On the role of productive government spendings for convergence of a growing economy with heterogenous specialists

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Abstract

This paper employs a dynamic framework to compare the effects of alternative government activities on convergence of industrialized economies to the technology frontier. The government's Instruments include facilitating private investment and education policy. The latter enhances skills of heterogenous specialists and imply the decision on their respective shares. The analysis distinguishes between an isolated policy of a single economy and coordinated policies of various countries. Which policy maximizes the speed of convergence is crucially affected by the economy's state of development. A policy switch between the mentioned instruments while catching-up may be preferable.

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1 Motivation

The term 'European Paradox', which has been coined by the European Commission (1995, p. 5) in the Green Book on Innovation, refers to the phenomena that "One of Europe's major weaknesses lies in its inferiority in terms of transforming the results of technological research and skills into innovations and competitive advantages." Although the strength of this statement has been relaxed during the last several years, there is broad consensus on the importance of human capital or, put differently, skills lying beyond pure technological knowledge, for being successful in innovation, growth and catching-up to the technology frontier. So far, the literature on the role of human capital for convergence distinguishes two sources of (national or regional) growth and hence for convergence of lagging economies to the technology frontier: first, innovation, which is assumed being realized by highly skilled workers, and second, imitation carried out by lowly skilled workers. However, this setting mainly describes the catching-up process of developing countries. As long as a country is not caught in a non-convergence trap, beginning with an imitation strategy and then, after having passed a certain threshold level of development, switching to an innovation strategy finally leads to convergence to the technology frontier (see e. g. Acemoglu et al. (2006), King and Levine (1993), Audretsch and Thurik (2001); Aghion and Howitt (2009) as well as Acemoglu (2009) provide recent overviews). The prominent role of knowledge and hence of human capital as argued by Lucas (1988) is broadly accepted as a major growth determinant which is most important in countries with scarce endowments of natural resources. Especially in industrialized economies, human capital frequently is considered as reflecting the stock of technological knowledge as well as being a central factor within the innovation process that strongly should be supported by the government. However, Krueger and Lindahl (2001), Vandenbussche et al. (2006) present a more sceptical view on the impact of education policy for industrialized countries. So far the literature on the role of government spendings in the context of human capital is not yet clear.

In contrast to this argument, the European Paradox highlights that being successful in developing cutting-edge technological knowledge does not necessarily imply economic success in the sense of determining the technology frontier. Obviously, there are other skills lacking, which mostly are interpreted, e.g., as a basic understanding for the timing of an innovation, societal acceptance of a new technology or just a feeling for the applicability of an idea in a certain economic environ-

ment. Consequently, aside from pure technological knowledge, individuals have to be endowed with additional skills. Besides, especially in the context of industrialized economies as e. g. OECD countries, the pure distinction into highly and lowly skilled workers is not apt to represent the state of the art of human capital. Although belonging to the economically most successful countries, there are quite different states of development also among OECD countries observable. It is reasonable to assume that the majority of individuals in these countries is highly skilled but that there exists a broad variety of skills, each of them contributing differently to catching-up. Usually, these skills are the outcome of specific education policies which are strongly supported by government policies. A short look at recent education indicators illustrates that across OECD countries governments are seeking policies to make education more effective (see OECD (2009)). Instruments, among others, are public spendings on education. In this context, not only the absolute amount, but also its composition with respect to various applications, impact on the success of investment in education and henceforth on growth and convergence. Education investments are also of interest in the work of Blankenau (2005) or Blankenau et al. (2007) who find a positive relationship between public education expenditures and growth for developed countries. Benhabib and Spiegel (2005) provide an overview on the impact of human capital on growth.

A more general view on the impact of productive government expenditures on growth has been well recognized since the seminal work of Aschauer (1990, 1989) who focuses on infrastructure investment though the overall valuation of the studies is mixed. The basic theoretical framework was provided by Barro (1990) and has been extended to include, among others, aspects like adjustment costs (e. g. Turnovsky (1996)), congestion (Fisher and Turnovsky (1998) or Eicher and Turnovsky (2000)), uncertainty (e. g. Turnovsky (1999)), open economies (e. g. Turnovsky (1996, 1997, 1999)) or arguments regarding development (e. g. Chatterjee et al. (2003)). The distinction of the government budget in consumptive and productive expenditure and its long-run implication has been addressed e. g. by Barro (1991) or Turnovsky and Fisher (1995).

