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Heterogenous skills, growth and convergence

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ABSTRACT

This paper analyzes the impact of different individual skills and their economy-wide distribution among heterogenous entrepreneurs on a country's catching up-process to the world technology frontier (WTF). Highly skilled entrepreneurs qualify as either technological specialists or as broadly skilled systemic entrepreneurs. Governmental policy may address individual skills or the aggregate composition of skills in society and may be interpreted as education policy. The effectiveness of alternative growth-promoting policies is shown to depend on the relationship between a country's state of development and the prevailing composition of entrepreneurs. Countries far from the WTF benefit from increasing the share of technological specialists, whereas countries close to the WTF benefit from increasing the share of broadly skilled systemic entrepreneurs.

1. Introduction

The particular appeal of recent models of Schumpeterian growth 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 (henceforth WTF). 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 WTF, governmental policy should support the switch towards an innovation-based strategy, younger firms and more selection (see Acemoglu et al. (2006) or Acemoglu (2009)).

While this literature has substantially improved our understanding of the mechanisms underlying long-term economic growth, it provides no convincing explanation for recent developments in the relative growth performance of the world's technologically most advanced economies, namely the US and Europe. 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 WTF (Aghion and Howitt, 2006). In fact, recent statistics on the number and growth rate of triadic patents per capita (OECD, 2008) and the number of scientific articles per million population (National Science Board, 2012) indicate that European countries have come very close to the WTF which is defined by the US as

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Table 1
Long-term labor productivity growth in Europe and the US (GDP per hour, annual average, percent).

	USA	Euro Area	France	GER	Italy	Spain	UK
1995–2005	2.4	1.4	1.8	1.6	0.5	0.5	2.2
2005–2009	1.5	0.5	0.8	0.2	−0.8	2.0	0.9

Source: The Conference Board Total Economy Database, January 2010 and January 2013.

the world's technologically leading country (see Benhabib and Spiegel (2005)), and in some cases even surpassed the US. However, this impressive technological catch-up has not translated into higher growth rates. By contrast, the average annual growth rate of real GDP in the period 1995–2009 was much higher for the US than for the EU (The Conference Board, 2010, 13). Moreover, annual labor productivity growth (in terms of GDP per hour worked) in the US accelerated from 1.2 percent in the 1973–1995 period to 2.3 percent from 1995 to 2006, whereas the EU-15 countries experienced a rapid productivity growth decline between these two time periods (see Krueger and Kumar (2004) and van Ark et al. (2008)).[1] Hence, it is quite obvious that growth (and convergence with the world's leading country) requires more than scientific and technological excellence, in particular for advanced industrialized countries that are already quite close to the WTF. This is, however, not adequately reflected in the theoretical literature as yet.

While current models of Schumpeterian growth theory suggest that growth in the most advanced industrialized countries is mainly technology-driven, the current paper offers a richer explanation of growth in countries close to the WTF by considering two different skills – denoted as systemic skills and technological skills – and by showing that when a country approaches the WTF systemic skills become relatively more important than technological skills. While surprising at first glance, the principal result is perfectly in line with recent empirical evidence on the growth performance of Europe relative to the US, and adds considerable value to the understanding of cross-country differences in innovation-driven growth performance.

The paper is organized as follows: Section 2 provides the empirical and theoretical motivation for a new growth model considering entrepreneurs with heterogenous skills, briefly reviews the related literature and lays out how the current paper fits in and adds value to the existing literature. Section 3 presents the basic model setup, whereas our innovative conception of heterogenous skills and their contribution to productivity at the individual (firm), national, and international level is developed in Section 4. Section 5 deals with the selection of entrepreneurs and the corresponding productivity implications in a static and a dynamic equilibrium context. Section 6 analyzes the impact of individual skills and their overall distribution on the speed of convergence and discusses the corresponding policy implications with a focus on education policy measures. Section 7 provides a summary of the main results and concludes.

[1] Note that also in the period 2005-2009 US labor productivity growth was clearly higher than labor productivity growth in Europe (The Conference Board, 2010, 13).

2. Motivation

2.1. Skills and growth: empirical background

Current models of Schumpeterian growth suggest that growth in the most advanced industrialized countries is mainly technology-driven. However, differences in scientific and technological excellence alone cannot explain differences in the relative growth performance of countries close to the WTF. While there can be little doubt that Europe has caught up with the US in terms of scientific and technological excellence (Aghion and Howitt, 2006; OECD, 2008; National Science Board, 2012), Europe as a whole as well as the major European economies have seen a rather poor growth performance relative to the US since the mid-1990s, as can be seen from Table 1.

So, while the technology gap between the US and Europe has been narrowing, the growth/productivity gap has not – a phenomenon that can hardly be explained by referring to standard Schumpeterian growth theory. Recent empirical work by (van Ark et al., 2008, 42) suggests that the (actually even) widening of the productivity gap between the US and Europe is not carried by technological differences but largely attributable to slower multi-factor productivity growth in market services, which depend less on technological skills and frontier technologies than on the capability to closely interact with customers and consumers, i.e. on skills and competencies that are embedded in national and local cultures and institutions. We call this latter kind of skills *systemic skills* to reflect the systemic character and the embeddedness of modern production processes.

These empirical findings suggest that growth in modern, industrialized economies might depend less on technological skills linked to the WTF than on systemic skills linked to a national or local frontier. Such an argument does, however, not only hold for modern market services but also – and in particular – for knowledge-based and high tech industries such as IT, multimedia or commercial biotech. In these industries, a high level of technological skills is necessary to enter the market and, therefore, many start-ups in these sectors are founded by scientists or technological specialists. However, once the young firms have survived the start-up phase and are entering the growth phase other, non-technical skills (which we call systemic skills) become increasingly important.

The importance of general non-technical skills and the consequences of a lack of such skills in society are well documented for the case of commercial biotechnology in Europe. As commercial biotech is held to be a key technology of the 21st century, European governments have invested large amounts of money to push basic and applied research as well as firm-start-ups in biotech. European biotech clusters such as Cambridge (UK), Oxford, Munich or Lund have established a reputation as centers of world class research and Europe has seen a rapid increase in the number of newly established dedicated biotech firms since the 1990s (see, for instance, Cooke (2007), Dohse (2007), and Ernst and Young (2013)). Europe's scientific and technological excellence in modern biotech has, however, not transformed into growth and commercial success. Although the number of dedicated biotech firms on both sides of the Atlantic is approximately the same,[2] European biotech firms perform poorly in terms of growth and commercial success compared to their US competitors. European biotech companies are on average smaller, invest less in R&D, employ less people and generate less revenue than US companies (CRITICAL I, 2006; Ernst and Young, 2013).[3] The poor growth performance of commercial biotech in Europe is aggravated by the fact that numerous more mature European firms have moved large parts of their business to the United States.[4] The process of outsourcing commercialization to US entrepreneurs is referred to as 'conveyor belt' method of innovation or simply as 'decapitation' (Cooke, 2007). Decapitation means retaining R&D capabilities in Europe while accessing commercialization capabilities in the US (Ward, 2006). Phil Cooke has nicely summarized the economic rationale behind this phenomenon, stating that "Europe [...] has exploration knowledge capabilities", whereas "the most highly developed exploitation knowledge capabilities are concentrated in US bioscience megacenters" (Cooke, 2007, 471). Again, this suggests that in countries close to the WTF systemic skills (which Cooke calls 'exploitation knowledge capabilities') have a stronger impact on growth than scientific and technological skills in a narrow sense.

