feature but consider public schooling as given, our study endogenizes human capital accumulation. It thereby adds a public economics argument that explains why it might be optimal for the government not to invest in education but to remain in the lower income club.

Certainly, there exist other reasons justifying why governments provide public education aside from its growth-enhancing aspect, such as establishing equality of opportunity. In reality one can, therefore, not expect to actually observe a complete lack of public investments but rather a lower level of spending as the growth-facilitating motive for public education is absent in poorly-endowed countries. Consequently, on the basis of the present model results, it is plausible to conjecture that public investments in education in these poorly-endowed countries are too low to affect the growth process. This is in line with the recent empirical finding by Blankenau et al. (2007) who document that the governmental commitment to educational spending is much smaller in poorer economies and detect a robust positive effect of public education expenditures on growth in rich countries but no effect in poor countries.

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