Aside from mere growth, a broadly accepted policy goal is to reduce regional disparities, and public expenditure is utilized in order to achieve convergence. The current regional policy of the European Union during the period 2007–2013 serves as good example. The goal is to help lagging regions to catch up to per-capita income of the most advanced country within the EU. Some basic mechanisms how

a productive government input may affect the process of convergence within a two-country setting can be found in Ott and Soretz (2010). They highlight the crucial importance of the decision on the type of public input provided by the government. Recent surveys summarizing the current state of the literature on government activity and growth both from a theoretical and an empirical point of view can be found by Romp and de Haan (2007) or Irmen and Kuehnel (2009). Nevertheless, the relationship between productive government expenditure and convergence still remains an unresolved puzzle.

However, being conscious about the growth enhancing effect of productive public spendings the main question addressed in this paper is to determine those policies that maximize an economy's productivity growth rate in order to converge to the technology frontier. For a given state of development, we especially address which skills should be supported and how the composition of specialists at the economy-wide level should be. The formal framework is a straightforward extension of the model of Acemoglu et al. (2006) but in contrast to them here the focus is laid on highly skilled specialists. Each of them is endowed with two types of skills though to different extents and hence we distinguish between technological and systemic specialists. An additional perspective of the analysis assumes that any successful catching-up policy of a single economy will be adopted by others or, put differently, that policy coordination between various countries leads to a uniform policy of various countries. The phenomenon of coordinated policies may, e. g., be observed in the context of the monetary policy of the European Union. However, concerning fiscal policy coordination there exists some diffuse consensus that it should also be coordinated but so far it is not yet close to becoming reality.

Given this background the paper analyzes the effectiveness of various policies that act as enhancing economy wide productivity either via focusing on individual specialists or on their overall distribution. This is done by comparing the contexts of isolated and coordinated governmental policies. These include increasing the specialists' investment opportunities, e.g. via relaxing credit market imperfections thereby allowing for bigger project sizes. Since governments usually have to meet a financing constraint, the composition of a certain budget and thereby the channels through which government activity becomes effective is a major policy issue. Aside from individual factors, like the skill endowment or investment size, also the economic environment in which specialists are active, affects their individual productivity. In the context of catching-up, two channels are of primary interest:

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First, productivity at the technology frontier that defines the state to which convergence takes place and, second, the economic environment in which the specialists are active as defined by an economy's state of development.

The paper is organized as follows. Section 2 describes the setup of the model. Section 3 analyzes the relationship between the specialists' skills, their productivity, and the impact of government activity. The macroeconomic equilibrium is derived in Section 4 while Section 5 begins with detailing the policy implications. Sections 6 and 7 distinguish the consequences for the two frameworks of isolated and coordinated policies and presents some selected simulations. Section 8 briefly concludes.

2   The basic framework

General setup: Like in Acemoglu et al. (2006), the economy is populated by overlapping generations of risk-neutral agents, who live for two periods and discount the future at the rate r. Each generation is composed of highly skilled specialists that are endowed with two types of skills though to different extents. Accordingly, one might distinguish *technological* and *systemic specialists*.

Within the model, government activity may be interpreted as reflecting several determinants of education policy. This includes the provision of a certain public budget to finance spendings on education. Another component provides an indication for the emphasis as regards content of public spendings. This includes the structure of the budget as well as the determination of the respective shares of the heterogenous specialists. For the sake of simplicity, we assume growth neutral financing of the public input and that the public budget constraint is met in each period.

Throughout the paper the analysis deals with *different levels of aggregation* which interact and are linked to each other as follows: (i) the individual perspective of single specialists which determines productivity at the firm level; (ii) the national level which focuses on a country's overall productivity. It is affected by the productivity of single specialists as well as by their economy-wide distribution; and (iii) the worldwide view which captures productivity at the technology frontier. It is determined by the most productive country.

Due to the various levels of aggregation one has to be precise about the distinction between growth and convergence. From the perspective of a single economy, growth is realized whenever an initially given distance to frontier vanishes over time thereby inducing convergence country to the technology frontier.

Two sector economy and the role of productivity: The two-sector economy is composed of a perfectly competitive final product sector and an intermediate good sector with imperfect competition. The final good, y_t, is produced using a continuum of intermediate inputs, $x_t(i)$, according to

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

where $A_t(i)$ is productivity of firm i in the intermediate good sector at time t. Each intermediate good is produced by a technologically leading monopolist at a unit marginal cost in terms of the final good which thus is used as numéraire. Demand for intermediates provides the inverse demand schedule

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

where $p_t(i)$ is the price for intermediate i set by the monopolist. The monopolist faces a competitive fringe of imitators that can produce the same intermediate good but at higher cost. This forces the monopolist to charge a limit price, $p_t(i) = \xi > 1$, in order to avoid competition by imitators. To secure that only one monopolist is active for each intermediate it is assumed that $1/\alpha \geq \xi > 1$.[1] Given inverse demand (2) and the limit price, ξ, equilibrium monopoly profits in the intermediate good sector are

$$\pi_t(i) = [p_t(i) - 1] x_t(i) = (\xi - 1)\xi^{-\frac{1}{1-\alpha}} A_t(i) \tag{3}$$

