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Individual skills of heterogenous entrepreneurs and their economy-wide distribution – implications for growth and convergence

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Abstract This paper analyzes the impact of different individual skills and their economy-wide distribution on a country's catching up-process to the world technology frontier. Highly skilled heterogenous entrepreneurs, who are endowed with different skills, qualify as either technological or systemic specialists. Governmental policy may address individual skills or the aggregate composition of an economy with different types of specialists. It hence may be interpreted as education policy. Basically, two different regimes are compatible with equilibrium growth at the world technology frontier thereby representing either the predominance of capital market imperfections or the country's systemic capacity. It is shown that for both regimes the effectiveness of alternative growth-promoting policies depends on the relationship between a country's state of development and the prevailing composition of entrepreneurs. Countries far from the world technology frontier benefit from increasing the share of technological specialists whereas countries close to the world technology frontier benefit from increasing the share of systemic specialists.

Key words: technological and systemic skills; education policy; capital market imperfections; convergence.

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1 Motivation

The particular appeal of recent models of Schumpeterian growth theory lies in their combination of formal elegance and strong policy implications. A central reasoning of the latest model generation is that appropriate government interventions to foster economic growth depend critically on a country's distance to the world technology frontier. It is suggested that governments of relatively backward economies should intervene to increase investment and to induce faster copying and adoption of existing technologies. As an economy approaches the world technology frontier, governmental policy should support the switch towards an innovation-based strategy, featuring lower investment, younger firms and more selection (see Acemoglu et al. (2006) or Acemoglu (2009)). While this literature has substantially improved the understanding of relative growth performance in the world economy, this paper argues that there are cases in which an exclusive policy focus on technological innovation, the distinction among highly skilled vs. lowly skilled entrepreneurs, as well as on the corresponding selection process, is not apt to tell the entire growth story of a country.

In particular, the sole distinction between high skill and low skill entrepreneurs fails to highlight the specifics of those economies where knowledge is essential for production. Here, for each entrepreneur, a minimum level of knowledge in several fields is inevitable. Nevertheless, in spite of a broad basic knowledge, the individuals still possess relative strength; e.g., one might easily distinguish between an engineer and a manager or a scientist and a lawyer. Although each is highly qualified and a specialist in her own field, the contribution of different specialists for a country's growth, and hence for catching-up to the technology frontier, depends upon a country's state of development. Accordingly, it is not solely technological competence, but instead the interaction between various individual skills, as well as their overall distribution in the economy, that drives the process of convergence.

In fact, in their Joseph Schumpeter Lecture presented to the 20th Annual Congress of the European Economic Association Philippe Aghion and Peter Howitt characterized Europe as an economy that has long lagged behind the world's technological leader (the US), but which, after a long period of catching-up, has now closely approached the world technology frontier. Take the advanced European economies of Germany, Switzerland and the Netherlands as an example. All three countries are arguably very close to the world technology frontier which is defined by the US as the world's technologically leading country (see Benhabib and Spiegel (2005)). As a matter of fact, all three European countries had more triadic patents per inhabitant than the US in 2005 (OECD (2008)). More importantly, the growth rate in patenting between 1995 and 2005 for Germany and Switzerland was much higher than the respective growth rate for the US. Moreover, Germany, Switzerland and the Netherlands saw a marked increase in the number of scientific articles per million population between 1993 and 2003, while the respective rate for the US declined (NSF (2006)). Hence, one may argue that the above-mentioned European economies have caught up with the US (representing the world technology frontier) after the mid-1990s. However, this technological catch-up has not translated into higher growth rates. By contrast, the average annual growth rate of real GDP in the period 1995-2005 was much higher for the US than for Germany, Switzerland, and the Netherlands. Obviously, growth (and convergence with the leading country in terms of GDP per capita) requires more than scientific and technological competence, in particular for advanced industrialized countries that are already quite close to the world technology frontier.

In any case, the skills of the economy's actors play a central role in growth and convergence. Nelson and Phelps (1966) were probably the first to fully recognize the importance of human capital investment for innovation, technological progress and diffusion. Benhabib and Spiegel (2005) built on this reasoning referring to Gerschenkron (1962). They distinguished between growth at the world technology frontier and catching-up to it. The rate at which the gap between the technology frontier and a country's current level of productivity is narrowed depends upon the level of human capital, which is composed of highly skilled and lowly skilled workers (see also Vandenbussche et al. (2006) for a recent model that adopts this distinction). In addition there are several lines of reasoning within the literature on growth and convergence: The average human capital stock, accompanied by human capital externalities, and its contribution to aggregate growth has been extensively studied since the seminal work of Lucas (1988). A variety of papers have focused on wage inequality between highly skilled and lowly skilled workers, skill biased or directed technological change (see e. g. Galor and Moav (2000)). Recent work that analyzes the replacement of physical capital accumulation by human capital accumulation that acts as prime engine of growth along the process of catching-up was carried out by Galor and Moav (2004), whereas Goldin and Katz (2008) or Lloyd-Ellis and Roberts (2002) focused on the complementarity between education respectively skills and technology.

Another strand of research, still rarely developed, drew attention to the relationship between entrepreneurship and growth (see for example King and Levine (1993), Audretsch and Thurik (2001) and Murphy et al. (1991)). As Bianchi and Henrekson (2005) argued, entrepreneurship is invariably narrowly defined in models of mainstream economics. Some modelling approaches focus on talent, others on risk-taking, and a third group on entrepreneurs as innovators. A particularly interesting development in the personal economics and entrepreneurship literature is the work by Lazear (2004, 2005), who argued that people with unbalanced skills (i.e., specialists) tend to become employees whereas people with balanced skills (i.e., generalists) tend to become entrepreneurs.

The present model is closest in spirit to the work of Acemoglu et al. (2006) in which a country's growth-maximizing strategy (innovation versus imitation) depends on the country's distance to the world technology frontier. This framework is used to adopt Lazear's idea of heterogeneous entrepreneurial skills, applying it at an individual (firm) level and at an aggregate (economy) level. In doing so we differentiate highly skilled entrepreneurs in technological specialists from systemic specialists. The latter capture those individuals with a variety of non-technical skills. This allows for a differentiated analysis of the interdependencies between investment, individual skills, and their overall distribution via the composition of entrepreneurs across the economy on the one hand, and growth and convergence or catching-up to the technology frontier, on the other hand. Moreover, it allows us to drop another restrictive assumption of the Acemoglu et al. (2006) model, according to which old entrepreneurs are always able to perform larger projects than young entrepreneurs. In the present model, such an investment advantage, which may be due to credit market constraints, is possible but not necessary for the functioning of the model. Put differently, our model also works under perfect capital markets. The main mechanisms are driven by the interaction between a country's systemic capacity (thereby reflecting the distribution of skills at the individual and at an aggregate level) and the prevailing degree of capital market imperfections.

The model has various implications for the effectiveness of alternative growth promoting policies. Naturally, increasing any skill of any individual entrepreneur enhances aggregate knowledge and thus fosters growth. But the argument here is more differentiated, since (at least in the long run) economic policy might also affect the economy wide composition of specialists which, as will be shown, aside from a country's state of development, crucially affects the growth maximizing policy.

The remainder of the paper is organized as follows. After the presentation of the model setup (Section 2), we develop our conception of skills and their contribution to productivity at the individual (firm), national, and international level (Section 3). Section 4 deals with the selection of entrepreneurs and the corresponding productivity implications in a static and a dynamic equilibrium context. Section 5 analyzes the impact of individual skills and their overall distribution on the speed of convergence and discusses the corresponding policy implications. Section 6 briefly concludes the paper.

2 Setup of the model

Following Acemoglu et al. (2006), we model the economy as populated by overlapping generations of risk-neutral agents, who live for two periods, and discount the future at the rate r. The population is constant. Each generation consists of two types of individuals:

(i) capitalists: these are individuals who have access to the capital market and who are able to raise money at a market interest rate. They are not endowed with any skill. Hence one could interpret this clientele as having successfully founded a firm in the past. Capitalists select entrepreneurs with different skills in order to maximize firm profits.

(ii) entrepreneurs: these are individuals who are born with no wealth but are endowed with what we call *technological* and *systemic* skills, which are detailed below. Entrepreneurs run the firms and provide them with skill and knowledge inputs. Entrepreneurial skills are thus crucial determinants of micro- (i.e., firm-level) and macroeconomic productivity (the latter mainly via the overall distribution of entrepreneurs).