It is noteworthy that the diverging development of commercial biotech in Europe and the US is just an illustrative example of a broader pattern. The more general literature on growth determinants of New Technology-Based Firms (NTBFs) finds that narrowly-defined technological skills of the founder are particularly important in the entry-phase, but that once a firm has entered the stage of rapid growth more general, non-technical (i.e. systemic) skills become pivotal. Lack of such more general, business-oriented skills is one of the most important bottlenecks for the long-run growth and survival of New Technology-based Enterprises (see, for instance, Oakey (2007) or Macpherson and Holt (2007)). These facts on skill structure and growth dynamics – well known to scholars of industrial dynamics in technology- and knowledge-based industries – have to the best of our knowledge not been considered in models of Schumpeterian growth theory as yet.

A core contribution of the current paper is, therefore, to endow entrepreneurs in a Schumpeterian growth model with two different skills – which we call technological skills and systemic skills – and to analyze the relative impact of these differential skills on growth and convergence, depending on an economy's state of development. Note that all entrepreneurs dispose of both technological and systemic skills but to different extents thus providing the basis for heterogenous entrepreneurs. Moreover, it is assumed that technological skills are distinctly suited for global technology adoption (i.e. they are linked to the productivity at the WTF) whereas systemic skills are distinctly better at adopting local or national knowledge. The underlying idea is as follows: we understand entrepreneurship as a knowledge-driven process in which knowledge from different sources is combined. An entrepreneur located in an arbitrary region/country combines local knowledge (available in her region or country of residence) with global knowledge that originates and spills over from the WTF. We consciously adopt the notion of WTF which suggests that cutting-edge technological or scientific knowledge is a resource that has a global dimension and a worldwide impact. We further assume that entrepreneurs with distinct technological skills (whom we call technological specialists) can benefit from what is going on at the WTF, i.e. they are able to make use of the latest technological and scientific breakthroughs (e.g. by using them as inputs into their production) without necessarily being world technological leaders themselves.

While being a technological specialist gives entrepreneurs a higher absorptive capacity that facilitates the adaptation of new scientific and technological knowledge (what may be called 'frontier knowledge'), the acquirement of such a specialization is very time consuming and likely to come at the expense of the development of broader, non-technological (i.e. systemic) skills such as communication and networking skills, management skills, responsiveness to dynamically changing environments and opportunities or the ability to mobilize local resources. Entrepreneurs with broad systemic skills, by contrast, are likely to dispose of less absorptive capacity with respect to the latest technological breakthroughs at the WTF than technological specialists, but they are better connected, more opportunity-seeking and more able to mobilize the idiosyncratic resources of their country or region.[5] Notice that a country's endowment with systemic skills includes aside from the individual skill levels also the aggregate share of systemic entrepreneurs. We denote this comprehensive view a country's *systemic capacity*.

In fact, it is often argued that the resources that really matter for long term competitiveness and corporate performance are not those which are ubiquitously available but those which stick to particular locations.[6] Hence the

[2] According to Ernst and Young (2013) there are approximately 2000 dedicated biotech firms in Europe as well as in the US.

[3] Note that the poor growth performance of European biotech companies cannot be blamed on their younger average age. Even if differences in firm age are controlled for, one finds in nearly every age group that the average US biotech company grows faster – and is, accordingly, larger – than the average European company (CRITICAL I, 2006).

[4] Among the most prominent examples are firms like Cyclacel, BioVex, Solexa, Zeneus, Lorantis or Microscience. See Ward (2006) and Cooke (2007) for further details.

[5] To use the terms coined by Cooke (2007), entrepreneurs with broad, systemic skills dispose of 'exploitation knowledge', whereas technological specialists dispose of 'exploration knowledge'.

[6] Note that by assumption each entrepreneur in our model is embedded in a single country or region which may be denoted as his or her home region. Our modeling framework does, therefore, not include the case of multiply embedded entrepreneurs, i.e. entrepreneurs who are embedded

Table 2
Share of population (aged 25–64) with tertiary-type-A and tertiary-type-B education 2010.

	USA	OECD	EU21	France	GER	Italy	Spain	UK
Type A	32%	22%	20%	18%	17%	14%	21%	28%
Type B	10%	10%	9%	12%	10%	n.a.	9%	10%

Source: OECD (2012b, 36).

mobilization of regional resources (e.g. the mobilization of the unique tacit knowledge that is embedded in a regional innovation system) which requires systemic skills rather than technological skills may in the longer run be more growth-enhancing than the quick adoption of knowledge from the WTF. This is a key aspect of growth in modern, highly integrated economies which appears to be largely neglected in recent (Schumpeterian) growth theories.

2.2. Long-run impact of education policy on skills, skill structure, and growth

In the short run, the skill structure of an economy is exogenous. In the longer run, however, education policy can change both the skill levels and the skill structure of the economy and thereby has an influence on a country's growth and convergence to the WTF. Quite obviously, different priorities of educational policy lead to diverse skill structures.

The most important difference in the educational system between Europe and the US is Europe's focus on rather specialized, vocational education, whereas the US have a strong focus on general higher education.[7] As can be seen from Table 2, there is substantial cross-country variation in the share of the university-educated population.[8]

The US population share with tertiary-type A (university) education is far above the OECD average, whereas the EU average and the European 'big five' economies except the UK are below OECD average. The population share with higher general education is particularly low in Italy, Germany and France.[9] By contrast, specialized vocational education and training (vocational upper secondary or post-secondary non-tertiary education) is a major factor in the educational attainment of people in many European countries, in particular in Austria, the Czech Republic, Germany, Hungary, the Slovak Republic and Slovenia (OECD, 2012b, 27). Hence, one might argue that European countries invest more in specific, often technology-related skills, whereas the US invest more in general, systemic skills of their population. But how do these differences in educational systems impact on the respective countries' growth performance?

As early as 1987, Lawrence and Schultze have criticized that the European education system with its focus on apprenticeships provides rather specific skills (often related to established technologies) which become obsolete in times of rapid technological change (Lawrence and Schultze, 1987). Moreover, they have advised European countries to adapt their education systems and to invest more in general education and skills that facilitate to adapt to new tasks and dynamic environments (Lawrence and Schultze, 1987) – i.e. in the kind of skills that we call *systemic skills*. As evidenced by Table 2, however, Europe is still lagging far behind the US with respect to general higher education, and recent evidence provided by the OECD suggests that this might indeed be a core factor underlying the European growth weakness.

The most recent issue of "Education at a Glance" (OECD, 2012a) suggests a direct link between countries' educational structure and their GDP growth in the period 2000–2010. A core result of this study is that over the decade 2000–2010 more than half of the GDP growth in OECD countries is related to labor income growth among tertiary-educated individuals (OECD, 2012c, 182). As can be seen from Table 3, there are, however, marked differences across countries.[10] While Table 3 is indicative of a strong contribution of tertiary educated people to US growth, their contribution to GDP growth in Europe appears much more modest, and seems particularly low in Germany. Keeping in mind that the population share of working-age people with general higher education (tertiary type A education) is much higher in the US than in Europe, whereas specialized vocational education and training plays a larger role in the EU and, in particular, in Germany, the data clearly suggest that Europe (and, in particular, Germany) do not exploit the growth potential that a high share of tertiary educated people with relatively broad, systemic skills offers.[11]

Aside from the recent OECD studies there exists ample empirical evidence on the long-run impact of education and skills on economic growth (see, for instance the comprehensive survey articles by Temple (2001) or Hanushek

in more than one region or country. We are most grateful to an anonymous referee for hinting at this point.