Aggregate final output is then given by

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

with A_t representing the average level of knowledge in the considered economy at time t according to

$$A_t \equiv \int_0^1 A_t(i) di \tag{5}$$

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[1] Broadly speaking, one can think of the parameter ξ as capturing competitive policies. Higher values of ξ correspond to a less competitive market for intermediates and imply higher profits for the monopolist. This aspect and the corresponding implications are detailed in Acemoglu et al. (2006).

We assume $A_t \leq \bar{A}_t$, where $\bar{A}_t$ is determined by the most productive country which represents the world technology frontier. Productivity at the technology frontier grows at rate g and evolves according to[2]

$$\bar{A}_t = (1+g)\bar{A}_{t-1} \tag{6}$$

The technological state of development of the representative economy at time t is reflected by its proximity to the technology frontier and is defined as

$$a_t \equiv A_t/\bar{A}_t \tag{7}$$

In this context, convergence of an economy to the technology frontier is equivalent to an increasing level of a_t. As will be shown, the main determinant of growth and convergence within the considered framework is provided by those factors that affect productivity, namely skills as well as their overall distribution. Hence governmental policy which affects these parameters becomes essential for convergence policy.

3 Highly skilled specialists and government activity

Specialists act in the intermediate sector at which productivity of a single specialist at time t is given by

$$A_t(i) = s_t(i)\left[\eta(i)\bar{A}_{t-1} + \beta\bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \gamma(i)A_{t-1}\right], \quad \rho \in [0,1] \tag{8}$$

Here, s_t is investment size; $\eta(i)$ and $\gamma(i)$ denote time invariant but different skills; $\bar{A}_t$ reflects productivity at the technology frontier (global knowledge); and A_t is the state of technology of a single economy (local knowledge), each at time t. Government activity enters productivity of the specialist via the individually available amount of productive spendings, β, and their composition as determined by the parameter $\rho \in [0,1]$. The latter parameterizes to which extent the government budget lays emphasis on activities at the technology frontier or has a more regional/local focus.[3]

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[2]Throughout the paper, the growth rate g is first assumed to be exogenous. However, in the context of the macroeconomic equilibrium (Section 4) it will be shown how the equilibrium level of g is determined by individual skills, the overall composition of specialists, and the amount of the government budget.

[3]Due to the respective characteristics of productive spendings, β may be either the total amount of public spendings given there is no rivalry, or public spendings per capita if rivalry is complete,

As argued before, each specialist, *i*, in the intermediate sector is endowed with two types of skills:

(i) *Technological skills* (denoted as $\eta(i)$), which reflect technological and scientific knowledge and which could be understood as cutting edge skills in the technological domain. These skills are linked to productivity at the technology frontier, $\bar{A}_{t-1}$. What we have in mind are, e. g., engineers or scientists that work at universities or in research labs thereby having access to the most advanced knowledge.

(ii) *Systemic skills* (denoted as $\gamma(i)$), which could e. g. be understood as being the specialist's skills with respect to management activities, communication and/or networking. The reference point for systemic skills is national or local knowledge (A_{t-1}) which includes the knowledge of the economy's peculiarities, such as institutions, national tastes and preferences or region specific production factors. This implies that a specialist's systemic skills are the more productive the higher her regional or societal embeddedness or the better her network contacts are in the economic environment in which the specialist is active.

It appears reasonable to assume that specialists in industrialized economies possess competencies with respect to both technological and systemic skills although, at an individual level, the skill endowments usually differ among individuals. As a consequence specialists are heterogenous in the sense that they are characterized by different sources of productivity.

As can be seen in (8), productivity of the individual specialist is enhanced by government activity namely both by the amount (β) and the composition (ρ) of public spendings. Given the benchmark case of $\rho = 0$, the total amount of public expenditures enhance systemic skills thereby relying on local knowledge (A_{t-1}). On the other polar case, i.e. given $\rho = 1$, the public budget supports technological skills and hence benefits from knowledge and productivity at the technology frontier ($\bar{A}_{t-1}$). Intermediate values of ρ imply that the government's budget is divided in the sense that it supports both skills though to varying extents. For the sake of simplicity, we assume that there exist upper and lower boundaries for both technological and systemic skills; $\bar{\eta} > \underline{\eta}$ and $\bar{\gamma} > \underline{\gamma}$. Given these characteristics,