We assume a two sector economy composed of a perfectly competitive final product sector and an intermediate sector with imperfect competition. The unique final good, y_t, is used as numéraire, and labor, N_t, and a continuum of intermediate goods, $x_t(i)$, serve as inputs. The aggregate production function in the final product sector is given by

$$y_t = \frac{1}{\alpha} N_t^{1-\alpha} \left(\int_0^1 (A_t(i))^{1-\alpha} x_t(i)^{\alpha} di \right), \quad i \in (0,1) \tag{1}$$

where $A_t(i)$ is productivity of firm i, $x_t(i)$ is the flow of intermediate goods i used in final-good production at time t, and $\alpha \in (0,1)$. Each intermediate good is produced by a technologically leading monopolist at a unit marginal cost in terms of the final good. As usual, demand for intermediates provides the inverse demand schedule

$$p_t(i) = \left(\frac{A_t(i) N_t}{x_t(i)} \right)^{1-\alpha} \tag{2}$$

where $p_t(i)$ is the price for intermediate i. The monopolist faces a competitive fringe of imitators that can produce the intermediate good at the cost $\xi > 1$ units of the final good. This forces the monopolist to charge a limit price that nevertheless exceeds unity. To ensure that only one monopolist is active for each intermediate it is assumed that $1/\alpha \geq \xi > 1$. Broadly, one can think of the parameter ξ as capturing both technological factors and competitive policies. Higher values of ξ correspond to a less competitive market for intermediates. Given inverse demand (2) and the limit price, equilibrium monopoly profits are

$$\pi_t(i) = [p_t(i) - 1] x_t(i) = \delta A_t(i) N_t \tag{3}$$

where $\delta \equiv (\xi - 1)\xi^{-\frac{1}{1-\alpha}}$ is monotonically increasing in $\xi \leq 1/\alpha$. Higher levels of δ then correspond to a less competitive market and imply higher profits for the leading firm. The labor market clears for wages that equal marginal labor productivity

$$w_t = \frac{1-\alpha}{\alpha}\xi^{-\frac{\alpha}{1-\alpha}}A_t \tag{4}$$

Aggregate final output is given by $y_t = \alpha^{-1}\xi^{-(\alpha/(1-\alpha))}A_t N_t$.

3 Entrepreneurial skills and productivity

Entrepreneurs act in the intermediate sector and productivity of an individual entrepreneur at time t is given by

$$A_t(i) = s_t\left[\eta(i)\overline{A}_{t-1} + \gamma(i)A_{t-1}\right] \tag{5}$$

Here s_t is investment size, $\eta(i)$ and $\gamma(i)$ denote time invariant but different skills; $\overline{A}_t$ reflects productivity at the world technology frontier (global knowledge), and A_t is the state of technology of a single country (local knowledge), each at time t. The average level of the (national) technology in the economy at time t is given by

$$A_t \equiv \int_0^1 A_t(i)di \tag{6}$$

For the representative economy we assume $A_t \leq \overline{A}_t$, and $\overline{A}_t$ is determined by the most productive country, i. e. $\overline{A}_t = \{\text{arg max } A_t\}$.

While the above assumptions are fairly standard in Schumpeterian growth models, we go one step further by endowing entrepreneurs with different skills. Each entrepreneur, i, in the intermediate sector is endowed with two kinds of skills: (i) *Technological skills* ($\eta(i)$) reflect the technological and scientific knowledge of the entrepreneur. They are linked to the productivity level at the world technology frontier, $\overline{A}_{t-1}$, and could be understood as cutting edge skills in the technological domain. (ii) *Systemic skills* ($\gamma(i)$) could be understood as the entrepreneur's skills with respect to management activities, communication, and/or networking. The reference point for systemic skills is national or local knowledge (A_{t-1}), by which we mean the knowledge of local and national peculiarities such as institutions, national tastes and preferences or region specific production factors. This implies that an entrepreneur's systemic skills are more productive given higher regional or societal embeddedness and better network contacts.

Entrepreneurs in industrialized economies possess competencies with respect to both technological and systemic skills. However, entrepreneurs are heterogenous in the sense that their endowments differ with their respective skills. To be more precise, we assume two types of entrepreneurs with different individual productivities

$$A_t^T(i) = s_t[\overline{\eta}\overline{A}_{t-1} + \underline{\gamma}A_{t-1}] \tag{7a}$$

$$A_t^S(i) = s_t[\underline{\eta}\overline{A}_{t-1} + \overline{\gamma}A_{t-1}] \tag{7b}$$

where $\overline{\eta} > \underline{\eta}$ and $\overline{\gamma} > \underline{\gamma}$. Depending upon the prevailing skill composition the two types of entrepreneurs are henceforth called *technological specialists* (see (7a)) and *systemic specialists* (see (7b)). Entrepreneurs are technological specialists with probability λ and systemic specialists with probability $1-\lambda$.

The growth rate of a country's aggregate technology is given by

$$\frac{A_t}{A_{t-1}} = \frac{\int_0^1 A_t(i)}{A_{t-1}} = \int_0^1 s_t\left[\eta(i)\frac{\overline{A}_{t-1}}{A_{t-1}} + \gamma(i)\right]di \tag{8}$$

This growth rate also drives convergence of the country to the world technology frontier (henceforth referred to as WTF). Both types of skills contribute to this convergence process, though to different extents, depending upon the stage of development of a country.[1] As long as a country is far away from the WTF (or formally spoken if $\bar{A}_{t-1}/A_{t-1}$ is relatively large), technological skills strongly contribute to the growth rate of the aggregate technology. Accordingly, technological skills are the major forces that drive growth of national productivity, and with this, convergence. All things being equal, the growth rate of national productivity declines while catching-up: As a country converges to the WTF, technological skills become relatively less important, while systemic skills become relatively more important for the catching-up process.

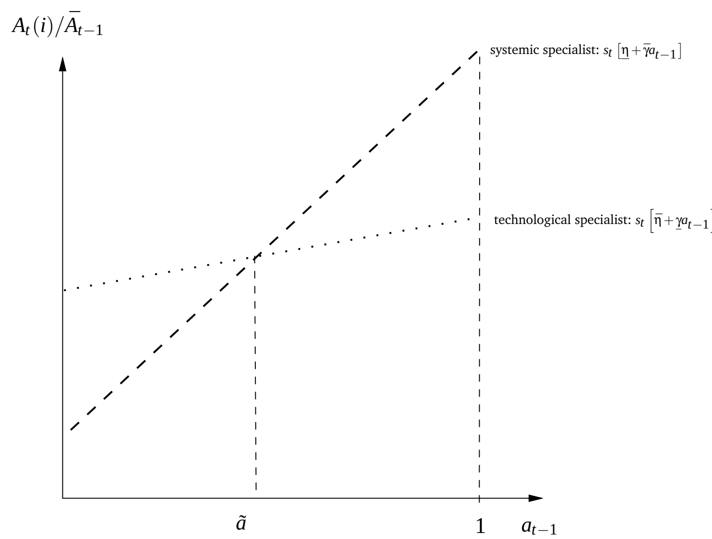


Figure 1 Technological and systemic specialists: the individual view

Figure 1 illustrates the embedding of an individual entrepreneur in a national and in a worldwide context in the following sense. The technological state of the art of the representative economy at time t is given by the country's proximity to frontier, which is defined as

$$a_t \equiv A_t/\bar{A}_t \tag{9}$$

Hence, a_{t-1} could also be interpreted as reflecting the state of development of the country in which an entrepreneur is active at time $t-1$. The relative position of a single entrepreneur, however, is given by the individual distance to frontier, $A_t(i)/\bar{A}_{t-1}$, which is depicted at the vertical axis. Accordingly, Figure 1 illustrates the relative position of a systemic and a technological specialist as functions of the state of economic development in which the respective entrepreneur acts. Both functions are derived by dividing individual productivities of technological and systemic specialists from (7) by $\bar{A}_{t-1}$. In the case of identical investment, s_t, both graphs intersect at the state of development[2]

$$a_{t-1} = \frac{\bar{\eta}-\underline{\eta}}{\bar{\gamma}-\underline{\gamma}} \equiv \tilde{a} \tag{10}$$

[1] This is a major difference to the paper of Acemoglu et al. (2006), in which for 'low-skill entrepreneurs' the value of $\gamma(i)$ becomes zero.

[2] Given identical investment sizes of both entrepreneurs, $\tilde{a} \leq 1$ only if $\bar{\eta}-\underline{\eta} \leq \bar{\gamma}-\underline{\gamma}$.

It becomes apparent that, as long as $a_{t-1} < \tilde{a}$, which means that the country is relatively far away from the WTF, at an individual level, technological specialists are more productive; in contrast, systemic specialists have a higher productivity if the state of development of a country exceeds $\tilde{a}$. This reflects the fact that, all other things being equal, the marginal productivity of technological specialists – and thus their marginal contribution to growth and convergence of the economy as a whole – declines the more the economy approaches the world technology frontier. The opposite is true for systemic specialists. Their marginal productivity increases – at least in relative terms – the closer the economy is to the WTF.