[7] Compare e.g. OECD (2012b), indicator A1 (To what level have adults studied) or OECD (2012c), indicator A10 (How does education influence economic growth, labor costs and earning power).

[8] *Tertiary-type A* (university-type) programs (ISCED 5A) are largely theory-based and are designed to provide sufficient qualifications for entry to advanced research programs and professions with high skill requirements. They have a minimum cumulative duration (at tertiary level) of three years' full-time equivalent. *Tertiary-type B* programs (ISCED 5B) are typically shorter than those of tertiary-type A and focus on practical, technical or occupational skills for direct entry into the labor market, although some theoretical foundations may also be covered. They have a minimum duration of two years' full-time equivalent at the tertiary level (see OECD (2002)).

[9] It should, however, be noted that this share is clearly increasing over time in France whereas it is stagnating in Germany.

[10] Note that the ISCED (international standard classification of education) classification is sometimes criticized because the Statistical Offices of the respective countries which report their national data to UNCTAD have some latitude in allocating qualifications to ISCED classifications, such that cross-country comparability is less than perfect. However, even if one assumes that the share of tertiary educated people in Europe (Germany, respectively) is somewhat underestimated, the numbers in Table 3 speak for themselves.

[11] It should be noted, however, that while these data nicely illustrate that skill structure and GDP growth are related they do not necessarily imply a (uni-directional) causal relationship.

Table 3
Labor income growth by educational category and contribution of labor income growth of tertiary educated people to GDP growth 2000–2010.

	ISCED classification	USA	EU-21	GER
Labor income growth by educational category	0/1/2 (primary education)	−0.04	−0.26	−0.03
	3/4 (secondary educatopn)	−0.06	0.01	0.26
	5A/5B/6 (tertiary education)	0.92	0.74	0.18
Share of labor income growth of tertiary educated people in total GDP growth		**50.8%**	**31.5%**	**16.4%**

Source: OECD (2012c, 194), own calculations.

and Woessmann (2008)). Although education and, in particular, schooling, is no panacea as other factors such as family, institutions and culture also affect skill formation, education policy remains a natural place to look for policy makers who intend to raise the long-term growth rate of their country (Temple, 2001, 32). Moreover, there is increasing evidence that it is not only the skill level but also the skill structure (i.e. the composition of the existing skills in society), the kind of education (elite education versus mass education) and the complementarity of skills and institutions that matter. Hanushek and Woessmann (2008, 607), have put it this way: "New empirical results show the importance of both minimal and high skill levels, the complementarity of skills and the quality of economic institutions, and the robustness of the relationship between skills and growth."

Taking the empirical evidence into account, we put great emphasis on the analysis of the potential role of education policy in fostering economic growth. In Section 6 on growth policy we investigate, for instance, the effects of changes in the skill composition for catch-up with the WTF or the differential effects of elite and mass education. Moreover, we compare the effectiveness of different education policy options depending on a country's state of development and its composition of entrepreneurs.

2.3. *Contribution to the literature*

The paper at hand builds on and contributes to the rich and growing literature on knowledge-based growth. Nelson and Phelps (1966) were probably the first to fully recognize the importance of human capital investment for innovation, technological progress and diffusion. Their seminal work had enormous influence on advanced models of endogenous growth, in particular on Schumpeterian growth theory. Among the most influential papers that developed the foundations of Schumpeterian growth theory are Romer (1990), Segerstrom et al. (1990), Grossman and Helpman (1991), or Aghion and Howitt (1992). Their essential feature is the incorporation of technological progress which is generated by the endogenous introduction of product and/or process innovations (Dinopoulos and Sener, 2007). More recent models of Schumpeterian growth theory (Acemoglu et al., 2006; Acemoglu, 2009) – on which the current paper is based – analyze the role of distance to the WTF, investment and selection of entrepreneurs for growth and convergence. Benhabib and Spiegel (2005) generalize the Nelson-Phelps catch-up model of technology diffusion distinguishing between growth at the WTF and catching-up to it. In the empirical part of their paper they find that the rate at which the gap between the technology frontier and a country's current level of productivity is narrowing depends upon the level of human capital, which is composed of high skilled and low skilled workers (see also Vandenbussche et al. (2006) for a recent model that adopts this distinction). Recently, Cosar (2011) also emphasizes that different types of human capital perform separate tasks throughout the process of convergence.

In addition there are several closely related lines of research 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 high skilled and low 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 (skills, respectively) 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 modeling approaches focus on talent (Lucas, 1988), others on risk-taking (Kihlstrom and Laffont, 1979), and a third group on entrepreneurs as innovators (Aghion and Howitt, 1992). A more recent and 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.

A major innovation of the current paper is that it brings together Lazear-type models of entrepreneurial choice with Schumpeterian growth theory by incorporating Lazear's notion of heterogenous entrepreneurial skills into a standard Schumpeterian growth model. The model set up is closest in spirit to the work of Acemoglu et al. (2006) in which a country's growth-maximizing strategy (innovation by high-skilled entrepreneurs versus imitation by low skilled entrepreneurs) depends on the country's distance to the WTF. We augment the Acemoglu et al. (2006) modeling framework by endowing entrepreneurs with two different skills: technological skills that allow entrepreneurs to adopt technology from the global frontier and systemic skills that allow entrepreneurs to adopt knowledge/best practices from a local frontier. The richer modeling approach 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, as well as 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 considered as one possible setting but – in contrast to Acemoglu et al. (2006) – it is not necessary for the functioning of the model. Put differently, our model is more general in that it also works under perfect capital markets.

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 skills which, as will be shown, aside from a country's state of development, crucially affects the growth maximizing policy. Hence, the richer modeling approach does not only provide a sound explanation for the recent relative growth performance of countries close to the WTF which – as discussed in Section 2.1 – can hardly be explained by standard Schumpeterian growth models, but also yields strong policy conclusions.[12]

In sum, the current paper contributes to the pertinent literature on skills and innovation-based growth in several ways: (i) It enriches existing approaches by endowing entrepreneurs in a Schumpeterian growth model with heterogenous skills and distinguishes two types of entrepreneurs according to their skill profile.[13] (ii) It relates the productivity of the different types of entrepreneurs to the economy's state of development (as reflected by its distance to the WTF) and to the economy-wide skill distribution. (iii) The richer modeling approach provides a sound theoretical explanation for the relative growth and productivity performance of Europe versus the US since the mid-90s which can hardly be explained by standard Schumpeterian growth models. (iv) It yields several policy-relevant findings, in particular with respect to education policy, which is – as argued in Section 2.2 – a main determinant of a country's long-run skill distribution.

[12] While the focus of the model is on industrialized countries in close proximity to each other (and to the WTF) the modeling framework is also applicable to less developed economies.

[13] Note that all entrepreneurs dispose of technological as well as systemic skills and thus are unequivocally highly skilled but differ in the relative strength of the respective skills.

