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by Dirk Dohse and Ingrid Ott

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Kiel Institute for the World Economy, Düsternbrooker Weg 120, 24105 Kiel, Germany

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Key words: growth, skills, innovation, selection, distance to frontier

JEL: O31, O33, O38, J24, L26

Kiel Institute for the World Economy
24100 Kiel, Germany
Telephone: ++431-8814-460
E-Mail: dirk.dohse@ifw-kiel.de,
ingrid.ott@ifw-kiel.de

Determinants of growth and convergence in a growing economy with heterogeneous entrepreneurs

Dirk Dohse
Institute for the World Economy*

Ingrid Ott
Institute for the World Economy**

November 28, 2008

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*dirk.dohse@ifw-kiel.de
**ingrid.ott@ifw-kiel.de

1 Introduction

What drives the growth of modern economies? Who are the pivotal actors, which skills do they need and what is the role of distance to the world technology frontier, selection of entrepreneurs and economic policy in this context? These are the questions Acemoglu/Aghion/Zilibotti (2006) (referred to as AAZ in the remainder of this paper) raise in their seminal paper entitled 'Distance to Frontier, Selection, and Economic Growth'. The pivotal agents in their model are capitalists and entrepreneurs and their model has three key features (Acemoglu et al. (2006, 38)): (i) entrepreneurs are either high skill or low skill (ii) they engage both in imitation and adoption of technologies from the world technology frontier (iii) there are credit constraints restricting the amount of investment. Successful entrepreneurs (those revealed to be high skill) are always retained by the capitalists, whereas unsuccessful entrepreneurs (those revealed to be low skill) can either be dismissed and replaced by a new draw who will have on average higher skills or be retained. Retention of low skill entrepreneurs may happen due to credit market imperfections that enable insider entrepreneurs to undertake greater investments than newcomers. AAZ are able to show that under such a setting firms in countries far away from the world technology frontier pursue an investment-based strategy featuring long-term relationships, large investments but little selection. The closer the economy approaches the world technology frontier the greater becomes the importance of innovation relative to imitation as a source of productivity growth. Consequently, there is an equilibrium switch towards an innovation-based strategy featured by short-term relationships, stricter selection of entrepreneurs, more innovation and less investment.

Although the model by AAZ is clearly a major contribution to our understanding of the growth-technology nexus the central agents of the model referred to as 'entrepreneurs' are drawn in a rather simplistic and uni-dimensional fashion, as their skills can only take two forms: high or low. All things being equal, the high skill entrepreneurs clearly dominate the low skill entrepreneurs with respect to productivity and it takes a gimmick, namely the assumption that insider entrepreneurs can undertake greater investments than newcomers, to justify that low skill entrepreneurs may be retained at all. Modern economic theories of entrepreneurship (Lazear (2004, 2005)) do, however, suggest that it is not the absolute level of (a unidimensional) skill but rather the balance between different skills that makes out an entrepreneur. So, to implement 'real' entrepreneurs into a growth context one has to endow them with at least two skills which may be thought of as being 'technological' and 'systemic or management' skills. Depending upon the relative skill advantage firms are either called technological or systemic specialists. As will become apparent during the course of the paper these skills differ with respect to their contribution to growth depending upon the relative distance of an economy to productivity at the world technology frontier. Note that although at an individual level the firms are specialists and hence exhibit 'unbalanced' skills, the situation may be different if one looks at an aggregate level. Then the distribution of the skills, which are unbalanced at an individual level, might well be balanced. It will especially become apparent that balanced vs. unbalanced skills at an aggregate level are one determinant that affects convergence to the world technology frontier but that there exist other influencing factors, especially productivity and skill differentials. We are able to show that this richer formulation of entrepreneurial skills does not only better reflect the role of entrepreneurship in a growing economy but also challenges some fundamental results (and policy conclusions) of the AAZ model.

The paper is organized as follows: After a brief review of the related literature (Section 2) we develop our conception of skills and their contribution to productivity at the individual (firm), national and international level (Section3). Section 4 introduces the main concepts of growth at the world technology frontier on the one hand and convergence to the world technology frontier on the other hand while Section 5 formalizes these concepts. They are then discussed in the subsequent Sections 6 (growth) and 7 (convergence). The paper closes with the policy implications and an outlook on future research.

2 Related literature

Our work draws on and combines two highly prominent but currently unrelated literatures: Schumpeterian growth theory (which mentions the entrepreneur but doesn't really model him/her) and Lazear's work on modelling entrepreneurship.

Nelson and Phelps (1966) were probably the first to fully recognize the importance of human capital investment for innovation and technological progress. Models of endogenous growth based solely on *innovation* were, inter alia, provided by Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt

(1992). These standard models have seen several extensions and refinements in recent years, e.g., Lloyd-Ellis and Roberts (2002). Standard references concerning growth and *convergence* include Barro and Sala-I-Martin (1997), Zeira (1998), Howitt (2000) and Howitt and Mayer (2002). The work on *entrepreneurship and growth* is relatively underdeveloped, although there are some exemptions (see for example King and Levine (1993), Audretsch and Thurik (2001) and Murphy et al. (1991)). A particularly interesting development in the personal economics and entrepreneurship literature is the recent work by Edward Lazear who argues that people with unbalanced skills (whom he calls specialists) tend to become employees whereas people with balanced skills (whom he calls generalists) tend to become entrepreneurs.