In knowledge-based and high tech sectors (as, for instance, commercial biotech), a high level of technological skills is necessary in order to enter the market. Thus, many start-ups in these sectors are founded by scientists or technological specialists. As the sector grows and approaches the world technological frontier, technological skills remain undoubtedly important. However, to be successful in international competition that becomes fiercer the closer the sector approaches the world technological frontier, technological competence alone is not sufficient. Systemic skills such as the ability to raise funds, to perceive and react quickly to customers' needs, or the ability to exploit knowledge spillovers or other location-specific assets, become relatively more important.

Productivity at the WTF evolves according to

$$\bar{A}_t = (1+g)\bar{A}_{t-1} \tag{11}$$

with g reflecting productivity growth at the WTF.[3]

Throughout the paper, the analysis deals with different levels of aggregation, which interact and which are linked to each other as follows: (i) the individual perspective of single entrepreneurs, $A(i)$; (ii) the national level, which focuses on a country's overall productivity, A, and is affected by the productivity of single entrepreneurs as well as by their overall composition within the economy; and (iii) the worldwide view, which captures productivity at the technology frontier, $\bar{A}$, and is determined by the most productive country.

Note that due to the various levels of aggregation, one has to be precise about the distinction between growth and convergence. From a national perspective, growth is realized whenever for a given initial distance to frontier, a_{t-1}, the level of a_t increases, thereby implicitly inducing convergence to the WTF. Growth, however, may also refer to a shift in the WTF itself.[4]

4 Selection strategies and equilibrium growth

The focus of the current paper is on entrepreneurs endowed with differentiated skills, selection of entrepreneurs, and growth. In this context, growth of a country's productivity depends not only on the individual level of differentiated skills and their aggregate distribution, but also on a country's financial system and – in particular – the market for firm credit: It is intuitively clear that perfect (or nearly perfect) credit markets favor entrepreneurial selection, while credit market imperfections (may) shelter old entrepreneurs,as they are able to realize larger project sizes than their young counterparts

[3] The growth rate of the world technology frontier, g, is assumed to be exogenous. However, it is implicitly endogenized by the termination of those strategies that are compatible with equilibrium growth of productivity at the WTF (see Section 4 where the strategies are detailed).

[4] Then the parameters determining the level of g come into focus but this aspect will not be addressed throughout the paper.

($s_o > s_y$).[5] This implies that in a world with imperfect capital markets – which are quite common in reality – entrepreneurial selection is less likely. The interaction between individual skills and their overall distribution on the one hand and the degree of capital market imperfections on the other hand has major implications for a country's process of convergence to the WTF.

The analysis focuses on a two period setting, thereby considering young entrepreneurs who became active in time t and old entrepreneurs who started business in time $t-1$. Like Acemoglu et al. (2006), we assume that a capitalist, together with an entrepreneur, establishes a firm. Entrepreneurs are engaged by a capitalist who, in each period, decides whether to continue collaboration with old entrepreneurs whose skills are already revealed (capitalists then pursue a retention strategy) or to terminate collaboration with those entrepreneurs who are less productive (capitalists then pursue a termination strategy). As discussed in the context of Figure 1, it is reasonable to assume that, having passed a certain level of development, in the instance of selection, only technological specialists are replaced. Due to the aggregate perspective the corresponding state of development might deviate from $\tilde{a}$. Capitalists choose among retention and termination according to profit maximization by comparing the following two options: (i) well-known profits in the case of collaboration with old entrepreneurs, and (ii) expected profits where the share λ of relatively unproductive old technological specialists is replaced by a new draw of young entrepreneurs who are systemic specialists with probability $1-\lambda$.[6] Since it is quite plausible to assume that established firms can realize bigger projects, e. g. due due to credit market constraints for young firms, it is also assumed that firms may perform different project sizes, $s_o \geq s_y$.[7] The extent of a possible investment gap, $s_o - s_y$, can be interpreted as the existence of capital market imperfections. They may arise due to reputation advantages of old (established) entrepreneurs over young (and hence unknown) entrepreneurs, or because old entrepreneurs have received an income in the first period that they can invest in the next period or use as collateral. Capital market imperfections have a productivity reducing effect on young firms and thus may reflect the costs of the termination strategy. In contrast to that are the benefits of the termination strategy, which are the consequence of productivity gains arising from the activities of systemic specialists.[8]

We begin with a description of the static equilibrium, which captures the optimal decision of the capitalists concerning their choice of entrepreneurs in each period, and then proceed with the dynamic equilibrium thereby describing a country's convergence process to the WTF. It becomes clear that a complex interaction between individual skills, the overall distribution of entrepreneurs, and the extent of capital market imperfections are the main forces affecting the processes of growth and convergence. Consequently, one has to be precise about the distinction between the individual (skills and investment sizes) and the aggregate view (the economy's overall composition of entrepreneurs).

The static equilibrium: Given the individual productivities of systemic versus technological specialists in (7) and their respective economy wide distribution, λ and $1-\lambda$, *average productivity among young entrepreneurs at time t* is given by

$$A_t^y = s_y\left[\left(\lambda\bar{\eta}+(1-\lambda)\underline{\eta}\right)\bar{A}_{t-1}+\left(\lambda\underline{\gamma}+(1-\lambda)\bar{\gamma}\right)A_{t-1}\right] \tag{12}$$

[5] This is simply because old entrepreneurs can invest part of their earnings from the previous period whereas young entrepreneurs by definition possess no own wealth that they could invest.

[6] A formal derivation of both guaranteed and expected value of the firm is given in Appendix B.

[7] For a further discussion of the impact of different project sizes of old and young firms problems see e. g. Evans and Jovanovic (1989) or Martinelli (1997).

[8] However, to evaluate the overall productivity enhancing effect of termination not only individual productivity but also the share of systemic specialists has to be considered.

In contrast to this, *average productivity of old firms* depends upon the retention decision of the capitalist. Hence, one might distinguish between productivity of old firms given retention (henceforth denoted by $R = 1$) and productivity of old firms given termination (henceforth denoted by $R = 0$). If capitalists retain all firms of the antecedent period, average productivity of old firms is basically the same as productivity of young firms in (12) with the sole difference that old entrepreneurs realize the project size s_o. However, if capitalists terminate collaboration with (relatively) less productive entrepreneurs, the fraction λ of technological specialists is replaced by young entrepreneurs, which are again technological specialists with probability λ and systemic specialists with probability $1-\lambda$. Thus, *average productivity among old firms*, depending upon the chosen retention or termination strategy, amounts to

$$A_t^o[R=1] = s_o\left[\left(\lambda\overline{\eta}+(1-\lambda)\underline{\eta}\right)\overline{A}_{t-1}+\left(\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma}\right)A_{t-1}\right] \tag{13a}$$

$$\begin{aligned} A_t^o[R=0] = &\left[s_o(1-\lambda)\underline{\eta}+s_y\lambda\left(\lambda\overline{\eta}+(1-\lambda)\underline{\eta}\right)\right]\overline{A}_{t-1} \\ &+\left[s_o(1-\lambda)\overline{\gamma}+s_y\lambda\left(\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma}\right)\right]A_{t-1} \end{aligned} \tag{13b}$$

For the sake of simplicity, we assume that in each period, half of the entrepreneurs are old and half are young, such that *aggregate productivity* in the economy results as

$$A_t \equiv \int_0^1 A_t(i)di = \frac{1}{2}\left[A_t^y + A_t^o\right] \tag{14}$$

with average productivities of old and young firms calculated according to (12) and (13).

The dynamic equilibrium: The equilibrium dynamics describe how the distance to frontier of a selected country, a_t from (9), evolves depending upon its initial state of development, a_{t-1}, conditional on the capitalist's retention or termination strategy, $R_t = \{0,1\}$. Introducing (12) and (13) into (14), utilizing (11) and dividing by $\overline{A}_t$ yields the dynamic equilibrium of the considered economy as piecewise linear first-order difference equations, thereby capturing the aggregate perspective

$$a_t = \begin{cases} \frac{s_o+s_y}{2(1+g)}\left[\lambda\overline{\eta}+(1-\lambda)\underline{\eta}+\{\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma}\}a_{t-1}\right] & \text{if} \quad \text{R=1;} \\ \\ \frac{1}{2(1+g)}\left[s_o(1-\lambda)\underline{\eta}+(s_y+s_y\lambda)(\lambda\overline{\eta}+(1-\lambda)\underline{\eta})\right. & \\ \qquad \left.+\{s_o(1-\lambda)\overline{\gamma}+(s_y+s_y\lambda)(\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma})\}a_{t-1}\right] & \text{if} \quad \text{R=0.} \end{cases} \tag{15}$$

Both functions depend upon the state of development of the considered economy, a_{t-1}, the individual skills, the overall shares of technological and systemic specialists, investment of old and young firms, as well as the growth rate of productivity at the WTF, g.