3. Setup of the model

Aside from firm investment, entrepreneurial skills are a crucial determinant of micro- (i.e. firm-level) and macroeconomic productivity – the latter also via the overall distribution of entrepreneurs. Following Acemoglu et al. (2006), we model the economy as being 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* who have access to the capital market and who are able to raise money at the market interest rate. One could interpret this clientele as having successfully founded a firm in the past. Their sole contribution to aggregate productivity consists in selecting certain types of entrepreneurs to maximize firm profits. In doing so they consider possible capital market imperfections which restrict the investment size of young and old entrepreneurs. (ii) *High skilled entrepreneurs* run the firms. They are born with no wealth but are endowed with what we call technological and systemic skills. 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, as well as a continuum of intermediate goods, $x_t(i)$, serve as inputs. The aggregate production function in the final product sector is given by

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

where $A_t(i)$ is productivity of firm i at time t. 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. To ensure that only one monopolist is active for each intermediate it is assumed that $1/\alpha \geq \xi > 1$. Equilibrium monopoly profits in the intermediate sector are then given by

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

where $\delta \equiv (\xi - 1)\xi^{-(1/(1-\alpha))}$ is monotonically increasing in $\xi \leq 1/\alpha$. The labor market clears for wages that equal marginal labor productivity

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

and aggregate final output amounts to $y_t = \alpha^{-1} \xi^{-(\alpha/(1-\alpha))} A_t N_t$.

4. Entrepreneurial skills and productivity

Entrepreneurs act in the intermediate sector and individual productivity 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 WTF (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 $A_t \le \overline{A}_t$, where $\overline{A}_t$ is determined by the most productive country.

While the above assumptions are fairly standard in Schumpeterian growth models, we go one step further by introducing heterogenous entrepreneurs that differ according to their skill endowment:

(i) *Technological skills*, $\eta(i)$, reflect the technological and scientific knowledge of the entrepreneur. They are linked to the productivity level at the WTF, $\overline{A}_{t-1}$, and could be understood as cutting edge skills in the technological domain. (ii) *Systemic skills*, $\gamma(i)$, could be understood as broad, non-technological skills such as communication and networking skills, management skills, responsiveness to dynamically changing environments and opportunities or the ability to mobilize local resources. The reference point for systemic skills is national or local knowledge (A_{t-1} as defined by (6)), by which we mean knowledge and understanding of local and national peculiarities such as formal and informal institutions (e.g. customs), national tastes and preferences or region specific production factors. This implies that an entrepreneur's systemic skills are the more productive the higher regional or societal embeddedness and the better network contacts are.

We assume two types of entrepreneurs with different individual productivities[14]

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

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

where $\overline{\eta} > \underline{\eta}$ and $\overline{\gamma} > \underline{\gamma}$. Entrepreneurs are technological specialists with probability λ and systemic entrepreneurs with probability $1-\lambda$.

Aggregate technology of a country evolves according to

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

thereby also driving convergence of a country to the WTF. Both types of skills contribute to this convergence process, though to different extents, depending upon the state of development of a country. As long as a country is far away from the WTF (or formally spoken if $\overline{A}_{t-1}/A_{t-1}$ is relatively large), technological skills strongly impact on the growth rate of the aggregate technology. Accordingly, technological skills are the major forces that drive growth of national productivity, and with this, convergence of the considered country to the WTF. All things being equal, the growth rate of national productivity declines while catching-up. As a country converges to the WTF, technological skills become continuously less important thus enhancing the relative importance of systemic skills during the catching-up process.

Fig. 1 illustrates the embedding of an individual entrepreneur both in a national and 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

$$a_t \equiv \frac{A_t}{\overline{A}_t} \tag{9}$$

Correspondingly, a_{t-1} could 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 – be it a systemic or a technological entrepreneur – is given by the individual distance to frontier, $A_t(i)/\overline{A}_{t-1}$, which is depicted at the vertical axis. Both functions are derived by dividing individual productivities of technological and systemic entrepreneurs from (7a) and (7b) by $\overline{A}_{t-1}$. In the case of identical investment, s_t, the two graphs intersect at the state of development

$$a_{t-1} = \frac{\overline{\eta}-\underline{\eta}}{\overline{\gamma}-\underline{\gamma}} \equiv \tilde{a} \quad \le 1 \Leftrightarrow \overline{\eta}-\underline{\eta} \le \overline{\gamma}-\underline{\gamma} \tag{10}$$

The intersection of both functions thus applies to economies in which the technological skill advantage, $\overline{\eta}-\underline{\eta}$ falls short of the systemic skill advantage, $\overline{\gamma}-\underline{\gamma}$.[15] 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 entrepreneurs 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 WTF. The opposite applies for systemic entrepreneurs. Their marginal productivity increases – at least in relative terms – the closer the economy is to the WTF. An intuition for this representation may be the following: in knowledge-based and high tech sectors (as, for instance, commercial biotech or, more recently, nanotechnology), 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, according to our reasoning, by technological specialists. As the technology matures and approaches the state of the art at the WTF, technological skills remain undoubtedly important.

[14] Notice that in contrast to the model of Acemoglu et al. (2006) who address high and low skilled entrepreneurs there is no clear predominance of either type of entrepreneur in our model.

[15] It also provides the argument for the specification of the capitalists' selection strategy, i.e. continuing or terminating collaboration with technological specialists. Details are derived below in Section 5.

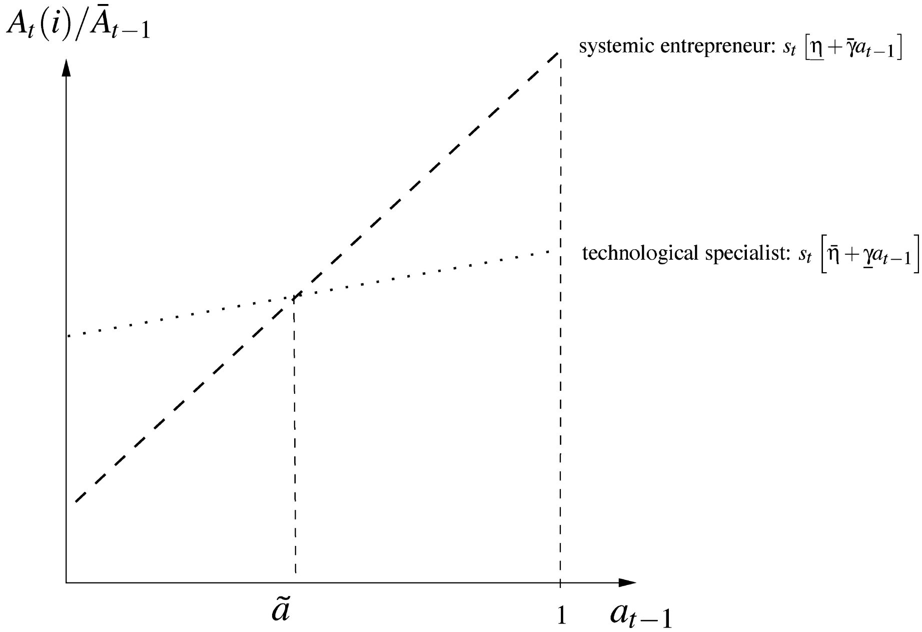


Fig. 1. Technological and systemic entrepreneurs: the micro view; $\tilde{a}$ from (10), identical investment sizes, s_t.