Our model is closest in spirit to the model by 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. We use this framework and adopt Lazears idea of skill balance, thereby transferring it also from the individual (firm) level to the aggregate (economy) level. This allows for a differentiated analysis of the interdependencies between investment, skills, the distribution of entrepreneurs among the economy on the one hand and growth and convergence on the other hand.

3 Skills and their contribution to productivity

As AAZ we assume a two sector economy composed of a perfectly competitive final product sector and an intermediate sector with imperfect competition. Entrepreneurs act in the intermediate sector and productivity of an individual entrepreneur at time t is given by

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

Here s_t is investment size, $\eta(i)$ and $\gamma(i)$ denote time invariant different skills, $\bar{A}$ reflects productivity at the world technology frontier (global knowledge), and A is the state of technology of a single country (local knowledge). For the representative economy we assume $A_t \leq \bar{A}_t$. Each entrepreneur in the intermediate sector is endowed with two types of skills:

- technological skills, denoted by $\eta(i)$, which reflect the technological and scientific knowledge of the entrepreneur. It is linked to the knowledge level at the world technology frontier, $\bar{A}_{t-1}$, and could be understood as cutting edge skills,

- systemic skills, denoted by $\gamma(i)$, which could be understood as being the entrepreneur's skills with respect to management activities, communication and/or networking. Then the reference point are local or national peculiarities, such as institutions, regional or societal embeddedness or national tastes and preferences.

Although production in the intermediate sector requires for all firms to possess competencies with respect to both technological and systemic skills, firms are heterogenous in the sense that they differ with respect to their skill endowment. To be more precise we assume two types of entrepreneurs with different individual productivities

$$A_t(i) = s_t[\bar{\eta}\bar{A}_{t-1} + \underline{\gamma}A_{t-1}] \tag{2a}$$

$$A_t(i) = s_t[\underline{\eta}\bar{A}_{t-1} + \bar{\gamma}A_{t-1}] \tag{2b}$$

where $\bar{\eta} > \underline{\eta}$ and $\bar{\gamma} > \underline{\gamma}$. Depending upon their comparative skill advantage the two types of entrepreneurs are called *technological specialists* (see (2a)) and *systemic specialists* (see (2b)). Ex ante it is unknown if entrepreneurs are either technological or systemic specialists but their competencies are revealed when they act for the first time. Young firms are assumed to be technological specialists with probability λ and systemic specialists with probability $1 - \lambda$.

Figure 1 illustrates the embedding of an individual entrepreneur in a national and in a world wide context in the following sense: The state of the representative economy at time *t* is given by the country's proximity to frontier which is defined as

$$a_t \equiv \frac{A_t}{\bar{A}_t} \tag{3}$$

and may be interpreted as reflecting the economic surrounding in which an individual entrepreneur is active. The relative position of an individual 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 an individual entrepreneur as function of the state of economic development in which the entrepreneur acts. The straight lines are derived by dividing (2) by

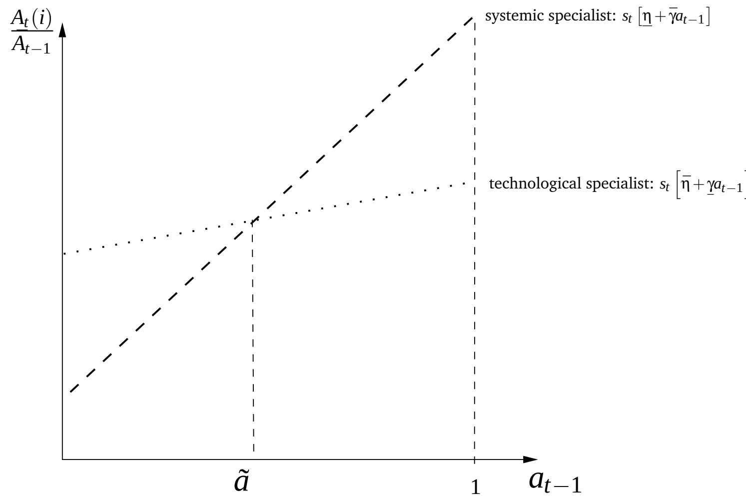


Figure 1: individual productivity of technological and systemic specialists and distance to frontier

$\bar{A}_{t-1}$. In case of identical investment, $s_o = s_y$, both graphs intersect at the state of development

$$a_{t-1} = \frac{\bar{\eta} - \underline{\eta}}{\bar{\gamma} - \underline{\gamma}} \quad \equiv \tilde{a} \tag{4}$$

It becomes apparent that, as long as $a_{t-1} < \tilde{a}$, technological specialists are more productive in the sense that they are closer to the WTF while systemic specialists are superior if the state of a development of a country exceeds $\tilde{a}$. We assume that productivity at the world technology frontier (from now on WTF) evolves according to

$$\bar{A}_t = \bar{A}_0(1+g)^t \tag{5}$$

So far the growth rate is exogenous but will be endogenized later in the paper via the choices of the capitalists.

4 Growth and convergence

The argumentation so far illustrates that the analysis deals with different levels of aggregation which interact and are linked to each other via different productivities: individual level - entrepreneurs ($A(i)$), national level - countries (A), technology frontier - world wide context ($\bar{A}$). The following coherences arise: entrepreneurs determine average productivity of a country $\left(\int_0^1 A_t(i)di = A_t\right)$ while productivity at the WTF is determined by the most productive country, i. e. $\bar{A}_t = \{\arg\max A_t\}$.