Proposition 1 *Depending upon a country's endowment with systemic skills and their overall distribution (the systemic capacity) on the one hand and the degree of capital market imperfections on the other hand, there arise two regimes that are compatible with growth at the WTF. Regime 1 is characterized by a dominance of capital market imperfections with the consequence that old entrepreneurs are retained; in regime 2, the systemic capacity dominates, and selection is realized.*

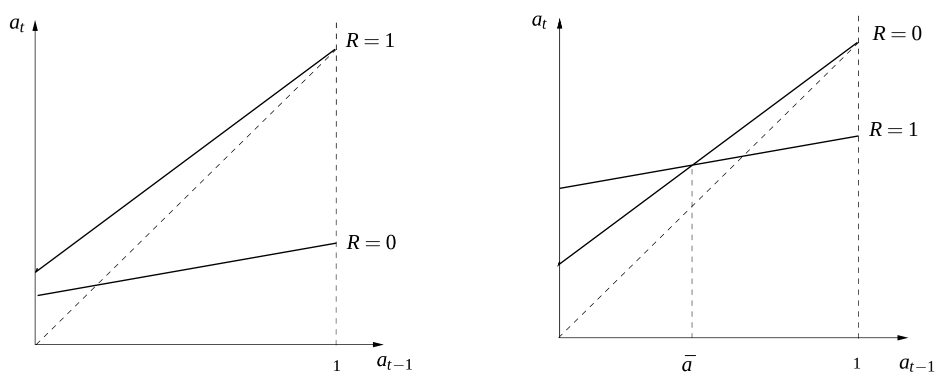
Both equations of motion in (15) differ with respect to the retention and the termination strategy; both are linear and intersect at a certain level of technology development

$$a_{t-1} = \frac{(\overline{\eta}-\underline{\eta})s_y(1-\lambda)+\overline{\eta}(s_o-s_y)}{(\overline{\gamma}-\underline{\gamma})s_y(1-\lambda)-\underline{\gamma}(s_o-s_y)} \equiv \overline{a} \tag{16}$$

This level is affected by individual skill differentials $(\overline{\gamma}-\underline{\gamma}, \overline{\eta}-\underline{\eta})$, the share of systemic specialists ($1-\lambda$, thereby also capturing the aggregate perspective), and the degree of capital market imperfection as included in the investment size gap, $s_o - s_y$.[9] Above, and most importantly, the sign of $\bar{a}$ is indeterminate with[10]

$$\bar{a} \gtreqless 0 \quad \Longleftrightarrow \quad (1-\lambda)\frac{\bar{\gamma}-\underline{\gamma}}{\underline{\gamma}} \gtreqless \frac{s_o - s_y}{s_y} \tag{17}$$

The intuition behind the inequality is straightforward: The left-hand side (LHS) includes the overall share of systemic specialists, $1-\lambda$, and the relative extent of their systemic skill advantage, $(\bar{\gamma}-\underline{\gamma})/\underline{\gamma}$. The whole term characterizes a situation denoted as a country's *systemic capacity*. In contrast, the right hand side (RHS) reflects the relative extent of *capital market imperfections* as measured by the disadvantage of young firms compared to old firms concerning the respective investment sizes. At the limit, the term becomes zero given perfect capital markets in which both young and old firms reach the same investment size. This argumentation holds in the extreme case of perfect capital markets, but also whenever possible capital market imperfections are so small that their productivity reducing effect on young systemic specialists is clearly dominated by systemic skill advantages at an individual $(\bar{\gamma}-\underline{\gamma})$ and an aggregate level $(1-\lambda)$. In what follows the focus will be placed on the interaction between these two forces and their impact on the threshold value $\bar{a}$. Basically two different regimes that are compatible with equilibrium growth at the WTF are distinguished:



(a) regime 1: $(1-\lambda)\frac{\bar{\gamma}-\underline{\gamma}}{\underline{\gamma}} < \frac{s_o-s_y}{s_y}$ capital market imperfections dominate

(b) regime 2: $(1-\lambda)\frac{\bar{\gamma}-\underline{\gamma}}{\underline{\gamma}} > \frac{s_o-s_y}{s_y}$ systemic capacity dominates

Figure 2 Interaction between capital market imperfections and systemic capacity

Regime 1: Given that capital market imperfections are so pronounced that they dominate productivity advantages of young systemic specialists, both at an individual level $(\bar{\gamma}-\underline{\gamma})$ and at an aggregate level $(1-\lambda)$, and if capital market imperfections dominate a country's systemic capacity (i. e. LHS<RHS in (17)), retention is compatible with economic growth at the WTF according to the following reasoning. During the process of catching-up, both technological and systemic skills are required. As a country converges to the WTF, the systemic skills become relatively more important (see (8)). However, even if the country approaches the world technological frontier retention of old entrepreneurs remains the

[9] Note that in case of perfect capital markets, $s_o - s_y$, the level of $\bar{a}$ becomes independent of the overall distribution of entrepreneurs.

[10] The numerator of (16) is unequivocally positive while the sign of the denominator may be positive or negative. This is the immediate consequence of the aggregate consideration and the fact that neither specialist dominates productivity of the other for all states of development.

equilibrium strategy. From an aggregate view, the potential of the systemic specialists as measured by the systemic skill differential, $\overline{\gamma} - \underline{\gamma}$, is not so distinct as to compensate for the sheer dominance of technological specialists, λ, plus the investment advantage of old firms, $s_o - s_y$. The profit maximizing strategy of capitalists is then to continue collaboration with the old entrepreneurs that are able to compensate productivity disadvantages by larger investment sizes. Consequently, retention is the effective strategy for equilibrium growth at the WTF; a switch from retention to termination is never useful (see Figure 2(a)).[11]

Regime 2: Figure 2(b) illustrates an economy in which the systemic capacity dominates possible capital market imperfections. In this context, promoting national growth in the sense of maximizing a_t for any given level of a_{t-1} is determined by the upper envelope of the two strategies, retention and termination. A growth maximizing country far away from the WTF should begin with retaining old firms until the state of development as indicated by $\bar{a}$ is reached; it then should switch to the termination strategy. Otherwise, the economy would get stuck in a non-convergence trap.[12]

To conclude: Which strategy, retention or termination, allows for equilibrium growth of productivity at the WTF depends on both the degree of capital market imperfections and its interaction with a country's systemic capacity.

5 Convergence and policy implications

From the point of view of any single country or a national policy maker, the central issue is not productivity growth at the WTF, but catching up to it, thereby considering the growth rate g from (11) as an exogenous parameter. Important in this context is the impact of those determinants that affect convergence as the resulting state of development, a_t, for any initially given level a_{t-1}.[13]

Policy considerations focus on the determinants affecting the speed of convergence and accordingly the policy implications are strongly linked to a country's education and financial system. With respect to the former the focus lies on the overall composition of specialists (λ) as well as on individual skill levels thereby referring to elite education (affecting the upper skill levels, $\overline{\eta}$ and/or $\overline{\gamma}$) or mass education (affecting the lower skill levels, $\underline{\eta}$ and/or $\underline{\gamma}$). With respect to the financial system the degree of capital market imperfections as represented by the investment gap ($s_o > s_y$) comes into focus.

The following discussion is split and contrasts the two regimes in which either the systemic capacity or capital market imperfections dominate, i.e. if there are no capital market restrictions selection of

[11] Notice that due to parameter restrictions the corresponding value $\bar{a}$ then becomes negative. From (15) results that functions reflecting the retention strategy unequivocally intercepts the vertical axis at a higher level than does the function reflecting the termination strategy.

[12] Formally, a non-convergence trap arises if the economy does not switch its strategy from retention to termination before the state of development determined by the intersection of the $R = 1$ line and the bisecting line is achieved. Along the bisecting line the relationship $a_t = a_{t-1}$ holds and thus characterizes a state of development where a country stops further convergence. The paper of Acemoglu et al. (2006) explicitly addresses this aspect on possibly arising non-convergence traps.

[13] Note that due to the interdependencies between the levels of aggregation, the assumption of an exogenously given growth rate, g, is only valid in the short run. As argued before, this is assumed to hold throughout the paper. In the long run and all other things being equal, a national policy to foster convergence and hence catch-up to the WTF would finally lead to leap-frogging of the initially lagging country in the sense that it firstly converges to the WTF and then passes the frontier, thereby becoming the leading country. Given this, it is not clear whether a unilateral convergence policy can be realized without inducing reactions of other countries intent on imitating the successful policy. However, the convergence process of the initially considered country will be affected by feedback effects of productivity growth at the WTF, g.

entrepreneurs is always the growth-maximizing strategy. Notice that the former includes the special case of perfect capital markets. Formally, the impact of alternative policies and their strengths is analyzed via sensitivity analysis of (15). Table 1 shows the threshold values, a^{th} and λ^{th}, while Figures 3 and 4 provide selected illustrations.