However, to be successful in international competition that becomes fiercer the closer the sector approaches the WTF, 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. Finally, we assume that 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.[16]

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 which is affected by the productivity of single entrepreneurs as well as by their overall composition within the economy – this perspective includes the country's systemic capacity; 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 any given initial distance to frontier, a_{t-1}, the level of a_t increases, thereby implicitly inducing convergence of the considered country to the WTF. Growth, however, may also refer to a shift in the WTF itself.

5. Selection strategies and equilibrium growth

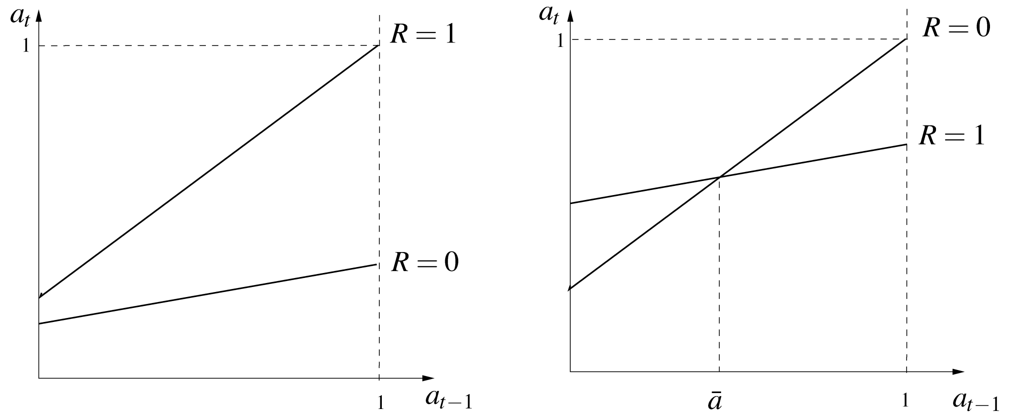
The focus of the current paper is on entrepreneurs endowed with differentiated skills, selection of entrepreneurs, convergence, and growth. In this context, growth of a country's productivity depends not only on differentiated skills but also on a country's financial system and – in particular – the market for firm credit: it is intuitively clear and also well recognized in the literature on entrepreneurship that in case of (almost) perfect credit markets, the entrepreneur's productivity is determined by its skill endowment, while credit market imperfections tend to shelter experienced entrepreneurs, as these are able to realize larger project sizes than their young counterparts.[17] Then, the productivity advantage of old entrepreneurs is the outcome of capital market imperfections which dominate skill related productivity advantages of young entrepreneurs. Thus, entrepreneurial selection, i.e. the replacement of unproductive old entrepreneurs by a new draw of young entrepreneurs is less likely.

5.1. Selection strategy

The analysis focuses on a two period setting, thereby considering young entrepreneurs (y) who became active in time t and old entrepreneurs (o) 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 or not to continue collaboration with old entrepreneurs whose skills are already revealed ('retention strategy' of the capitalist) or to

[16] The growth rate of the WTF, 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 5 where the strategies are detailed).

[17] 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.



(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

Fig. 2. Interaction between capital market imperfections and systemic capacity.

terminate collaboration with those entrepreneurs who are less productive ('termination strategy' of the capitalist). As discussed in the context of Fig. 1, it is reasonable to assume that, having passed a certain level of development, in the instance of selection, technological specialists are the ones being replaced. Due to the aggregate perspective, which includes the economy-wide composition of entrepreneurs, the corresponding state of development might deviate from $\tilde{a}$ as derived in (10). Capitalists choose among 'retention' and 'termination' according to profit maximization by comparing the following two options: (i) well-known profits in 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 (technological) specialists with probability $1-\lambda$ (λ). Since frequently well established firms are able to realize bigger projects, it is also assumed that according to age firms may perform different project sizes, $s_o \geq s_y$.[18] The extent of credit market constraints for young firms, $s_o - s_y$, can be interpreted as a measure of the degree of capital market imperfections which induce a disadvantage on young firms as they finally reduce the firms' productivity (see (5)).[19]

The capitalist, by determining its selection strategy, balances costs and benefits of terminating the collaboration with old entrepreneurs. Thereby the costs of termination are to some extent reflected by the size of capital market imperfections (the investment gap $s_o - s_y$) and thus the foregone productivity gain of the old entrepreneurs' large project sizes. In contrast are the productivity gains arising from the activities of the systemic entrepreneurs. As consequence of termination, the overall share of systemic entrepreneurs among old and young entrepreneurs rises thereby increasing the country's systemic capacity.

It becomes apparent that a complex interaction between individual skills, the overall distribution of entrepreneurs, and the extent of capital market imperfections together with the capitalists' selection strategy 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).

5.2. *Static and dynamic equilibrium*

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.

5.2.1. *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

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

In contrast to this, *average productivity of old firms* depends upon the retention decision of the capitalist. Correspondingly, 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

[18] For a further discussion of the impact of the relationship between investment size and firm age see e.g. Evans and Jovanovic (1989) or Martinelli (1997).

[19] Credit constraints on young firms may arise due to reputation advantages of old (established) entrepreneurs, or because they have received an income in the first period that can be invested in the next period or used as a collateral.

entrepreneurs, which are again technological specialists with probability λ and systemic entrepreneurs with probability $1-\lambda$. Altogether, *average productivity among old firms*, depending upon the chosen retention or termination strategy, amounts to

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

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

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).

5.2.2. 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 (13a) and (13b) 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

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

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

5.3. Capital market imperfections and the country's systemic capacity

Given the assumed parameter specifications, the two equations of motion in (15) intersect at the level of technology[20]

$$a_{t-1} = \frac{(\overline{\eta}-\underline{\eta})s_y(1-\lambda)+\overline{\eta}(s_o-s_y)}{(\overline{\gamma}-\underline{\gamma})s_y(1-\lambda)-\underline{\gamma}(s_o-s_y)} \equiv \overline{a} \quad \left(\geq\tilde{a} \Leftrightarrow s_o\geq s_y\right). \tag{16}$$

The sign of $\overline{a}$ is indeterminate with[21]

$$\overline{a} \gtrless 0 \quad \Leftrightarrow \quad (1-\lambda)\frac{\overline{\gamma}-\underline{\gamma}}{\underline{\gamma}} \gtrless \frac{s_o-s_y}{s_y} \tag{17}$$

The intuition behind the inequality is straightforward: the left-hand side (LHS) includes the overall share of systemic entrepreneurs and the relative extent of their systemic skill advantage. It thus represents a country's endowment with systemic skills at the individual $(\overline{\gamma}-\underline{\gamma})$ as well as at the aggregate level $(1-\lambda)$. We define this broad perspective as a country's *systemic capacity*. In contrast, the right hand side (RHS) reflects the relative extent of *capital market imperfections* as measured by possible investment disadvantages of young firms.