In such a surrounding growth can be considered from two perspectives: On the one hand growth of average productivity of a single country (which then affects the catch-up process (and hence convergence) of that country to the WTF) while on the other hand this catching-up process may lead back to productivity of the WTF. Note that catching up is essentially driven by several factors, among them the prevailing state of development of the considered country which, due to the interdependencies, feeds back to growth at the WTF.[1] As will become apparent below other influencing factors are the shares of the respective types of specialists, λ and $1-\lambda$, as well as the absolute levels of technological and systemic skills, $\eta(i)$ and $\gamma(i)$, and their respective differentials, $\bar{\eta}-\underline{\eta}$ and $\bar{\gamma}-\underline{\gamma}$. Due to the interdependencies between the various levels of aggregation, and since the analysis is carried out in a dynamic context, one also has to distinguish between the *short and/or intermediate run*, which primarily focusses on the catch-up process of a single country that considers productivity at the WTF, g, as exogenous and constant, and the *long run* which includes all feedback effects that arise due to the interdependencies at the various levels of aggregation and hence also for changes of g.

The growth rate of aggregate technology of a single country is given by

$$\frac{A_t}{A_{t-1}} = \frac{\int_0^1 A_t(i)}{A_{t-1}} = \int_0^1 s_t \left[\eta(i)\frac{\bar{A}_{t-1}}{A_{t-1}} + \gamma(i)\right] di \tag{6}$$

As long as a country is far away from the world technology frontier (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. Hence technological skills are the major force that drive growth of national productivity and with this convergence to the world technology frontier. Note that, all things being equal, the growth rate of national productivity declines while catching up. Formally, as a country converges to the WTF, $\bar{A}$, technological skills become relatively less important, and in contrast, now systemic skills are more important for catching up.[2]

A more precise analysis requires a closer look not only on the individual skills but also on their distribution across the economy, i. e. the respective shares of the

[1]Hence we can think of catching-up in the sense of the so called $(\beta-)$convergence.

[2]This can e. g. be motivated by the fact that productivity at the WTF is extended in the sense of recombining already existing innovations.

heterogenous entrepreneurs. At an individual level there are either technological or systemic specialists. However, this does not automatically imply an unbalanced skill distribution at the aggregate level. On the contrary, whether or not skills at an aggregate level are balanced is affected by the prevailing shares, λ, on the one hand, and the above mentioned skill differentials on the other hand.

5 Selection and profit maximizing strategies

We now analyze how the process of growth and convergence takes place given the individual productivities as captured within (2) and their respective distributions λ and $1-\lambda$ for a given country. Entrepreneurs are engaged by a capitalist who in each period decides whether to produce with an old team of entrepreneurs – whose skills are already revealed – or to terminate collaboration with those being less productive. As already argued in the context of (2) and illustrated in Figure 1, given identical investment sizes of old and young firms, systemic skills are more important the closer a country approximates the WTF. Hence in the course of catching-up termination refers to selection of technological specialists and to their replacement by young firms. The latter are technological specialists again with probability λ, and systemic specialists with probability $1-\lambda$. As AAZ we assume that young and old firms perform different project sizes, s_o and s_y.

Capitalists choose the strategy that maximizes profits in the intermediate product sector and thereby have to compare (i) well known profits in case of collaboration with a known team of entrepreneurs with already revealed skills, and (ii) expected profits in case that they replace technological specialists by young entrepreneurs whose skills are still unknown. Due to different investment sizes, old and young firms differ with respect to their productivities (see (1)). Given the individual productivities in (2) and their respective economy wide distribution, average productivity among young entrepreneurs is then given by

$$A_t^y = s_y \left[\left(\lambda\bar{\eta} + (1-\lambda)\underline{\eta}\right) \bar{A}_{t-1} + \left(\lambda\underline{\gamma} + (1-\lambda)\bar{\gamma}\right) A_{t-1} \right] \tag{7}$$

In contrast to this, productivity of old firms depends upon the retention decision of the capitalist. If capitalists retain all firms of the anteceding period, average productivity of old firms is the same as in (7) with the sole difference that old entrepreneurs realize another project size, namely s_o. Hence, given the retention decision ($R=1$) average productivity among old firms is

$$A_t^o[R=1] = s_o\left[\left(\lambda\bar{\eta}+(1-\lambda)\underline{\eta}\right)\bar{A}_{t-1}+\left(\lambda\underline{\gamma}+(1-\lambda)\bar{\gamma}\right)A_{t-1}\right] \tag{8}$$

If instead capitalists decide to terminate collaboration with relatively unproductive entrepreneurs their fraction λ will be replaced by young entrepreneurs (and hence all things being equal with technological specialists) and average productivity then amounts to

$$\begin{aligned} A_t^o[R=0] \quad &= \quad \left[s_o(1-\lambda)\underline{\eta}+s_y\lambda\left(\lambda\bar{\eta}+(1-\lambda)\underline{\eta}\right)\right]\bar{A}_{t-1} \\ &\quad + \left[s_o(1-\lambda)\bar{\gamma}+s_y\lambda\left(\lambda\underline{\gamma}+(1-\lambda)\bar{\gamma}\right)\right]A_{t-1} \end{aligned} \tag{9}$$

Given that half the entrepreneurs are old and half are young, aggregate productivity in the economy results as

$$A_t \equiv \int_0^1 A_t(i)di = \frac{1}{2}\left[A_t^y + A_t^o\right] \tag{10}$$

with average productivities of old and young firms corresponding to (7), (8) and (9). Consequently, average productivity is not only affected by entrepreneurial distribution (they are technological specialists with probability λ and systemic specialists with probability $1-\lambda$) and their respective skill levels but also by the capitalist's retention and termination strategies, $R=0$ and $R=1$.[3]