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or something in-between given partial rivalry. However, this paper does not address issues of congestion as discussed, e. g., by Fisher and Turnovsky (1998).

productivities of the heterogenous specialists arise according to

$$A_t^{tS}(i) = s_t \left[\bar{\eta} \bar{A}_{t-1} + \beta \bar{A}_{t-1}^{\rho} A_{t-1}^{1-\rho} + \underline{\gamma} A_{t-1} \right] \tag{9a}$$

$$A_t^{sS}(i) = s_t \left[\underline{\eta} \bar{A}_{t-1} + \beta \bar{A}_{t-1}^{\rho} A_{t-1}^{1-\rho} + \bar{\gamma} A_{t-1} \right] \tag{9b}$$

Depending upon the prevailing skill advantage, the two types of actors are henceforth called *technological specialists* (see (9a)) and *systemic specialists* (see (9b)).
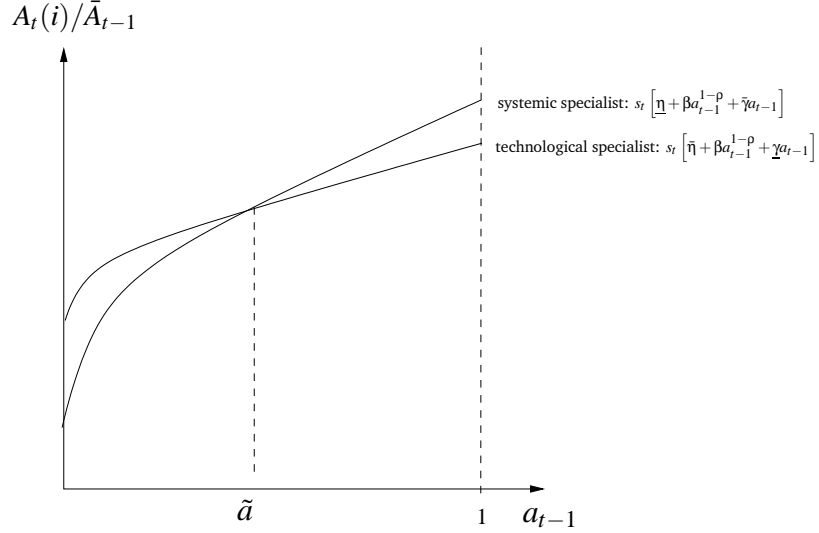

Figure 1: Technological and systemic specialists

Figure 1 illustrates the embedding of an individual specialist in an international context where the horizontal axis a_{t-1} could be interpreted as reflecting the state of development of the considered economy. The position of a single specialist, however, is given by the individual's distance to frontier, $A_t(i)/\bar{A}_{t-1}$, which is depicted at the vertical axis. Accordingly, Figure 1 illustrates the relative position of a systemic and a technological specialist as functions of the state of economic development in which the respective specialist acts. Both functions are derived by dividing individual productivities of technological and systemic specialists from (9a) and (9b) by productivity at the technology frontier, $\bar{A}_{t-1}$. In case of identical investment, s_t, both graphs intersect at the state of development[4]

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

[4]Given identical investment sizes of both specialists, $\tilde{a} \leq 1$ only if $\bar{\eta} - \underline{\eta} \leq \bar{\gamma} - \underline{\gamma}$. This implies that technological skills are less spread than systemic skills, an assumption which is quite plausible within developed countries. It is assumed that this parameter restriction holds throughout the paper.

It becomes apparent that, as long as $a_{t-1} < \tilde{a}$, at an individual level, technological specialists are more productive while, in contrast, systemic specialists have a higher productivity if the state of development of a country exceeds $\tilde{a}$. This reflects the fact that, all other things being equal, the marginal productivity of technological specialists – and thus their marginal contribution to growth and convergence of the economy as a whole – is declining the more the economy approaches the technology frontier. The opposite is true for systemic specialists. Their marginal productivity increases – at least in relative terms – the closer the economy is to the technology frontier.[5]

From (5) and (8) the growth rate of the economy's aggregate technology is given by

$$\frac{A_t}{A_{t-1}} = \int_0^1 s_t(i) \left[\eta(i) \frac{\bar{A}_{t-1}}{A_{t-1}} + \beta \left(\frac{\bar{A}_{t-1}}{A_{t-1}} \right)^\rho + \gamma(i) \right] di \tag{11}$$

This growth rate also drives convergence of the economy to the technology frontier. It becomes obvious that both types of skills contribute to this convergence process, though to different extents, depending upon the economy's state of development. As long as it is far away from the technology frontier technological skills strongly contribute to the growth rate of the aggregate technology.[6] Accordingly, technological skills are the major forces that drive growth of national productivity and with this also convergence to the technology frontier. All other things being equal, the growth rate of national productivity declines while catching-up:[7] As a country converges to the technology frontier, technological skills become relatively less important while systemic skills become relatively more important.