Table 1 What drives convergence?

	regime 1: dominance of cap. market imperfections $\Rightarrow$ retention	regime 2: dominance of systemic capacity $\Rightarrow$ selection
$\frac{\partial a_t}{\partial s_o}, \frac{\partial a_t}{\partial s_y}$	$\frac{\partial a_t}{\partial s_o} = \frac{\partial a_t}{\partial s_y}$	$\frac{\partial a_t}{\partial s_o} < \frac{\partial a_t}{\partial s_y}$
$\frac{\partial a_t}{\partial \lambda}$	$\gtrless 0 \Leftrightarrow a_{t-1} \lesseqgtr \tilde{a}$	$\gtrless 0 \Leftrightarrow a_{t-1} \lesseqgtr \tilde{\tilde{a}}$
$\frac{\partial a_t}{\partial \bar{\eta}} > \frac{\partial a_t}{\partial \underline{\gamma}}$	$a_{t-1} < 1$	$a_{t-1} < 1$
$\frac{\partial a_t}{\partial \underline{\eta}} > \frac{\partial a_t}{\partial \bar{\gamma}}$	$a_{t-1} < 1$	$a_{t-1} < 1$
$\frac{\partial a_t}{\partial \bar{\eta}} \gtrless \frac{\partial a_t}{\partial \underline{\eta}}$	$\lambda \gtrless \frac{1}{2}$	$\lambda \gtrless -\frac{s_o+s_y}{4s_y} + \frac{1}{4s_y}\sqrt{\left(\frac{s_o+3s_y}{4s_y}\right)^2 + \frac{s_o}{4s_y}}$
$\frac{\partial a_t}{\partial \bar{\gamma}} \gtrless \frac{\partial a_t}{\partial \underline{\gamma}}$	$\lambda \lesseqgtr \frac{1}{2}$	$\lambda \lesseqgtr -\frac{s_o+s_y}{4s_y} + \frac{1}{4s_y}\sqrt{\left(\frac{s_o+3s_y}{4s_y}\right)^2 + \frac{s_o}{4s_y}}$
$\frac{\partial a_t}{\partial \bar{\eta}} \gtrless \frac{\partial a_t}{\partial \bar{\gamma}}$	$a_{t-1} \lesseqgtr \frac{\lambda}{1-\lambda}$	$a_{t-1} \lesseqgtr \frac{\lambda}{1-\lambda} \cdot \frac{s_y(1+\lambda)}{s_o+s_y(1+\lambda)}$
$\frac{\partial a_t}{\partial \underline{\eta}} \gtrless \frac{\partial a_t}{\partial \underline{\gamma}}$	$a_{t-1} \lesseqgtr \frac{1-\lambda}{\lambda}$	$a_{t-1} \lesseqgtr \frac{1-\lambda}{\lambda} \cdot \frac{s_o+s_y(1+\lambda)}{s_y(1+\lambda)}$
$\frac{\partial a_t}{\partial g}$	<0	<0

Proposition 2 *Investment of old and young entrepreneurs (Table 1, line 1):*
More investment unequivocally increases the speed of convergence. The impact of young firms' investment is higher if the systemic capacity dominates (regime 2).

Regime 1: Since no replacement of old entrepreneurs takes place, overall productivity equally benefits from higher investment of young and old entrepreneurs.

Regime 2: Increasing the investment size of young entrepreneurs has a larger positive impact on productivity than does increasing the investment size of old entrepreneurs. The economic rationale is that giving young entrepreneurs better access to capital (by reducing capital market constraints, provision of venture capital, etc.) increases their relative attractiveness, makes replacement of low productivity old entrepreneurs more likely, and increases aggregate productivity.

Proposition 3 *Overall composition of entrepreneurs or education policy at large (Table 1, line 2):*
In both regimes, countries far from the WTF benefit from increasing the share of technological specialists while countries close to the WTF benefit from increasing the share of systemic specialists. The threshold state of development, a_{t-1}^{th}, increases with the prevailing share of technological specialists and is higher if capital market imperfections dominate (regime 1).

Education policy at large is important as it determines the share of technological specialists, λ, in the economy. If a country invests (substantially) more in the education of technological specialists than in the education of systemic specialists the fraction of technological specialists, λ, will rise. By contrast, if a country invests (substantially) more in the education of systemic specialists than in the education of technological specialists the result will be a decrease in λ and an increase in the fraction of systemic specialists, $1-\lambda$. As seen from Table 1, a focus on the education of technological specialists (which increases λ) is growth-enhancing as long as a_{t-1} remains below a certain threshold level. In regime 2, this threshold level is smaller than (or, in the extreme case of perfect capital markets, equal to) the threshold level in regime 1. If replacement of relatively unproductive old entrepreneurs is feasible, a switch in education policy towards investment in systemic skills pays off earlier than in the case where selection is not feasible.

Regime 1: The threshold value $\tilde{a}$ is provided by equation (10). It reflects the individual productivity advantage of either technological or systemic specialists as argued in the context of Figure 1. Enhancing the share of technological specialists then speeds up convergence if the state of development of a country lies in the range in which technological specialists are more productive, i. e., as long as $a_{t-1} < \tilde{a}$. Otherwise, higher speed of convergence is achieved with increasing the share of systemic specialists.

Regime 2: In the case of entrepreneurial selection the trade-off between productivity enhancement that is due to systemic skills and productivity reduction as a consequence of lower investment of young entrepreneurs comes into play. The corresponding threshold state of development is[14]

$$\tilde{\tilde{a}} \equiv \frac{s_y(1+2\lambda)(\overline{\eta}-\underline{\eta})-(s_o-s_y)\underline{\eta}}{(s_o-s_y)\overline{\gamma}+s_y(1+2\lambda)(\overline{\gamma}-\underline{\gamma})} \leq \tilde{a} \quad \forall s_o \geq s_y, \quad \frac{\partial \tilde{\tilde{a}}}{\partial \lambda} > 0 \tag{18}$$

This threshold level is smaller (or, in the extreme case of perfect capital markets, equal to) the threshold level in regime 1, $\tilde{a}$ from (10). If replacement of relatively unproductive old entrepreneurs is feasible, a switch in education policy towards investment in systemic skills pays off earlier than in the case where selection is not feasible.

Proposition 4 *Contribution of the specialist's skills for catching up (Table 1, lines 3 and 4):*
During the process of catching up, the relative importance of technological skill decreases while systemic skills become relatively more important. This holds true regardless of a country's state of development and the type of specialist.

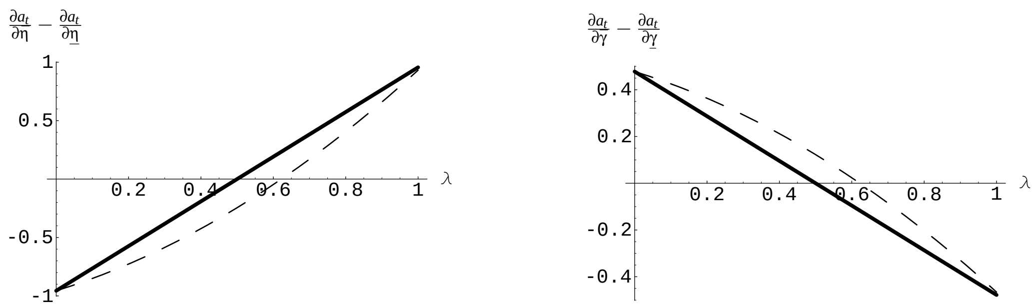
According to (8), the contribution of technological skills towards a country's productivity growth rate is magnified by the inverse of the distance to frontier. This latter term decreases during the process of catching up. Since at an individual level this relationship holds for either type of entrepreneur, quicker convergence is unequivocally achieved by increasing technological skills.

Proposition 5 *Skill boundaries and impact of the share of entrepreneurs (Table 1, lines 5 and 6; Figures 3):*
Which (the upper of the lower) skill boundary should be enhanced depends upon the overall composition of entrepreneurs. If $\lambda > \lambda^{th}$, the preferred policy is to increase the skill boundaries of technological specialists, namely $\overline{\eta}$ and $\underline{\gamma}$. If in contrast $\lambda < \lambda^{th}$, education policy should foster the individual skills of systemic specialists, i. e., $\overline{\gamma}$ and $\underline{\eta}$. This effect holds independent of a country's state of development, a_{t-1}. If capital market imperfections dominate (regime 1), the threshold amounts to $\lambda^{th} = 1/2$, which is independent of investment. If the systemic capacity dominates (regime 2), the threshold value is magnified by investment and $\lambda^{th}(s_o, s_y) > 1/2$.