Merging all these factors provides the dynamic equilibrium of a considered economy. Formally spoken it describes how the distance to frontier of a selected country, a_t, evolves depending upon an initial state, a_{t-1}. We therefore determine the law of motion of a_t as a function of a_{t-1} conditional on the retention decision $R_t=\{0,1\}$. This may be derived by combining A_t^o, A_t^y and a_t and using the fact that $\bar{A}_t$ grows at the rate g (see (5)). At first this growth rate is assumed to be exogenous but in the next section it will be endogenized thereby reflecting growth of aggregate productivity of the country that defines the WTF. Hence the equation of motion depending upon the retention decision evolves according to

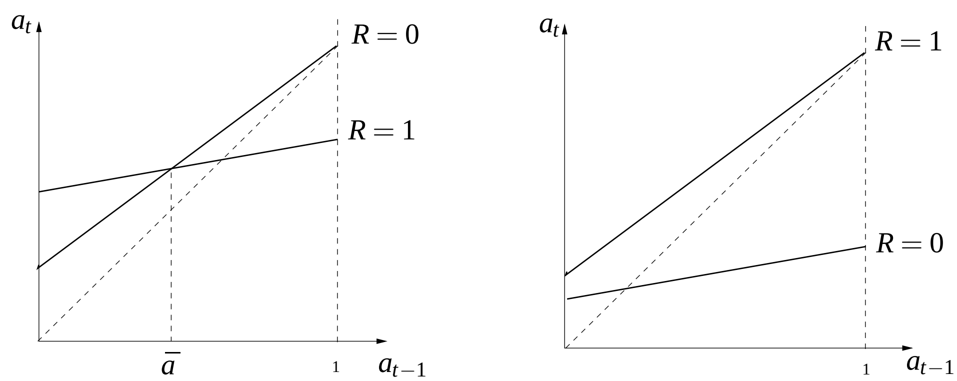
$$a_t = \begin{cases} \frac{s_o+s_y}{2(1+g)}\left[\lambda\bar{\eta}+(1-\lambda)\underline{\eta}+\{\lambda\underline{\gamma}+(1-\lambda)\bar{\gamma}\}a_{t-1}\right] & \text{if} \quad \text{R=1;} \\ \\ \frac{1}{2(1+g)}\left[s_o(1-\lambda)\underline{\eta}+(s_y+s_y\lambda)(\lambda\bar{\eta}+(1-\lambda)\underline{\eta})\right. & \\ \qquad \left.+\{s_o(1-\lambda)\bar{\gamma}+(s_y+s_y\lambda)(\lambda\underline{\gamma}+(1-\lambda)\bar{\gamma})\}a_{t-1}\right] & \text{if} \quad \text{R=0.} \end{cases} \tag{11}$$

[3]A detailed analysis of the derivation of both termination and retention decision can be found in Acemoglu et al. (2006).

Both functions are linear and intersect at a certain level of technology development

$$a_{t-1} = \frac{(\bar{\eta} - \underline{\eta}) s_y (1-\lambda) + \bar{\eta}(s_o - s_y)}{(\bar{\gamma} - \underline{\gamma}) s_y (1-\lambda) - \underline{\gamma}(s_o - s_y)} \quad \equiv \bar{a} \tag{12}$$

As long as $a_{t-1} < \bar{a}$, the function $R = 1$ lies above $R = 0$. The numerator in (12) is always positive while the sign of the denominator is indetermined.[4] Hence the value of $\bar{a}$ may be either positive or negative. This is the immediate consequence of the fact that, all things being equal, neither specialist dominates productivity of the other for all levels of the distance to frontier.[5] As a consequence of these productivity differences two cases have to be distinguished. Figure 2 depicts the corresponding equilibrium dynamics. As (11) shows, equilibrium dynamics are given by a piecewise linear first-order difference equation.



(a) $(1-\lambda)s_y(\bar{\gamma} - \underline{\gamma}) > \underline{\gamma}(s_o - s_y)$ termination

(b) $(1-\lambda)s_y(\bar{\gamma} - \underline{\gamma}) < \underline{\gamma}(s_o - s_y)$ retention

Figure 2: Technological and systemic specialists

Both Figures 2(a) and 2(b) incorporate the interaction between (i) the systemic skill differential $(\bar{\gamma} - \underline{\gamma})$ which incorporates the comparative advantage of the systemic specialist, (ii) the investment differential $(s_0 - s_y)$ which provides an advantage to old firms that is due to the higher investment size of old firms and (iii) the share of systemic specialists, $1 - \lambda$.[6]

[4] Note that $\bar{a} = \tilde{a}$ as given by (4) if we assume identical investments of old and young entrepreneurs, $s_o = s_y$, in (12).

[5] This is a major difference to the model of AAZ in which for identical investment of young and old entrepreneurs the high-level entrepreneur always dominates productivity of the low-level entrepreneur.

[6] Note that although the distinction between the two cases in Figure 2 is driven by investment

It is plausible to argue that in case of a high productivity differential the termination strategy ($R = 0$) determines growth at the WTF (see Figure 2(a)). If instead the skill differential is not very extent but credit market imperfections imply a high investment advantage for old firms, then retention maximizes growth at the WTF (see Figure 2(b)).