Notice that this line of argumentation enlarges the former discussion of the individual level (compare Fig. 1 or (10)) by the aggregate perspective. Important for aggregate productivity are aside from individual skills also the entrepreneurial composition $(1-\lambda)$ as well as investment of old and young entrepreneurs. The aggregate perspective leads to two different regimes that both are compatible with equilibrium growth at the WTF and which are highlighted in the subsequent graphical illustrations: in Fig. 2(a), capital market imperfections dominate. It is thus never worthwhile for the capitalist to stop collaboration with old entrepreneurs that have access to large investment projects. In contrast, given that the systemic capacity dominates, it is not possible to determine one unique dominant strategy of the capitalists but the optimal strategy depends upon the state of development (with the threshold given from $\tilde{a}$ from (18)). The increasing importance of systemic skills to convergence then requires a regime switch which is illustrated by the intersection of the two lines in Fig. 2(b). The systemic capacity unequivocally dominates in the extreme case of perfect capital markets, but – more generally – is also prevalent whenever existing capital market imperfections are small enough that their productivity reducing effect on young systemic entrepreneurs may be compensated by systemic skill advantages reflected both at the individual and the aggregate level. In what follows the focus will be placed on the interaction between capital market imperfections and the systemic capacity and how they impact the threshold value $\overline{a}$.

Proposition 1 (two regimes). *Depending upon the interaction of a country's systemic capacity, on the one hand, and the degree of capital market imperfections, on the other hand,*

[20] Note that in case of perfect capital markets $\overline{a}=\tilde{a}$ which is independent of the overall distribution of entrepreneurs.

[21] 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, the integration of investment, and the fact that, other things being equal, neither specialist dominates productivity of the other for all states of development.

Table 4
What drives convergence?

		Regime 1 $\Rightarrow$ retention	Regime 2 $\Rightarrow$ selection
(i)	$\frac{\partial a_t}{\partial s_o}, \frac{\partial a_t}{\partial s_y}$	$\frac{\partial a_t}{\partial s_o} = \frac{\partial a_t}{\partial s_y}$	$\frac{\partial a_t}{\partial s_o} < \frac{\partial a_t}{\partial s_y}$
(ii)	$\frac{\partial a_t}{\partial \lambda}$	$\gtrless 0 \Leftrightarrow a_{t-1} \lessgtr \tilde{a}$ cf. (10)	$\gtrless 0 \Leftrightarrow a_{t-1} \lessgtr \tilde{\tilde{a}}$ cf. (18)
(iii)	$\frac{\partial a_t}{\partial \overline{\eta}} > \frac{\partial a_t}{\partial \underline{\gamma}}$	$a_{t-1} < 1$	$a_{t-1} < 1$
(iv)	$\frac{\partial a_t}{\partial \underline{\eta}} > \frac{\partial a_t}{\partial \overline{\gamma}}$	$a_{t-1} < 1$	$a_{t-1} < 1$
(v)	$\frac{\partial a_t}{\partial \overline{\eta}} \gtrless \frac{\partial a_t}{\partial \underline{\eta}}$	$\lambda \gtrless \frac{1}{2}$	$\lambda \gtrless \frac{-s_o - s_y + \sqrt{(s_o+s_y)(s_o+9s_y)}}{4s_y}$
(vi)	$\frac{\partial a_t}{\partial \overline{\gamma}} \gtrless \frac{\partial a_t}{\partial \underline{\gamma}}$	$\lambda \lessgtr \frac{1}{2}$	$\lambda \lessgtr \frac{-s_o - s_y + \sqrt{(s_o+s_y)(s_o+9s_y)}}{4s_y}$
(vii)	$\frac{\partial a_t}{\partial \overline{\eta}} \gtrless \frac{\partial a_t}{\partial \overline{\gamma}}$	$a_{t-1} \lessgtr \frac{\lambda}{1-\lambda}$	$a_{t-1} \lessgtr \frac{\lambda}{1-\lambda} \cdot \frac{s_y(1+\lambda)}{s_o + s_y(1+\lambda)}$
(viii)	$\frac{\partial a_t}{\partial \underline{\eta}} \gtrless \frac{\partial a_t}{\partial \underline{\gamma}}$	$a_{t-1} \lessgtr \frac{1-\lambda}{\lambda}$	$a_{t-1} \lessgtr \frac{1-\lambda}{\lambda} \cdot \frac{s_o + s_y(1+\lambda)}{s_y(1+\lambda)}$
(ix)	$\frac{\partial a_t}{\partial g}$	<0	<0

two 'regimes' are compatible with equilibrium growth at the WTF: regime 1 ('retention') is characterized by a dominance of capital market imperfections with the consequence that old entrepreneurs are retained; in regime 2 ('termination'), the systemic capacity dominates, and selection is realized.

Regime 1 (capital market imperfections dominate): retention is compatible with equilibrium 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, systemic skills become relatively more important (see (8)).[22] But from an aggregate view, the potential of the systemic entrepreneurs 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 thus to continue collaboration with the old entrepreneurs that are able to compensate skill disadvantages by larger investment sizes and a switch from retention to termination is never useful (see Fig. 2(a)).[23]

Regime 2 (systemic capacitiy dominates): Fig. 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 $\overline{a}$ is reached; it then should switch to the termination strategy. Otherwise, the economy would get stuck in a non-convergence trap.[24]

6. Convergence and policy implications

From the viewpoint of a national policy maker, the issue of interest is not productivity growth at the WTF, but catching up to it, thereby considering the growth rate g from (11) as an exogenous parameter. Policy variables are those determinants that affect the resulting national state of development, a_t, for any initially given level a_{t-1}.[25] Within the discussed framework, policy considerations may be strongly linked to a country's education and financial system. With respect to the former, the focus lies on the skill distribution of entrepreneurs as well as on individual skills. Corresponding policy instruments refer to the shares of entrepreneurs, λ and $1-\lambda$, or may be interpreted as either referring to elite education (affecting upper skill levels, $\overline{\eta}$ and/or $\overline{\gamma}$) or mass education (affecting lower skill levels, $\underline{\eta}$ and/or $\underline{\gamma}$). Education policies thus also affect a country's

[22] However, even if the country approaches the WTF retention of old entrepreneurs remains the equilibrium strategy.

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

[24] 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.

[25] Note that due to the interdependencies between the levels of aggregation, the assumption of an exogenously given growth rate of productivity at the WTF, 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. In any case, the convergence process of the initially considered country will be affected by feedback effects of productivity growth at the WTF, g.

systemic capacity as defined in the context of (17). Concerning the financial system, the degree of capital market imperfections comes into play.

Formally, the impact of alternative policies and their strengths is analyzed via sensitivity analysis of (15); the distinction of the two regimes follows the former discussion in (17). It turns out that the effect of those instruments that affect individual skills depends upon either the state of development or the overall distribution of entrepreneurs. Investment sizes may amplify or dampen the derived threshold values. Table 4 gives an overview on the corresponding threshold values, while Figs. 3 and 4 provide selected illustrations. The main results are summarized in Propositions 2–8. Table 5 summarizes several rankings of education policies for different economic environments.

Proposition 2 (investment of old and young entrepreneurs). *(Table 4, line (i)): Higher investment unequivocally increases the speed of convergence. The impact of young firms' investment is more pronounced if the systemic capacity dominates (regime 2).*

Regime 1: Since no replacement of old entrepreneurs takes place, and since we assume that half are old and half are young, overall productivity equally benefits from higher investment independent of the entrepreneurs' age structure. *Regime 2:* Investment of young entrepreneurs has a larger impact on convergence according to the following reasoning: giving young entrepreneurs better access to capital (by reducing capital market constraints, provision of venture capital, etc.) increases their productivity thereby making replacement of old entrepreneurs more likely, thus increasing aggregate productivity.