[14] The value of $\tilde{a}$ is determined by differentiating (15) with respect to λ and solving for a_{t-1}. Together with (16) this implies $\tilde{\tilde{a}} \leq \tilde{a} \leq \bar{a}$.

Regime 1: The threshold level $\lambda^{th} = 1/2$ mirrors the assumption that in each period overall productivity is equally determined by young and old entrepreneurs (see (14)). Productivity is independent of investment size since the interdependencies between productivity enhancements (which are due to higher skills) and productivity reductions (which are due to the lower investment of young firms) induced via selection that have to be compensated for given selection do not arise.[15]

Regime 2: The threshold value $\lambda^{th}(s_o, s_y) > 1/2$ is a function of investment sizes. It represents a majority of technological specialists. Consequently, due to their higher share technological specialists have a relatively stronger impact on overall productivity than do systemic specialists. Nevertheless, individually, the latter are more productive, as the considered economy converges towards the WTF. To compensate for the relatively low productivity of technological specialists at the individual level, any productivity enhancing effect that is induced via increasing the technological specialist's skills, $\overline{\eta}$ and $\underline{\gamma}$, has to be effective for a significant share of these specialists in order to enhance overall productivity and expedite convergence. Conversely, for high shares of systemic specialists the preferred policy would target the skills of the systemic specialists, $\overline{\gamma}$ and $\underline{\eta}$.



(a) technological skills (b) systemic skills

Figure 3 Speed of convergence and productivity differentials as a function of λ;
parameters: $s_o = 1$, $s_y = 0.95$, $g = 0.02$, $a_{t-1} = 0.5$
solid line: capital market imperfections dominate; regime 1
dashed line: systemic capacity dominates; regime 2

An illustration of the discussed effects is given in Figures 3(a) and 3(b) which depict the productivity differentials between upper and lower skill boundaries for regime 1 (solid lines) and regime 2 (dashed lines).[16] Figure 3(a) focusses on technological skill differentials, $\frac{\partial a_t}{\partial \overline{\eta}} - \frac{\partial a_t}{\partial \underline{\eta}}$, while Figure 3(b) does so for systemic skill differential, $\frac{\partial a_t}{\partial \overline{\gamma}} - \frac{\partial a_t}{\partial \underline{\gamma}}$. Obviously, the solid lines intersect the horizontal axis at the threshold level $\lambda^{th} = 1/2$, while the respective threshold value lies unequivocally higher if the systemic capacity dominates, $\lambda^{th} > 1/2$, thereby supporting the previous argument.[17]

[15] See also the discussion of the indifference of higher investment of either young or old entrepreneurs in case of dominating capital market imperfections.

[16] Note that Figures 3(a)–4(b) are plotted for identical sizes of the investment gap, $s_o - s_y$. Nevertheless, combined with the other parameters the two functions in each figure may be unequivocally assigned to either regime 1 or regime 2. An identical investment size gap does not contradict the dominance of either the systemic capacity or capital market imperfections.

[17] The plots are independent of the absolute values of the systemic and technological skills. Besides, the plots in Figure 3(a) are independent of a_{t-1}. In contrast, the plots in Figure 3(b) quite well depend upon a_{t-1}. Since this effect applies

Proposition 6 *Skill boundaries, composition of entrepreneurs, and the impact of the distance to frontier (Table 1, lines 7 and 8; Figure 4):*
For both upper and lower skill boundaries, the predominance of either technological or systemic skills is crucially affected by the interplay between a country's state of development and the ratio of the overall shares of systemic and technological specialists, and hence $a^{th}(\lambda)$. If the systemic capacity dominates (regime 2), additionally investment sizes gain importance, and $a^{th}(\lambda, s_o, s_y)$. Compared to regime 1, investment dampens the threshold concerning upper skill boundaries (elite skills) and amplifies the threshold with respect to lower skill boundaries (mass skills).

Upper skill boundaries – which elite, $\overline{\eta}$ or $\overline{\gamma}$ (Figure 4(a)):

Regime 1: If capital market imperfections dominate, the preferred policy may be derived according to

$$\frac{\partial a_t}{\partial \overline{\eta}} \gtrless \frac{\partial a_t}{\partial \overline{\gamma}} \quad \Leftrightarrow \quad a_{t-1} \lessgtr \frac{\lambda}{1-\lambda} \qquad \text{with} \quad \frac{\lambda}{1-\lambda} \gtrless 1 \quad \Leftrightarrow \quad \lambda \gtrless \frac{1}{2} \tag{19}$$

Given $\lambda > 1/2$ (majority of technological specialists), the threshold value $\lambda/(1-\lambda)$ unequivocally exceeds unity, and quicker convergence is achieved by supporting the elite skills of technological specialists, $\overline{\eta}$. If no selection takes place, policy should support the skill of those entrepreneurs who represent the higher overall share. For $\lambda < 1/2$, i. e., a majority of systemic specialists, ambiguous effects arise. A switch from supporting a technological elite to a systemic elite is reasonable if a country's state of development exceeds the threshold value.[18]

Nevertheless, policy recommendations do not unequivocally imply support of systemic specialists; however, the interplay between a country's state of development and the ratio of technological and systemic specialists plays a crucial role. Poorly developed countries should still support the technological elite, thereby benefitting from increased contribution of technological skills to overall convergence (see (8)). However, after having passed the threshold state of development quicker convergence is achieved by supporting systemic elite skills.

Regime 2: If the systemic capacity dominates, the following relationships hold

$$\frac{\partial a_t}{\partial \overline{\eta}} \gtrless \frac{\partial a_t}{\partial \overline{\gamma}} \quad \Leftrightarrow \quad a_{t-1} \lessgtr \frac{\lambda}{1-\lambda} \cdot \frac{s_y(1+\lambda)}{s_o + s_y(1+\lambda)} \qquad \text{with} \quad \frac{s_y(1+\lambda)}{s_o + s_y(1+\lambda)} < 1 \tag{20}$$

The corresponding threshold value, a^{th}_{t-1}, is smaller than (19) because it is dampened by investment, $\frac{s_y(1+\lambda)}{s_o+s_y(1+\lambda)}$. Productivity of younger entrepreneurs compensates for the resulting overall productivity losses that are inherent in the smaller investment sizes. If a country's state of development is below the threshold value, education policy should foster technological elite skills. The argumentation is supported by the dashed line in Figure 4(a), which intersects the horizontal axis at the state of development $a^{th}_{t-1} < 1$. For lower states of development, supporting technological elite skills is favorable, while quicker convergence via increasing upper systemic elite skills is achieved if a country's state of development exceeds a^{th}_{t-1}. This

for both technological skills, $\overline{\gamma}$ and $\underline{\gamma}$, the consideration of the difference $\partial a_t/\partial\overline{\gamma} - \partial a_t/\partial\underline{\gamma}$ implies that both effects cancel. As a consequence the threshold values λ^{th} are independent of a country's state of development.

[18] Note that supporting the technological elite is equivalent to supporting technological specialists. Analogously act enhancements of systemic elite skills which are equivalent to fostering systemic specialists.

reflects the fact that during the process of catching-up, technological skills become relatively less important (see (8)).

Lower skill boundaries – which mass skills, $\underline{\eta}$ or $\underline{\gamma}$ (see Figure 4(b)):

Regime 1: The preferred policy may be derived according to

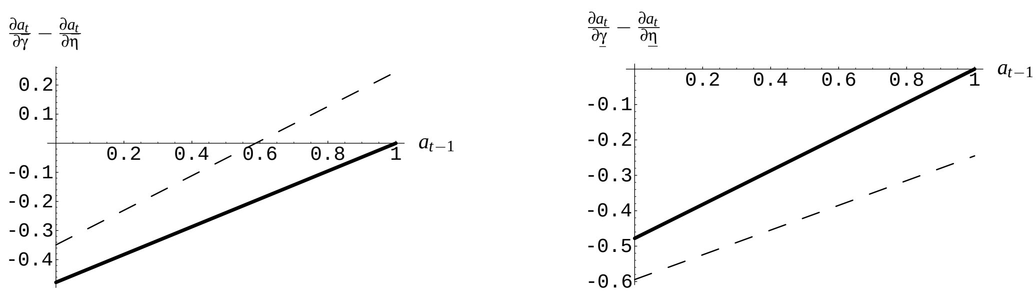
$$\frac{\partial a_t}{\partial \underline{\eta}} \gtreqless \frac{\partial a_t}{\partial \underline{\gamma}} \quad \Leftrightarrow \quad a_{t-1} \lesseqgtr \frac{1-\lambda}{\lambda} \tag{21}$$
$$\text{with} \quad \frac{1-\lambda}{\lambda} \gtreqless 1 \quad \Leftrightarrow \quad \lambda \lesseqgtr \frac{1}{2}$$

Given $\lambda < 1/2$ (majority of systemic specialists), quicker convergence is unequivocally achieved via supporting mass skills of systemic specialists, $\overline{\eta}$. For $\lambda > 1/2$ (majority of technological specialists), ambiguous effects might arise. The reasoning is analogous to that presented in (19).