Note that the retention decision provides an explanation for why different strategies maximize growth at the world technology frontier and why depending upon the specific situation of a country a switch of the strategy might be necessary in order to converge to the frontier. If the current collaboration between capitalists and entrepreneurs is terminated ($R = 0$) then the composition of the entrepreneurs changes and at the end relatively more systemic specialists will prevail.[7]

Let's dig a bit more in the economic implications of these results: If termination is the growth maximizing strategy then, from the point of view of a profit maximizing capitalists, it is worth to change the composition of the firms within the course of convergence. This is the case of a relatively high systemic skill differential, $\overline{\gamma} - \underline{\gamma}$, or put differently, in case of an extent comparative advantage of the systemic specialists. This effect is reinforced with increasing s_y because high investment sizes of young firms reduce the investment advantage of old firms. If then also the share of systemic specialists, $1 - \lambda$, is relatively high, termination of technological specialists implies that the new composition of entrepreneurs will be strongly dominated by systemic specialists. All these arguments make termination of technological specialists a valuable strategy and Figure 2(b) applies.

Two forces work in the opposite direction, namely the investment differential, $s_o - s_y$, which shields old firms against competition of young firms, and the level of $\underline{\gamma}$. If the latter is relatively high this reduces the productivity advantage $\overline{\gamma} - \underline{\gamma}$ of systemic specialists and makes termination less probable.[8]

and systemic skill differentials, the technological skill differential also is important. It affects the run of the graphs via the level of the vertical intercepts.

[7]Note also that Figure 2(a) is depicted for a world in which the termination strategy ($R = 0$ and hence selection of technological specialists) maximizes growth of the WTF with $\bar{a}$ being positive while, in contrast, the retention strategy ($R = 1$) does so within Figure 2(b) and the term $\bar{a}$ is negative.

[8]Note that in case of $\underline{\gamma} \rightarrow 0$ or for identical investment sizes of old and young firms, $s_o = s_y$, the systemic skill differential always dominates. Then the considered economy is depicted by Figure 2(a)

6 Growth at the world technology frontier

As argued before one has to distinguish different levels of aggregation: individual - national - world wide. We now consider growth of productivity at the world technology frontier, g, and analyze factors that affect its level and its variation. This is an important issue since in the analysis of convergence has to be precise about the situation to which an economy converges. The parameter g could also be interpreted as being of interest for supranational institutions that analyze the interdependencies and feedback effects between national economies and the rest of the world. Due to the interdependencies between individual productivity, $A_t(i)$, productivity of a single country, A_t, and world wide productivity, $\bar{A}_t$, productivity at the WTF is determined by the most productive country. At the same time this productivity is not static but is assumed to grow with rate g (see (5)).

This growth rate may be endogenized by evaluation of (11) at the WTF, $a_t = a_{t-1} = 1$, and solving for g. For the strategies retention and termination then the following growth rates result

$$g[R=1] = \frac{s_o + s_y}{2}\left[\lambda(\bar{\eta}+\underline{\gamma}) + (1-\lambda)(\underline{\eta}+\bar{\gamma})\right] - 1 \tag{13a}$$

$$\begin{aligned} g[R=0] =& \frac{1}{2}\left[s_o(1-\lambda)(\underline{\eta}+\bar{\gamma})\right. \\ &\left. +(s_y+s_y\lambda)\left(\lambda(\bar{\eta}+\underline{\gamma})+(1-\lambda)(\underline{\eta}+\bar{\gamma})\right)\right] - 1 \end{aligned} \tag{13b}$$

They describe aggregate productivity growth of the country that defines the WTF. Both growth rates are affected by investment, skills (absolute level and differentials) and the distribution of entrepreneurs. The further discussion is twofold: First we analyze the impact of alternative determinants on the absolute level of g for both strategies. We then proceed with a sensitivity analysis of g with respect to investment size, skill differentials, and entrepreneurial composition. The policy implications of these results will be discussed in Sectio 8.

Determinants of the absolute level: Both growth rates in (13) differ with respect to their absolute level, and

$$g[R=1] \gtrless g[R=0] \quad \Longleftrightarrow \quad (s_o - \lambda s_y)(\bar{\eta}+\underline{\gamma}) \gtrless s_y(1-\lambda)(\underline{\eta}+\bar{\gamma}) \tag{14}$$

From (14) the following cases might be distinguished:

(i) If there is no investment advantage of old firms (i. e. if $s_o = s_y$) the growth maximizing strategy is only driven by the dominating skill differential. Retaining technological specialists maximizes growth if the technological skill differential dominates, i. e. $\overline{\eta}-\underline{\eta}>\overline{\gamma}-\underline{\gamma}$. If this is not the case higher growth rates would be achieved by the termination strategy.

(ii) In case of an investment advantage of old firms (i. e. if $s_o > s_y$) the situation becomes more complex. Since a positive investment differential is advantageous for old entrepreneurs, retention basically fosters growth. To derive the total effect additionally the two skill differentials become important: If the technological skill differential exceeds the systemic skill differential, retention even more is growth maximizing. However, the result becomes ambiguous if the systemic skill differential dominates. Then contrary effects are at work and termination maximizes growth only if the systemic skill advantage is so pronounced that it offsets both technological skill differential and the investment advantage in case of old firms and retention. Otherwise, again retention ends up in a higher growth rate at the WTF.