Proposition 3 (distribution of entrepreneurs). *(Table 4, line (ii)): Independent of the prevailing regime, countries far below (close to) the WTF speed up convergence by decreasing (increasing) the share of systemic entrepreneurs. For the two regimes, the corresponding threshold states of development are given by $\tilde{a}$ from (10) and $\tilde{\tilde{a}}$ from (18). In doing so, $\tilde{\tilde{a}}$ itself is increasing in λ, the share of technological specialists, whereas $\tilde{a}$ is solely affected by individual skill levels. Besides, the gap between the two threshold values, $\tilde{a}$ and $\tilde{\tilde{a}}$, increases with the extent of capital market imperfections*

Regime 1: The threshold value $\tilde{a}$ is provided by equation (10). It reflects the individual productivity advantage of either technological or systemic entrepreneurs as argued in the context of Fig. 1. Enhancing the share of technological specialists 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 entrepreneurs. *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[26]

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

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. But the extent of this effect declines with increasing the share of technological specialists, λ.

Proposition 4 (entrepreneurial skills and catching up). *(Table 4, lines (iii) and (iv)): During the process of catching up, the relative importance of technological skills continuously decreases while systemic skills become relatively more important. This holds true regardless of a country's state of development and the type of specialists.*

According to (8), the contribution of technological skills towards the evolution of a country's productivity is magnified by the inverse of the distance to frontier. This 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 (different boundaries – same skills). *(Table 4, lines (v) and (vi); Fig. 3):*[27] *Which (the upper or 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 entrepreneurs, 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 $\lambda^{th}(s_o, s_y) > 1/2$.*

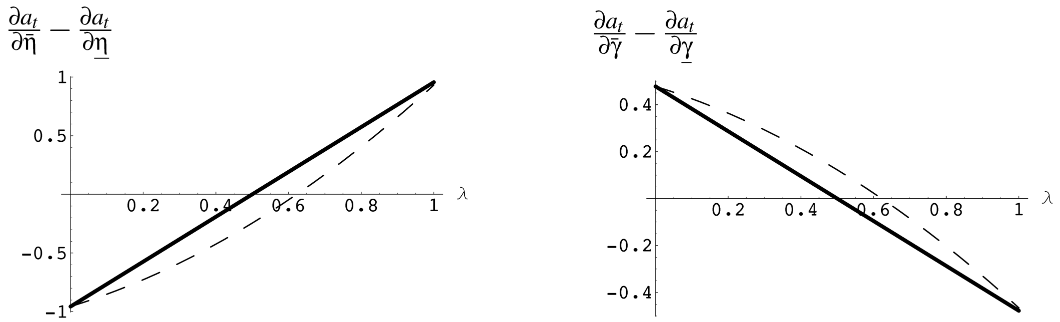
Regime 1: The threshold level $\lambda^{th} = 1/2$ mirrors the assumption that in each period overall productivity is equally determined by young and old entrepreneurs (compare (14)). Productivity is independent of investment size since the interdependencies between productivity enhancements (which are 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. *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, they have a relatively stronger impact

Table 5
Ranking of education policies.

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

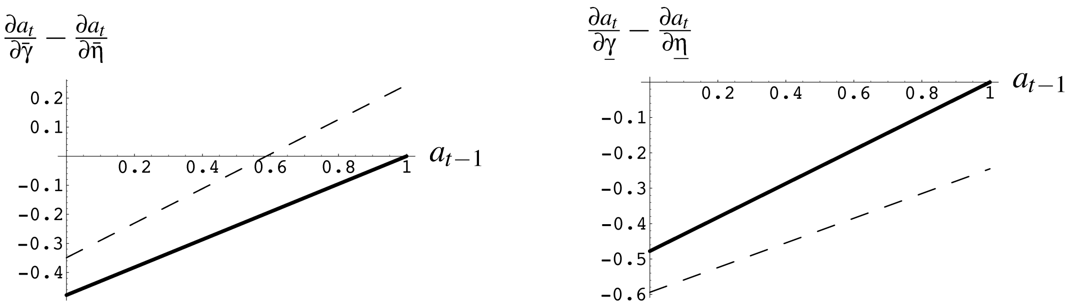
[26] The value of $\tilde{\tilde{a}}$ is determined by differentiating (15) with respect to λ and solving for a_{t-1}. Together with (16) this implies $\tilde{\tilde{a}} \le \tilde{a} \le \overline{a}$. Note that due to the aggregate perspective this is a sensible parameter constellation.

[27] For the sake of simplicity, we denote the threshold values provided in Table 4 throughout the continuous text with λ^{th} and a^{th}_{t-1}



(a) technological skills (b) systemic skills

Fig. 3. Speed of convergence and productivity differentials as a function of λ The intersections of the functions with the horizontal axis represent the threshold values derived in Table 4; parameters: $s_o = 1$, $s_y = 0.95$, $g = 0.02$, $a_{t-1} = 0.5$ solid line: regime 1; dashed line: regime 2.



(a) upper boundaries (b) lower boundaries

Fig. 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: regime 1; dashed line: regime 2

on overall productivity than do systemic entrepreneurs. 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 entrepreneurs, the preferred policy would target the skills of the systemic entrepreneurs, $\overline{\gamma}$ and $\underline{\eta}$.

Fig. 3(a) and (b) depicts the productivity differentials between upper and lower skill boundaries for regime 1 (solid lines) and regime 2 (dashed lines).[28] Fig. 3(a) focuses on technological skill differentials, $\frac{\partial a_t}{\partial \overline{\eta}} - \frac{\partial a_t}{\partial \underline{\eta}}$, while Fig. 3(b) does so for the 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 argumentation.[29]

Proposition 6 (same boundaries – different skills). *(Table 4, lines (vii) and (viii); Fig. 4): upper boundaries may be interpreted to represent elite skills whereas lower boundaries apply to mass skills. In both cases, the superiority of either technological or systemic skills is crucially affected by the interplay between a country's state of development and the ratio of systemic over technological specialists. If the systemic capacity dominates (regime 2), additionally investment sizes come into play thereby dampening the threshold concerning elite skills and amplifying the threshold with respect to mass skills.*

Elite skills: upper skill boundaries, $\overline{\eta}$ or $\overline{\gamma}$ (Fig. 4(a)):

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

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

with $\frac{\lambda}{1-\lambda} \gtrless 1 \quad \Leftrightarrow \quad \lambda \gtrless \frac{1}{2}$

[28] Note that Figs. 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 gap does not contradict the dominance of either the systemic capacity or capital market imperfections.

[29] The plots are independent of the absolute values of the systemic and technological skills. Besides, the plots in Fig. 3(a) are independent of a_{t-1}. In contrast, the plots in Fig. 3(b) which show the differential for the systemic skills $(\overline{\gamma}, \underline{\gamma})$ quite well depend upon a country's state of development. However, the underlying forces exactly cancel out for the threshold level as shown in Table 4, line vi, which is independent of a_{t-1}.