As argued before, the government's activity may affect convergence via enhancing individual productivity. The crucial policy parameters in this context are amount and structure of the public budget. Notice that its impact on convergence declines as an economy develops thereby following the same logic as in the context of the declining relative importance of technological skills (see (11)).

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[5]Notice that, aside from the introduction of productive government activity, this implication is a major difference of our paper to the one of Acemoglu et al. (2006) where, given the case of 'low-skill entrepreneurs', the value of $\gamma(i)$ becomes zero. In their model entrepreneurs might be distinguished in high-skill and low-skill entrepreneurs. Productivity of the latter falls short of productivity of high-skill entrepreneurs for all states of development, i.e. there exists a clear productivity ranking between the two agents which is independent of the economy's state of development.

[6]Formally, a quite distinct distance to frontier is reflected by values $\bar{A}_{t-1}/A_{t-1}$ that strongly exceed unity.

[7]Formally spoken, the term $\bar{A}_{t-1}/A_{t-1}$ declines and converges to unity.

4 The macroeconomic equilibrium

From an aggregate perspective, another policy variable which is not included in (11) gains importance, namely the economy-wide composition of specialists. Due to the OLG-setting, in each period there are young and old specialists. Their economy-wide distribution captures the share λ of technological specialists and the share $1 - \lambda$ of systemic specialists. Average productivity of young firms arises according to

$$
\begin{aligned}
A_t^y &= \lambda \int_0^1 A_t^{ts}(i)di + (1-\lambda) \int_0^1 A_t^{sS}(i)di && (12) \\
&= s_y \left[\left(\lambda \bar{\eta} + (1-\lambda)\underline{\eta} \right) \bar{A}_{t-1} + \beta \bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \left(\lambda \underline{\gamma} + (1-\lambda)\bar{\gamma} \right) A_{t-1} \right] && (13)
\end{aligned}
$$

Equivalently is average productivity of old firms, A_t^o, with the sole difference that old firms basically may realize other project sizes, $s_o \geq s_y$, and[8]

$$
A_t^o = s_o \left[\left(\lambda \bar{\eta} + (1-\lambda)\underline{\eta} \right) \bar{A}_{t-1} + \beta \bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \left(\lambda \underline{\gamma} + (1-\lambda)\bar{\gamma} \right) A_{t-1} \right] \tag{14}
$$

For the sake of simplicity it is assumed that half the specialists are young and half are old such that average productivity of specialists at time t is given by

$$
A_t = \frac{1}{2}[A_t^o + A_t^y] \tag{15}
$$

From (6) and (7), an economy's distance to frontier results in

$$
a_t = \frac{A_t}{\bar{A}_t} = \frac{A_t}{(1+g)\bar{A}_{t-1}} \tag{16}
$$

This, together with equations (13)–(15) determines an economy's process of convergence according the equation of motion

$$
a_t = \frac{\tilde{s}}{1+g} \left[\lambda \bar{\eta} + (1-\lambda)\underline{\eta} + \beta a_{t-1}^{1-\rho} + \left(\lambda \underline{\gamma} + (1-\lambda)\bar{\gamma} \right) a_{t-1} \right] \tag{17}
$$

where $\tilde{s} \equiv \frac{s_o + s_y}{2}$ represents average investment of old and young firms.

To close the model, equilibrium growth of productivity at the technology frontier has to be determined. It may be derived by evaluating (17) at the technology frontier, i.e. by setting $a_t = a_{t-1} = 1$, and solving for g. The corresponding equilibrium growth rate then results as

$$
g^* = \tilde{s} \left[\lambda(\bar{\eta} + \underline{\gamma}) + (1-\lambda)(\bar{\gamma} + \underline{\eta}) + \beta \right] - 1 \tag{18}
$$

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[8]This assumption is in accordance with the fact that younger firms usually are more frequently credit-constrained than old and well-known firms are.

It is a function of individual skills, the shares of technological and systemic specialists, investment size, and public spendings. All parameters provide the basis for governmental policy and thus their respective impact for convergence will be addressed in the following. Notice that productivity growth at the technology frontier, g^*, is increasing in the government budget, β, but is independent of its composition, ρ. This is in strong contrast to an economy's path of convergence to the technology frontier, a_t, which is increasing in both β and ρ (see (17)).