Proposition 1 *growth maximizing strategies at the WTF*

1. *if $s_o = s_y$ (no investment differential) the dominating skill differential determines the growth maximizing strategy.*

2. *if $s_o > s_y$ (investment advantage of old firms) retention maximizes growth if the technological skill differential dominates. In case of a dominating systemic skill differential the termination strategy only maximizes growth if the skill advantage is so pronounced that it offsets the advantage resulting from both investment and technological skill differential.*

3. *There are cases (described before) in which replacement of technological specialists by systemic specialists maximizes growth at the WTF. Consequently sole reliance on technological innovation is not always growth maximizing at the WTF.*

Sensitivity analysis: Aside from the sole consideration of the absolute levels of the growth rates also the impacts of the determinants of the growth rate gain importance. In order to analyze this, sensitivity analysis of (13) will be carried out with respect to the determinants discussed above, namely investment, skill differentials and the composition of the entrepreneurs for both strategies. Table 1 summarizes the relationships with $\overline{\lambda}$ as given by (15).

Table 1: Sensitivity of growth according to (13)

	$\partial g[R=1]$	$\partial g[R=0]$
∂s_o, ∂s_y	$+$	$+$
$\partial\overline{\eta}$, $\partial\underline{\eta}$	$+$	$+$
$\partial\overline{\gamma}$, $\partial\underline{\gamma}$	$+$	$+$
$\partial\lambda$	$\gtreqless 0 \Leftrightarrow \overline{\eta}-\underline{\eta} \gtreqless \overline{\gamma}-\underline{\gamma}$	$\gtreqless 0 \Leftrightarrow \lambda \gtreqless \overline{\lambda}$
$\partial\overline{\eta}-\underline{\eta}$, $\partial\overline{\gamma}-\underline{\gamma}$	$\gtreqless 0$	$\gtreqless 0$

$R=1$: In case of retention the growth rate (13a) increases with investment, s_o and s_y, and the absolute skill levels, $\overline{\eta},\underline{\eta},\overline{\gamma}$ and $\underline{\gamma}$. Both higher investment and better skills unequivocally foster growth. Increasing the share of technological specialists leads to higher growth only if these specialists are more productive, i. e. if the technological skill differential dominates the systemic skill differential, or put differently, if technological skills are less balanced than the systemic skills among the two types of entrepreneurs. Otherwise the growth rate declines with rising share of technological specialists, λ. The impact of changes in the skill differentials, however, depends upon how these changes are implemented. The reason therefore is that the growth rate unequivocally increases with any skill level whereas skill differentials may either increase with increasing upper boundaries or decreasing lower boundaries. Increasing the skill differential only enhances growth in case of higher upper boundaries whereas increasing the skill differential via reducing the lower boundaries reduces growth.

$R=0$: Again the results are more complex considering the termination strategy. As before, the growth rate (13b) unequivocally increases with investment and skills. With respect to changes in the skill differential the same argumentation as discussed in case of the retention strategy applies. The sole difference consists in the sensitivity analysis with respect to λ which now leads to a threshold value $\overline{\lambda}$ that is a function of investment and skill differentials. Differentiating (13b) with respect to λ provides

$$\frac{\partial g[R=0]}{\partial\lambda} \gtreqless 0 \quad \Longleftrightarrow \quad \lambda \gtreqless \frac{s_o\left(\underline{\eta}+\overline{\gamma}\right)-s_y\left(\overline{\eta}+\underline{\gamma}\right)}{2s_y\left((\overline{\eta}-\underline{\eta})-(\overline{\gamma}-\underline{\gamma})\right)} \quad \equiv \overline{\lambda} \tag{15}$$

The sign of this threshold is basically undetermined and it may represent either a maximum or a minimum of the growth rate (13b). Note that reasonable/sensible values of $\overline{\lambda}$ are limited to the interval $\overline{\lambda} \in (0,1)$ and hence that $\overline{\lambda} < 0$ or $\overline{\lambda} > 1$

are economically not relevant but lead back to the corner solutions $\lambda = 0$ or $\lambda = 1$. In the main text we only discuss the most interesting case of a threshold level $\bar{\lambda} \in (0,1)$ in which case $\bar{\lambda}$ corresponds to a minimum of the growth rate.[9] The intuition for this result is as follows: A positive numerator implies that old systemic specialists are more productive than young technological specialists. However, in case of a positive denominator the technological skill differential dominates and hence technological specialists are more productive than systemic specialists. As long as older firms realize bigger projects in conjunction with more productive systemic specialists, increasing the share of technological specialists reduces growth. In contrast to this works the dominating technological skill differential which increases the growth rate with the share of technological specialists. In case of an initially low share of technological specialists, the first force dominates and the growth rate declines. Both forces are equilibrated for an intermediate level of $\lambda = \bar{\lambda}$ while further increases finally speed up growth.

Proposition 2 *Sensitivity of growth according to* (13)

1. *Both growth rates g increase with investment of either old or young firms as well as with the absolute skill levels of technological and systemic entrepreneurs.*

2. *Increasing the skill differential leads only to higher growth if the upper skill boundaries are increased. If instead a higher skill differential is due to reduced lower skill boundaries, the growth rate declines.*

3. *$R = 1$: In case of retention the growth rate* (13a) *increasing the share of technological specialists, λ, increases growth only if the technological skill differential dominates the systemic skill differential. Otherwise the growth rate declines.*

4. *$R = 0$: The growth rate* (13b) *has a minimum for an intermediate share of technological specialists, $\bar{\lambda}$, as given by* (15). *Due to parameter restrictions this result may only be derived given that the technological skill differential dominates the systemic skill differential and if at the same time old systemic specialists invest more than young technological specialists. Two contrary effects are at work: on the one hand the investment advantage of old systemic specialists implies that increasing an initially small share of technological specialists, λ, reduces the growth rate. On the other hand, after having passed the*

[9] A detailed analysis of all possible parameter constellations is relegated to Appendix A.

mentioned threshold value the dominance of the technological skill differential increases the growth rate with the share of technological specialists.