Regime 2: If the systemic capacity dominates, the following relationship holds:

$$\frac{\partial a_t}{\partial \underline{\eta}} \gtreqless \frac{\partial a_t}{\partial \underline{\gamma}} \quad \Leftrightarrow \quad a_{t-1} \lesseqgtr \frac{1-\lambda}{\lambda} \cdot \frac{s_o + s_y(1+\lambda)}{s_y(1+\lambda)} \tag{22}$$
$$\text{with} \quad \frac{s_o + s_y(1+\lambda)}{s_y(1+\lambda)} > 1$$

Compared to (21), the threshold value, a_{t-1}^{th}, is magnified by investment, $\frac{s_o+s_y(1+\lambda)}{s_y(1+\lambda)} > 1$, and it remains sensible to support technological skills of technological specialists for a wider range of parameters, rather than technological skills of systemic specialists. Again, eduction policy should target that group of specialists which represents the higher share; the argumentation presented in the context of (20) applies.



(a) upper boundaries (b) lower boundaries

Figure 4 Speed of convergence and enhancing upper and lower skill boundaries as a function of the state of development, a_{t-1};
parameters: $s_o = 1$, $s_y = 0.95$, $\lambda = 0.5$, $g = 0.02$
solid line: capital market imperfections dominate; regime 1
dashed line: systemic capacity dominates; regime 2

Figures 4(a) and 4(b) plot productivity differentials of elite skills ($\overline{\eta}, \overline{\gamma}$) and mass skills ($\underline{\eta}, \underline{\gamma}$) for a balanced distribution of entrepreneurs, $\lambda = 1/2$.[19] Independent of the prevailing regime, increasing the

[19] Again, the results are independent of the absolute levels of any skill.

share of technological specialists, λ, has the following consequences: It shifts both functions in Figure 4(a) downwards, thereby reinforcing the predominance of technological elite skills (or put differently, technological specialists) over systemic elite skills (or put differently systemic specialists). Note that this result holds independent of the prevailing regime. The higher the share of technological specialists, the stronger is their impact on overall productivity and the more favorable is supporting any of their skills. For sufficiently high increases in λ, even in regime 2, the ambiguous effects discussed before finally vanish and then supporting technological skills enhances the speed of convergence independent of the distance to frontier. The opposite applies for higher shares of systemic specialists, $1-\lambda$. Then both functions in Figure 4(a) shift upwards, and even if capital market imperfections have dominated (regime 1; solid line) for countries close to the WTF, the support of systemic specialists becomes the growth-maximizing policy.

With respect to the lower skill boundaries, the following applies: Increasing λ shifts both functions in Figure 4(b) upwards, thereby destroying the unequivocal predominance of the support of technological skills. Notice that if capital market imperfections dominate, this effect at once applies for slight increases of $\lambda > 1/2$ (regime 1; solid line). However, with respect to the systemic capacity, the effect only arises for distinct shifts of λ. Illustratively, it requires a significant increase of λ to shift the dashed line to such an extent that it intersects the horizontal axis thereby inducing the ambiguous relations. This mirrors the fact that given a dominance of the systemic capacity, the threshold value in (21) is magnified by the second term that exceeds unity, and a higher share of technical specialists is confronted with a higher systemic capacity.

Proposition 7 *An ordinal ranking of education policies:*
At an individual level education policies might begin with enhancing any skill of any entrepreneur. Depending upon both a country's state of development and its composition of entrepreneurs, it is possible to derive an unambiguous ranking of alternative skill-enhancing policies and their respective contribution for catching up. According to this reasoning poorly developed countries should first enhance technological skills and then systemic skills. The order on upper vs. lower skills boundaries is determined by those entrepreneurs who represent the majority. The respective threshold values vary with the prevailing regimes, whereas, concerning the policy recommendations, the basic structure holds independent of the prevailing regime.

Merging the insights of Proposition 4 to 6, clear-cut rankings of different education policies, as portrayed in Table 2, may be derived:

Table 2 Ranking of education policies

	$\lambda > \lambda^{th}$	$\lambda < \lambda^{th}$
$a_{t-1} > a^{th}$	$\bar{\eta} \succ \underline{\gamma} \succ \underline{\eta} \succ \bar{\gamma}$	$\underline{\eta} \succ \bar{\gamma} \succ \bar{\eta} \succ \underline{\gamma}$
$a_{t-1} < a^{th}$	$\bar{\eta} \succ \underline{\eta} \succ \underline{\gamma} \succ \bar{\gamma}$	$\underline{\eta} \succ \bar{\eta} \succ \bar{\gamma} \succ \underline{\gamma}$

The threshold values a^{th} and λ^{th} are summarized in Table 1 and vary between the two regimes. Nevertheless, the basic structure is independent of the prevailing regime. A line by line look at Table 2 reveals that advanced economies, $a_{t-1} > a^{th}$, should begin by focusing on the skills of technological specialists, $\bar{\eta}$ and $\underline{\gamma}$, if their share exceeds the threshold; the skills of the systemic specialists, $\underline{\eta}$ and $\bar{\gamma}$, contribute more to convergence if the share of technological specialists falls below the threshold value, λ^{th}. In contrast, for poorly developed countries, $a_{t-1} < a^{th}$, the importance of technological skills for catching up becomes obvious, while the order of upper and lower skill boundaries again is determined by those entrepreneurs whose share exceeds the respective threshold.

Proposition 8 *The growth rate (Table 1, line 9):*
A higher growth rate of productivity at the WTF reduces the speed of convergence regardless of the prevailing regime.

Obviously, it is easier for a country to converge to the WTF the slower the latter grows.

6 Conclusions

This paper analyzes the impact of differentiated individual skills and the aggregate skill distribution on growth and convergence in a knowledge-based economy. The analysis extends existing Schumpeterian growth models in several respects. In particular, highly skilled entrepreneurs dispose of different specializations to become either technological or systemic specialists. The former integrate predominantly technological knowledge, while the latter possess, e.g., management skills, knowledge of national innovation systems, or societal and institutional embeddedness. Technological skills are linked to the knowledge stock at the world technology frontier, whereas the national/local knowledge stock is related to systemic skills. This considers the fact that national growth depends not only on the distance of the economy to the world technology frontier, but also on country-specific (e. g., institutions) and region-specific factors. In fact, it is argued here that the factors that drive growth and competitiveness in the world economy are not those which are globally available but those that stick to certain locations and hence are hard to imitate or replicate elsewhere. If growth (productivity, respectively) were only dependent on distance to the WTF, firms would e.g. show no tendency to cluster in certain locations in order to capture the productivity gains from these places. It has been shown that, basically, there are two different regimes that are compatible with equilibrium growth at the world technology frontier.

The analysis carried out has various implications for policy. Take start-up promotion policies as an example. Economic policy may improve young entrepreneurs' access to capital by reducing capital market constraints or by providing venture capital. A policy that provides easy credit finance to nascent entrepreneurs tends to increase the project size of young entrepreneurs and to decrease - all other things being equal - the difference in project size between old and young entrepreneurs. This has the following effects: It makes replacement of old entrepreneurs by young entrepreneurs more likely (i.e. selection becomes more attractive in relative terms); it enhances productivity and growth in the respective country; and it speeds up convergence of the country under consideration with the WTF. Alternative policy instruments affect either the individual skill levels of the specialist or the overall composition of entrepreneurs.

Another - and perhaps even more important - area of long term growth policy is education policy. A country may give priority to the education of technological specialists or to the education of systemic specialists; it may follow a strategy of mass education (affecting lower skill boundaries) or elite education (affecting upper skill boundaries). A major result of our analysis - that clearly contrasts with standard models of Schumpeterian growth theory like Acemoglu et al. (2006) - is that countries far from the WTF benefit from increasing the share of technological specialists while countries close to the WTF benefit from increasing the share of systemic specialists. Moreover, we are able to show that the optimal design of education policy depends critically upon the interplay between a country's state of development and the prevailing composition of specialists.