Given $\lambda > 1/2$ (majority of technological specialists), the threshold value $\lambda/(1-\lambda)$ exceeds unity, and quicker convergence is unequivocally 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 $\lambda < 1/2$, however, 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. Poorly developed countries should still support the technological elite, thereby benefiting 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

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

$$\text{with} \quad \frac{s_y(1+\lambda)}{s_o + s_y(1+\lambda)} < 1$$

The corresponding threshold value is dampened by investment, $\frac{s_y(1+\lambda)}{s_o+s_y(1+\lambda)}$ and thus falls short of (19). Productivity of younger entrepreneurs compensates for the resulting overall productivity losses that are inherent in the smaller investment sizes. Below the threshold state of development education policy should foster technological elite skills. The argumentation is supported by the dashed line in Fig. 4(a), which intersects the horizontal axis. For states of development below the threshold value, supporting technological elite skills is favorable, while quicker convergence via increasing systemic elite skills is achieved otherwise. This reflects the fact that during the process of catching-up, technological skills become relatively less important (see (8)).

Mass skills: lower skill boundaries, $\underline{\eta}$ or $\underline{\gamma}$ (see Fig. 4(b)):

Regime 1: The preferred policy may be derived according to

$$\frac{\partial a_t}{\partial \underline{\eta}} \gtrless \frac{\partial a_t}{\partial \underline{\gamma}} \quad \Leftrightarrow \quad a_{t-1} \lessgtr \frac{1-\lambda}{\lambda} \tag{21}$$

$$\text{with} \quad \tfrac{1-\lambda}{\lambda} \gtrless 1 \quad \Leftrightarrow \quad \lambda \lessgtr \tfrac{1}{2}$$

Given $\lambda < 1/2$ (majority of systemic entrepreneurs), quicker convergence is unequivocally achieved via supporting mass skills of systemic entrepreneurs, $\overline{\eta}$. 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:

$$\frac{\partial a_t}{\partial \underline{\eta}} \gtrless \frac{\partial a_t}{\partial \underline{\gamma}} \quad \Leftrightarrow \quad a_{t-1} \lessgtr \frac{1-\lambda}{\lambda} \cdot \frac{s_o + s_y(1+\lambda)}{s_y(1+\lambda)} \tag{22}$$

$$\text{with} \quad \frac{s_o + s_y(1+\lambda)}{s_y(1+\lambda)} > 1$$

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 entrepreneurs. Again, education policy should target that group of specialists which represents the higher share; the argumentation presented in the context of (20) applies.

Fig. 4(a) and (b) plots productivity differentials of elite skills $(\overline{\eta}, \overline{\gamma})$ and mass skills $(\underline{\eta}, \underline{\gamma})$ for a balanced distribution of entrepreneurs, $\lambda = 1/2$.[30] Independent of the prevailing regime, changes of the entrepreneurs' distribution, λ, shift the functions in Figs. 4(a) up- or downwards:

Increasing the share of technological specialists, λ, has the following consequences: It shifts both functions in Fig. 4(a) downwards, thereby reinforcing the predominance of technological elite skills (or put differently, technological specialists) over systemic elite skills (or put differently systemic entrepreneurs). 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 entrepreneurs, $1-\lambda$. Then both functions in Fig. 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 entrepreneurs becomes the growth-maximizing policy.

With respect to the lower skill boundaries, the following applies: increasing λ shifts both functions in Fig. 4(b) upwards, thereby destroying the unequivocal predominance of the support of technological skills. Notice that if capital market imperfections dominate, this effect unequivocally 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 versus 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*

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

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 5, may be derived:

The threshold values a^{th} and λ^{th} are summarized in Table 4 and vary between the two regimes. Nevertheless, the basic structure is independent of the prevailing regime. A line by line look at Table 5 reveals that advanced economies, $a_{t-1} > a^{th}$, should begin by focusing on the skills of technological specialists, $\overline{\eta}$ and $\underline{\gamma}$, if their share exceeds the threshold; the skills of the systemic specialists, $\underline{\eta}$ and $\overline{\gamma}$, 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.

It should be noted that Table 5 compares the marginal contributions of different education policies depending on the economy's development state and share of technological specialists. We consider this an important result, although we are aware of the fact that for use in practical policy making possible differences in the costs of different education measures have to be taken into account as well. A comparison of annual costs per student in different fields of study (see Table A1 in the Appendix) suggests that increasing technological skills (by educating engineers, mathematicians or natural scientists) is somewhat more expensive than increasing systemic skills (reflected by the lower costs per student in the humanities, cultural sciences, and social sciences). The cost differences between these two groups appear, however, not dramatic, if one puts them into perspective and takes the annual costs per student in fields like medicine into account. Finally,

Proposition 8 (growth at the WTF). *(Table 4, line 9): higher growth 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.

7. Conclusions

This paper has analyzed the impact of heterogenous individual skills and the aggregate skill distribution on growth and convergence towards the WTF. The analysis extends existing Schumpeterian growth models in several respects. In particular, highly skilled entrepreneurs dispose of different skill profiles, qualifying them either as technological specialists or broadly skilled systemic entrepreneurs. While both types of entrepreneurs dispose of technological as well as systemic skills they differ in the relative strength of the respective skills. Technological specialists mainly integrate technological knowledge, while systemic entrepreneurs are characterized by a high level of more general skills such as strong communication and management skills, responsiveness to dynamically changing environments and opportunities or the ability to mobilize regional (knowledge) resources. Technological skills are linked to the knowledge stock at the WTF, whereas systemic skills are linked to the national or local knowledge stock, considering the fact that economic growth depends not only on the distance of the economy to the WTF, but also on country-specific (e.g. institutions) and region-specific factors. In fact, it is argued here that for countries close to the WTF the factors that drive national growth and competitiveness in the world economy are not primarily 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, for instance, 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 WTF. A major result of the 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 entrepreneurs with broad systemic skills. Hence, our model provides a new, theory-based explanation for the much-discussed European productivity paradox: recent empirical work has revealed that the productivity and growth slowdown in Europe is largely attributable to slower multi factor productivity growth in sectors like market services, which depend less on frontier technologies than on close interaction with customers and consumers and are therefore embedded in national and local cultures and institutions (van Ark et al., 2008). These empirical findings suggest that growth in modern, highly-developed economies which are already close to the WTF depends less on technological skills linked to the WTF than on systemic skills linked to a national or local frontier - which is exactly what the model developed in this paper predicts.

To sum up: the current paper offers a richer explanation of growth in countries close to the WTF by considering heterogenous individual skills and their economy-wide distribution and by showing that when a country approaches the WTF systemic skills become relatively more important than technological skills. While surprising at first glance, the principal result is perfectly in line with recent empirical evidence on the growth performance of Europe relative to the US, and adds considerable value to the understanding of cross country difference in innovation-driven growth performance. Moreover, both, the empirical evidence presented and the findings from the theoretical analysis provided in this paper point to the importance of the skill-distribution in society for long-term economic growth and the central role of education policy as a main determinant of a country's long-term skill distribution. While the current paper has provided a modest first step towards a better understanding of the role of heterogenous skills for growth and convergence with the WTF, more work (both, theoretical and empirical) on the determinants of the economy-wide skill distribution and its impact on long-term economic growth is warranted.

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Appendix A.

See Table A1.

Table A1
Field of study and expenditure per student at German universities.

Field of study	Basic current expenditure per student (1999) in 1000 €
Languages and cultural sciences	3.11
Law, economics and social sciences	2.16
Sports	3.9
Engineering	4.31
Mathematics and natural sciences	5.81
Human medicine	24.36

Source: Statistisches Bundesamt (German Statistical Office) 2012, Laufende Grundmittel je Studierenden nach Fächergruppen.

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