7 Convergence

So far we have focussed on growth of the country determining productivity at WTF. However, from the point of view of any single country or a national policy maker the central issue is mostly not growth at the WTF but catching up thereby considering the growth rate g as exogenous parameter. Due to the interdependencies of the several levels of aggregation (individual - national - world wide) one hast to be clear about the existing feedback effects between these levels. In this context also the dynamic frame of the model has to be taken into account. However, from the point of view of any single country convergence to the WTF implies that a_t increases for all given states of development as long as $a_{t-1} < 1$. An important issue in this context is to take a look at how the distance to frontier is reduced or put differently, analyzing the impact of those determinants that affect the resulting level of a_t for a given level a_{t-1}.

As already argued we analyze the catch up process of a single country that considers g as exogenous and constant. Due to the interdependencies between the levels of aggregation this assumption is only valid in the short and intermediate run. In the long run, however, a national policy to foster convergence and hence catching up to the WTF could have the following consequences: On the one hand it would finally lead to a leap-frogging of the catching-up country in the sense that it firstly converges to the WTF and then even passes it thereby becoming the leading country that determines productivity at the WTF. On the other hand it is not per se clear whether a unilateral convergence policy can be realized without inducing reactions of other countries that intend copying the successful policy. But then, due to the resulting feedback effects, the convergence process of the initially considered country will be affected via feedback effects of changes of g. These latter arguments apply in the long run while the following considerations will be done in the context of the short and intermediate run.

Taking a look at Figures 2 it becomes immediately apparent that national growth promoting strategies in the sense of maximizing a_t for any given level of a_{t-1} are determined by the upper envelope of the two strategies. Hence in case of termination (see Figure 2(a)) a growth maximizing country should begin with retaining old firms until the state of development as indicated by $\bar{a}$ is reached and should then switch to the termination strategy. However, in Figure 2(b) retention is the growth maximizing strategy independent of the state of development.

The impact of alternative policies might be analyzed via carrying out sensitivity analysis of (11). Again we lay special attention on investment, the share of technological specialists and the skill differentials. Reference point is (11) and Table 2 summarizes the results.

Table 2: Sensitivity of the speed of convergence according to (11)

	$\partial a_t[R=1]$	$\partial a_t[R=0]$
∂s_o, ∂s_y	+	+
$\partial\bar{\eta}$, $\partial\underline{\eta}$	+	+
$\partial\bar{\gamma}$, $\partial\underline{\gamma}$	+	+
∂g	-	-
$\partial\lambda$	$\gtreqless 0 \Leftrightarrow a_{t-1} \lesseqgtr \tilde{a}$	$\gtreqless 0 \Leftrightarrow a_{t-1} \lesseqgtr \tilde{\tilde{a}}$
$\partial\bar{\eta}-\underline{\eta}$	$\gtreqless 0$	$\gtreqless 0$
$\partial\bar{\gamma}-\underline{\gamma}$	$\gtreqless 0$	$\gtreqless 0$

Independent of the chosen strategy and all things being equal, the state of development, a_t, increases with investment and the absolute levels of any skill. However, in the short run a_t decreases with g (thereby neglecting the feedback effects induced by changes of the other structural parameters). Increasing the share of technological specialists has ambiguous effects and depends upon the state of development as indicated by $\tilde{a}$ according to (4) and $\tilde{\tilde{a}}$ given by

$$\tilde{\tilde{a}} \equiv \frac{s_y(1+2\lambda)(\bar{\eta}-\underline{\eta})-(s_o-s_y)\underline{\eta}}{(s_o-s_y)\bar{\gamma}+s_y(1+2\lambda)(\bar{\gamma}-\underline{\gamma})} \tag{16}$$

Hence with respect to investment, absolute skill levels and skill differentials the same argumentation as carried out as in the last section. However, two results are different: (i) The level of the growth rate g negatively affects catching up of any single country. This is quite intuitive since for a single country it is easier to converge to the WTF the slower the latter grows. (ii) The impact of increasing the share of technological specialists now depends upon the state of development which in case of retention only depends upon the ratio of the skill differentials while in case of termination also investment and the prevailing level of λ is important.

$R = 1$: Provided that $\tilde{a} \leq 1$ implies that at the WTF technological specialists are less productive than systemic specialists. Then the speed of convergence increases with the share of technological specialists only if the actual state of development is smaller than $\tilde{a}$ whereas the speed of convergence decreases with λ if the state of development exceeds $\tilde{a}$. The reason for the latter relationship is the renouncement of productivity advantages of systemic specialists.

$R = 0$: In case of termination the results again become a bit more complex. Given identical investment of old and young firms the same result and argumentation as in case of $R = 1$ applies. If in contrast old firms possess an investment advantage the corresponding implications have to be considered as well. Then the speed of convergence increases with λ only if the investment advantage plus the productivity advantage are dominated by terminating collaboration with the technological specialists.