5   Policy implications

Within the considered framework, the goal of government policy is catching-up of lagging economies to the technology frontier. One way to achieve this goal is to enhance productivity of the economy's labor force as determined by the skill levels of the heterogenous specialists as well as by their overall distribution. Hence, the focus of government policy is laid on education policy determined by the skill levels of the heterogenous spec which includes various policy parameters.

Perspective of the single specialist: In this context, all components affecting individual productivity are of interest. They include investment size as well as those parameters related to individual skills, i. e. structure and amount of the public budget (see (8)). Higher investment sizes (e. g. via easier access to private capital) unequivocally spur the specialists' productivity thereby affecting technological and systemic skills uniformly.[9] Referring to government expenditure, the analysis is a bit more sophisticated. It includes skill-enhancing education as a consequence of either higher public spendings and/or reorganization of the existing public budget. Similar to higher investments, individual productivity unequivocally increases with the amount of the public budget. However, the structure of public expenditure highlights on which type of skill emphasis is laid by the government. Given the polar case $\rho = 0$, public expenditure act solely as enhancing systemic skills and reference point is then local knowledge, A_{t-1}. In the other polar case, $\rho = 1$, only technological skills are affected by government policy which thus is linked to global knowledge, $\bar{A}_{t-1}$. Intermediate values $0 < \rho < 1$ refer to policies that affect

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[9]Notice that enhancing private investment does not necessarily require government intervention in the sense of relaxing possibly existing credit market imperfections or via investment subsidies. We do not detail this aspect here since emphasis is not laid on the sources of higher productivity but on the consequences of higher productivity on catching-up.

both technological and systemic skills though to varying extents with increasing relative importance of technological (systemic) skills as ρ increases (decreases).

Economy-wide perspective: Aside from enhancing individual skills, education policy also includes the choice of the relative shares of technological and systemic specialists. This decision is independent of amount and structure of the public budget. The impact on the process of catching-up is captured within (17). Notice that one also has to consider that, since the impact of the government budget is magnified by an economy's distance to frontier, the corresponding impact of ρ is likewise affected: The relative contribution of technological and systemic skills varies throughout the process of convergence, and systemic skills become the more important the closer an economy is to the technology frontier (recall the discussion in the context of (11)).

From a formal point of view, the analysis conducts sensitivity analysis of the equation of motion (7) with respect to the government parameters (β, ρ, λ) and to investment (s) in order to derive the single effect of any policy. Due to complementarity between the skills on the one hand and investment (s) and government budget (β, ρ) on the other hand, any policy unequivocally enhances productivity of a single specialist, though to different extents.

In order to assess the absolute strengths of the various policy instruments, aside from partial derivatives, we also focus on productivity differentials thereby first comparing higher investment to higher public expenditure and then confronting the impact of increasing the public budget to reorganizing its structure. In addition, the impact of changes of the overall composition of specialists, λ, will be analyzed thereby capturing the aggregate perspective of government policy.

In what follows, the focus will be laid on determining those policies that speed up convergence of an economy to the technology frontier. Given a certain state of development, a_{t-1} (within (17)), that policy will be preferred that results in a higher level a_t. In doing so, attention will be given to two different perspectives: *(i) Isolated policy* of a single country that considers productivity growth at the technology frontier, and hence g^* in (18), as exogenous; and *(ii) coordinated policies*, thereby taking into account feedback effects of government policies on the equilibrium growth rate, g^*. The following analysis highlights that the impact of any government policy may vary between the two mentioned contexts and details the underlying economic mechanisms. It turns out that depending upon the structural parameters, it might be necessary to realize a policy switch considering the most

effective policy instrument during the process of catching up.[10] To substantiate the arguing some selected simulation plots are provided.

6 Isolated policy

6.1 The impact of various policy instruments

We now detail how the various policy instruments namely investment size, amount and structure of the public budget as well as the economy-wide composition of specialists affect an economy's speed of convergence. Formally, the latter is measured by the level of the partial derivatives of the equation of motion (17) with respect to the considered parameter. Throughout this section we assume that productivity growth at the technology frontier, g^*, is considered as being exogenous. This allows us to interpret the consequences of choices of instruments as isolated policy of the considered economy.

It is straightforward that both higher government expenditures and bigger investment sizes enhance productivity of the specialists and thus speed up convergence. Formally, this results from[11]

$$\frac{\partial a_t}{\partial s} = \frac{1}{2(1+g)}\left[\lambda\bar{\eta} + (1-\lambda)\underline{\eta} + \beta a_{t-1}^{1-\rho} + (\lambda\underline{\gamma} + (1-\lambda)\bar{\gamma})a_{t-1}\right] \quad > 0 \qquad (19a)$$

$$\frac{\partial a_t}{\partial \beta} = \frac{\tilde{s}}{1+g}\cdot a_{t-1}^{1-\rho} \quad > 0 \qquad (19b)$$

In both cases, in the context of isolated policies the parameter g reflects productivity growth at the technology frontier which is considered to be exogenous. The resulting effect on convergence increases with a country's state of development, a_{t-1}, or, put differently, decreases as the economy approaches the technology frontier. Hence, although the sign of both policies is unequivocally positive, the strength of the effect is weakened throughout the process of convergence thereby reflecting decreasing returns of the mentioned instruments, s and β.