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Mathematical appendix [not intended for publication]

Sensitivity of the speed of convergence

Sensitivity analysis in case of dominating systemic capacity (regime 2):
Reference is (15) for the termination strategy, $R=0$.

$$\frac{\partial a_t}{\partial s_o} = \frac{1-\lambda}{2(1+g)}\left[\underline{\eta}+\overline{\gamma}a_{t-1}\right] \quad > 0 \tag{23a}$$

$$\frac{\partial a_t}{\partial s_y} = \frac{1+\lambda}{2(1+g)}\left[\lambda\overline{\eta}+(1-\lambda)\underline{\eta}+\left\{\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma}\right\}a_{t-1}\right] \quad > 0 \tag{23b}$$

$$\frac{\partial a_t}{\partial \overline{\eta}} = \frac{1+\lambda}{2(1+g)}s_y\lambda \quad > 0 \tag{23c}$$

$$\frac{\partial a_t}{\partial \overline{\gamma}} = \frac{1-\lambda}{2(1+g)}\left[s_o+(1+\lambda)s_y\right]\cdot a_{t-1} \quad > 0 \tag{23d}$$

$$\frac{\partial a_t}{\partial \underline{\eta}} = \frac{1-\lambda}{2(1+g)}\left[s_o+s_y(1+\lambda)\right] \quad > 0 \tag{23e}$$

$$\frac{\partial a_t}{\partial \underline{\gamma}} = \frac{1+\lambda}{2(1+g)}s_y\lambda\cdot a_{t-1} \quad > 0 \tag{23f}$$

$$\begin{aligned}\frac{\partial a_t}{\partial \lambda} = {} & \frac{1}{2(1+g)}\Big[-s_o\underline{\eta}+s_y\left(\lambda\overline{\eta}+(1-\lambda)\underline{\eta}\right)+(s_y+s_y\lambda)(\overline{\eta}-\underline{\eta}) \\ & +\left\{-s_o\overline{\gamma}+s_y(\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma})+(s_y+s_y\lambda)(\underline{\gamma}-\overline{\gamma})\right\}a_{t-1}\Big] \quad > 0\end{aligned} \tag{23g}$$

$$\begin{aligned}\frac{\partial a_t}{\partial g} = {} & -\frac{1}{2(1+g)^2}\Big[s_o(1-\lambda)\underline{\eta}+(s_y+s_y\lambda)(\lambda\overline{\eta}+(1-\lambda)\underline{\eta}) \\ & +\{s_o(1-\lambda)\overline{\gamma}+(s_y+s_y\lambda)(\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma})\}a_{t-1}\Big] \quad < 0\end{aligned} \tag{23h}$$

Assessing the speed of convergence for alternative policies (regime 2)

$$\frac{\partial a_t}{\partial s_o} < \frac{\partial a_t}{\partial s_y} \tag{24a}$$

$$\frac{\partial a_t}{\partial \overline{\eta}} > \frac{\partial a_t}{\partial \underline{\gamma}} \quad \Longleftrightarrow \quad a_{t-1} < 1 \tag{24b}$$

$$\frac{\partial a_t}{\partial \underline{\eta}} > \frac{\partial a_t}{\partial \overline{\gamma}} \quad \Longleftrightarrow \quad a_{t-1} < 1 \tag{24c}$$

$$\frac{\partial a_t}{\partial \overline{\eta}} \gtrless \frac{\partial a_t}{\partial \underline{\eta}} \quad \Longleftrightarrow \quad \lambda \gtrless -\frac{s_o+s_y}{4s_y}+\frac{1}{4s_y}\sqrt{\left(\frac{s_o+3s_y}{4s_y}\right)^2+\frac{s_o}{4s_y}} \tag{24d}$$

$$\frac{\partial a_t}{\partial \overline{\gamma}} \gtrless \frac{\partial a_t}{\partial \underline{\gamma}} \quad \Longleftrightarrow \quad \lambda \lessgtr -\frac{s_o+s_y}{4s_y}+\frac{1}{4s_y}\sqrt{\left(\frac{s_o+3s_y}{4s_y}\right)^2+\frac{s_o}{4s_y}} \tag{24e}$$

$$\frac{\partial a_t}{\partial \overline{\eta}} \gtrless \frac{\partial a_t}{\partial \overline{\gamma}} \quad \Longleftrightarrow \quad a_{t-1} \lessgtr \frac{\lambda}{1-\lambda}\cdot\frac{s_y(1+\lambda)}{s_o+s_y(1+\lambda)} \tag{24f}$$

$$\frac{\partial a_t}{\partial \underline{\eta}} \gtrless \frac{\partial a_t}{\partial \underline{\gamma}} \quad \Longleftrightarrow \quad a_{t-1} \gtrless \frac{1-\lambda}{\lambda}\cdot\frac{s_o+s_y(1+\lambda)}{s_y(1+\lambda)} \tag{24g}$$

$$\frac{\partial a_t}{\partial \lambda} \gtrless 0 \quad \Longleftrightarrow \quad a_{t-1} \gtrless \frac{s_y(1+2\lambda)(\overline{\eta}-\underline{\eta})-(s_o-s_y)\underline{\eta}}{(s_o-s_y)\overline{\gamma}+s_y(1+2\lambda)(\overline{\gamma}-\underline{\gamma})} \tag{24h}$$

Sensitivity analysis in case of strong capital market imperfections (regime 1):
Reference point is (15) for the retention strategy, $R=1$

$$\frac{\partial a_t}{\partial s_o}=\frac{\partial a_t}{\partial s_y}=\frac{1}{2(1+g)}\left[\lambda\overline{\eta}+(1-\lambda)\underline{\eta}+\{\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma}\}a_{t-1}\right] \quad >0 \tag{25a}$$

$$\frac{\partial a_t}{\partial \overline{\eta}}=\frac{s_o+s_y}{2(1+g)}\lambda \quad >0 \tag{25b}$$

$$\frac{\partial a_t}{\partial \overline{\gamma}}=\frac{s_o+s_y}{2(1+g)}(1-\lambda)a_{t-1} \quad >0 \tag{25c}$$

$$\frac{\partial a_t}{\partial \underline{\eta}}=\frac{s_o+s_y}{2(1+g)}(1-\lambda) \quad >0 \tag{25d}$$

$$\frac{\partial a_t}{\partial \underline{\gamma}}=\frac{s_o+s_y}{2(1+g)}\lambda a_{t-1} \quad >0 \tag{25e}$$

$$\frac{\partial a_t}{\partial \lambda}=\frac{s_o+s_y}{2(1+g)}\left[\overline{\eta}-\underline{\eta}-(\overline{\gamma}-\underline{\gamma})a_{t-1}\right] \quad \gtrless 0 \Leftrightarrow a_{t-1}\lessgtr\frac{\overline{\eta}-\underline{\eta}}{\overline{\gamma}-\underline{\gamma}} \tag{25f}$$

$$\frac{\partial a_t}{\partial g}=-\frac{s_o+s_y}{2(1+g)^2}\left[\lambda\overline{\eta}+(1-\lambda)\underline{\eta}+\{\lambda\underline{\gamma}+(1-\lambda)\overline{\gamma}\}a_{t-1}\right] \quad <0 \tag{25g}$$

Assessing the speed of convergence for alternative policies [dominance of capital market imperfections]

$$\frac{\partial a_t}{\partial s_o}=\frac{\partial a_t}{\partial s_y} \tag{26a}$$

$$\frac{\partial a_t}{\partial \overline{\eta}}>\frac{\partial a_t}{\partial \underline{\gamma}} \quad \Longleftrightarrow \quad a_{t-1}<1 \tag{26b}$$

$$\frac{\partial a_t}{\partial \underline{\eta}}>\frac{\partial a_t}{\partial \overline{\gamma}} \quad \Longleftrightarrow \quad a_{t-1}<1 \tag{26c}$$

$$\frac{\partial a_t}{\partial \overline{\eta}}\gtrless\frac{\partial a_t}{\partial \underline{\eta}} \quad \Longleftrightarrow \quad \lambda\gtrless\frac{1}{2} \tag{26d}$$

$$\frac{\partial a_t}{\partial \overline{\gamma}}\gtrless\frac{\partial a_t}{\partial \underline{\gamma}} \quad \Longleftrightarrow \quad \lambda\lessgtr\frac{1}{2} \tag{26e}$$

$$\frac{\partial a_t}{\partial \overline{\eta}}\gtrless\frac{\partial a_t}{\partial \overline{\gamma}} \quad \Longleftrightarrow \quad a_{t-1}\lessgtr\frac{\lambda}{1-\lambda}; \quad a_{t-1}<1\Leftrightarrow\lambda<0.5 \tag{26f}$$

$$\frac{\partial a_t}{\partial \underline{\eta}}\gtrless\frac{\partial a_t}{\partial \underline{\gamma}} \quad \Longleftrightarrow \quad a_{t-1}\lessgtr\frac{1-\lambda}{\lambda}; \quad a_{t-1}<1\Leftrightarrow\lambda>0.5 \tag{26g}$$

$$\frac{\partial a_t}{\partial \lambda}\gtrless 0 \quad \Longleftrightarrow \quad a_{t-1}\lessgtr\tilde{a} \tag{26h}$$