Proposition 3 *Sensitivity analysis of the speed of convergence according to* (11)

1. *The speed of convergence increase with investment of either old or young firms as well as with the absolute skill levels of technological and systemic entrepreneurs.*

2. *Increasing the skill differential leads only to quicker catching up if the upper skill boundaries are increased. If instead a higher skill differential is due to reduced lower skill boundaries, the speed of convergence rate declines.*

3. $R = 1$*: In case of retention the speed of convergence is affected by a country's state of development. If the latter falls below a threshold value, denoted by* $\tilde{a}$ *in* (4)*, the speed of convergence increases with* λ*. Otherwise the growth rate declines.*

4. $R = 0$*: In case of termination the interdependencies between speed of convergence and share of technological specialists again depend upon the prevailing state of development. The corresponding threshold value* $\tilde{\tilde{a}}$ *in* (16) *is a function of* λ *and investment sizes. If the state of development falls below the threshold value* $\tilde{\tilde{a}}$*, the speed of convergence increases with* λ*. Otherwise the speed of convergence declines.*

8 Policy implications and outlook

Our analysis has extended existing Schumpeterian growth models in several respects. In particular, entrepreneurs in our model are not restricted to a single skill but dispose of different skills which we call either technological and systemic. The first integrate pure technological knowledge while the latter could be interpreted either as management skills, knowledge of national innovation systems, or societal embeddedness of a firm and its products. In the context of innovation models it is plausible to assume that all entrepreneurs are endowed with both skills but that the entrepreneurs differ with respect to their absolute skill endowments thereby allowing for different types of entrepreneurs. The different skills are linked to different stocks of knowledge (knowledge at the world technology frontier and national/local knowledge) thereby considering the fact that growth does not only depend on the distance of a country to the world technology frontier but also on country-specific (e. g. institutions) and region-specific factors. 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.

The argumentation throughout the paper is twofold: We first analyze the growth rates of productivity at the WTF for alternative profit-maximizing strategies, namely retention and termination. Then those factors are considered that affect catching-up of a single country to the frontier. A central result of our analysis is that it is not only the absolute skill level but also the aggregate distribution of different skills that drives growth and convergence of an economy towards the world technology frontier. Technological skills are the scarce factor and drive growth of economies that are (relatively) far away from the world technology frontier. The closer the economy approaches the world technology frontier the higher becomes the relative importance of skill balance and systemic skills (i.e. skills that are not directly linked to the knowledge at the world technology frontier). We do, of course, not deny the importance of innovation for long run growth, but we argue that sole reliance on technological innovation is not necessarily a dominant strategy when countries get very close to the world technology frontier. Systemic skills, institutions, regional embeddedness, etc. (i.e. factors that are country or region specific and not ubiquitously available) become particularly important when a firm very close to the WTF competes with others that have similar technological standards.

Our analysis offers various starting points for policy. Take *start-up promotion policies* as an example. A policy that provides easy credit finance to nascent entrepreneurs tends to increase the project size of young entrepreneurs and decrease - all things being equal - the difference in project size between old and young entrepreneurs. This has the following effects: (i) It makes replacement of old entrepreneurs by young entrepreneurs more likely (i.e. selection becomes more attractive in relative terms), (ii) it enhances productivity and growth in the respective country, and (iii) it speeds up convergence of the country under consideration with the WTF. Another point of reference is *education policy*: If a country invests (substantially) more in the education of technicians or natural scientists than in the education of systemic specialists this leads to a (macroeconomic) skill bias towards technological skills, i.e. the fraction of technological specialists becomes larger than the fraction of systemic specialists. By contrast, if a country invests (substantially) more in the education of systemic specialists than in the education of technicians/natural scientists the result will be a lower share of technological specialists and hence a skill bias towards systemic skills. A macroeconomic skill balance (identical shares of both types of specialists) will only result if investment in the education of technicians/natural scientists and in the education of systemic specialists is by-and-large balanced. Moreover, a country may follow a strategy of supporting in particular the most advanced and gifted students (regardless of their discipline) or to focus on mass education. The first strategy (focus on elite education) tends to increase either skill differential whereas a focus on mass education has the opposite effect. Thus, education policy offers a wide array of opportunities to affect macroeconomic growth and convergence which we intend to analyze in a follow-up paper.

Mathematical appendix

A Analysis of (15)

Table 3 summarizes which level of $\bar{\lambda}$ results provided different economic environments. There the notion 'Max' ('Min') corresponds to a level $\bar{\lambda}$ that maximizes (minimizes) the growth rate (13b).

The first two columns indicate the signs of numerator and denominator. If they differ the threshold value $\bar{\lambda}$ is negative thereby reflecting either a minimum or a

Table 3: Analysis of (15)

Numerator	Denominator	$s_o = s_y$	$s_o > s_y$	$s_o < s_y$
+	+	- - -	$\bar{\lambda} > 0$, Min	- - -
+	-	$\bar{\lambda} = -\frac{1}{2}$, Max.	$\bar{\lambda} < 0$, Max	$\bar{\lambda} < 0$, Max
-	+	$\bar{\lambda} = -\frac{1}{2}$, Min.	$\bar{\lambda} < 0$, Min	$\bar{\lambda} < 0$, Min
-	-	- - -	- - -	$\bar{\lambda} > 0$, Max

maximum. This can be seen in the 2nd and 3rd row. Those parameter constellations that contradict each other are indicated by dashes. To give one example: if $s_o > s_y$ it is not possible that both numerator and denominator are negative. A negative denominator implies $\bar{\eta} - \underline{\eta} < \bar{\gamma} - \underline{\gamma} \Rightarrow \bar{\eta} + \underline{\gamma} < \bar{\gamma} + \underline{\eta}$. But then the numerator obligatorily is positive.

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