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[10]Notice that this is another perspective than the one discussed by Acemoglu et al. (2006) who compare the impact of innovation and imitation strategies that are carried out by the individual firms are compared to each other.

[11]In order to simplify the presentation, we just talk about the impact of investment, s, since $\frac{\partial a_t}{\partial s_o} = \frac{\partial a_t}{\partial s_y} \equiv \frac{\partial a_t}{\partial s}$.

Considering the impact of the government budget structure and its contribution to convergence, a positive but non-monotonic relation arises, which results from

$$\frac{\partial a_t}{\partial \rho} = -\frac{\tilde{s}}{1+g} \cdot \beta(1-\rho)a_{t-1}^{1-\rho}\underbrace{\ln a_{t-1}}_{-} \quad > 0 \tag{20}$$

As argued before, education policy might also focus on the aggregate perspective in the sense that the government decides on the relative shares of technological and systemic specialists, respectively, as measured by λ. Again it turns out that the state of development of a country is of major importance for the corresponding effect on convergence. It follows

$$\frac{\partial a_t}{\partial \lambda} \gtreqless 0 \quad \Longleftrightarrow \quad a_{t-1} \lesseqgtr \frac{\bar{\eta}-\underline{\eta}}{\bar{\gamma}-\underline{\gamma}} \quad \equiv \tilde{a} \tag{21}$$

The state of development $\tilde{a}$ from (10) reflects the threshold that, all other things being equal, separates the productivity advantage of technological specialists (given $a_{t-1} < \tilde{a}$) and systemic specialists (given $a_{t-1} > \tilde{a}$) as illustrated in Figure 1. Applying this (individual) argument to the (aggregate) level of the economy highlights that increasing the share of technological specialists, λ, only speeds up convergence if a country's state of development falls short of $\tilde{a}$. After having passed the threshold level $\tilde{a}$, a policy switch which incorporates a shift from more technological to systemic specialists should be realized.[12]

An illustration of the results in (19a)–(20) is provided by Figures 2 – Figure 4. All figures plot the relationships for two different structures of the government budget as represented by the parameters $\rho = 0.3$ (dashed functions) and $\rho = 0.7$ (solid functions) as well as for various extents of the public budget (see figures (a)–(c)). As argued in the context of (11) the impact of the government budget decreases as an economy converges to the technology frontier. This effect is the stronger the more emphasis is laid on enhancing technological skills, i. e. the higher ρ. As a consequence, the solid functions always run above the dashed functions. We now detail the impact of the single policies on the speed of convergence.

The impact of investment, $\frac{\partial a_t}{\partial s}$, Figure 2: Higher investment of either old or young specialists enhances productivity equally (see also footnote 11). A positive effect already arises for an initial state of development equal to $a_{t-1} = 0$. With the

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[12]However, if one thinks about λ as reflecting a certain existing education system it becomes obvious that the corresponding effects would only becomes effective in the intermediate run and hence one might doubt the reasonability of such a policy.

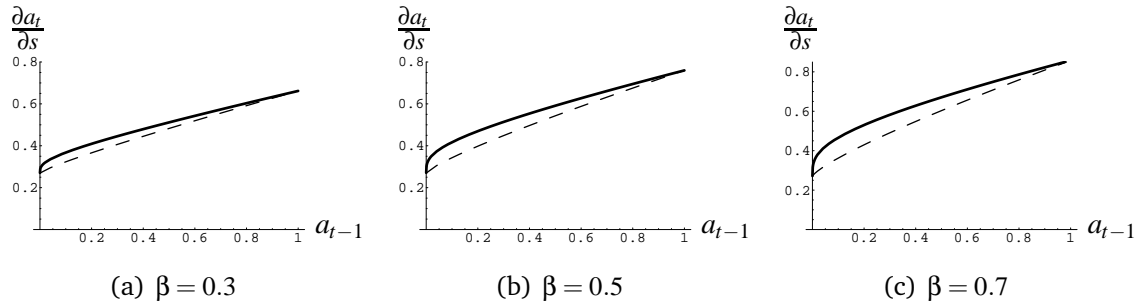| (a) $\beta = 0.3$ | (b) $\beta = 0.5$ | (c) $\beta = 0.7$ |

Figure 2: Investment and convergence

parameters: $\tilde{s} = 0.75$, $g = 0.02$ (exogenous), $\lambda = 0.5$, $\bar{\eta} = 0.6$, $\underline{\eta} = 0.5$, $\bar{\gamma} = 0.6$, $\underline{\gamma} = 0.4$

dashed function: $\rho = 0.3$, solid function: $\rho = 0.7$

exceptions of the two boundary values $a_{t-1} = 0$ and $a_{t-1} = 1$ where dashed and dotted functions intersect, the extent is stronger for high values of ρ. The level of investment, s, affects technological and systemic skills equally. Formally, this results from the fact that investment sizes are outside the brackets in (8). Since investment and government spendings are complementary, the impact of more investment on the speed of convergence increases with the size of the government budget. This can be seen within the derivative in (19a) which is a function of budget size, β, and illustratively by comparing Figures 2(a) – 2(c).

The impact of the budget size, $\frac{\partial a_t}{\partial \beta}$, Figure 3: Increasing the public budget size enhances the speed of convergence which results as a function of the project sizes, productivity growth at the technology frontier, a country's state of development, and of the government budget structure. But it is independent of its absolute level, β (see (19b)).[13] Hence the positive effect of a bigger governmental budget on the speed of convergence holds for all prevailing public budget sizes. Again, with the exceptions of $a_{t-1} = 0$ and $a_{t-1} = 1$ where again dashed and dotted functions intersect, the effect is more pronounced for high values of ρ. In the extreme case of $a_{t-1} = 0$, enhancing public expenditure doesn't speed up convergence (see Figure 3).[14]

The impact of the budget structure, $\frac{\partial a_t}{\partial \rho}$, Figure 4: From (20) and the illustrations in Figure 4 it becomes obvious that increasing ρ has a positive but non-monotonic impact on the speed of convergence. Generally speaking, higher levels of ρ imply a stronger emphasis on technological skills that are linked to productivity at the

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[13]Notice that the shares of specialists doesn't affect the speed of convergence.

[14]This result is in contrast to the afore analyzed impact of investment.
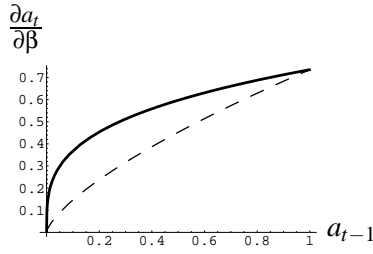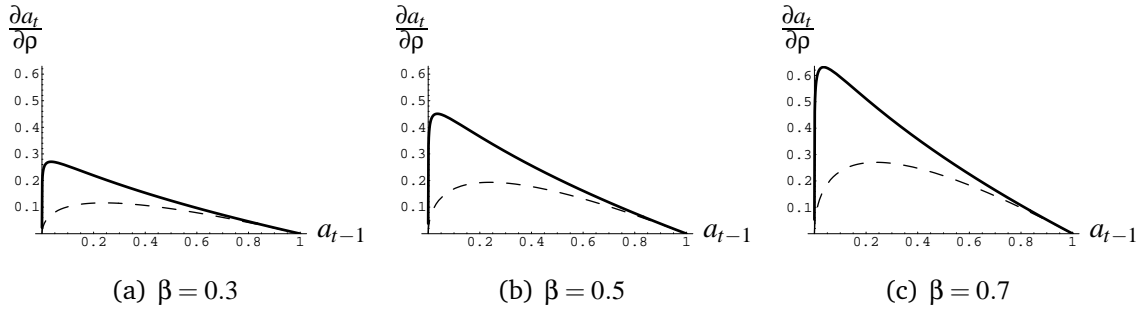
$$\frac{\partial a_t}{\partial \beta}$$

Figure 3: Government expenditures and convergence
parameters: $\tilde{s} = 0.75$, $g = 0.02$ (exogenous), $\bar{\eta} = 0.6$, $\underline{\eta} = 0.5$, $\bar{\gamma} = 0.6$, $\underline{\gamma} = 0.4$
dashed function: $\rho = 0.3$, solid function: $\rho = 0.7$

technology frontier and which increase with the budget size. Increasing ρ thus enhances productivity in the considered economy and the effect is strongest for intermediate states of development.

(a) $\beta = 0.3$

(b) $\beta = 0.5$

(c) $\beta = 0.7$

Figure 4: Structure of the government budget and convergence
parameters: $\tilde{s} = 0.75$, $g = 0.02$ (exogenous), $\bar{\eta} = 0.6$, $\underline{\eta} = 0.5$, $\bar{\gamma} = 0.6$, $\underline{\gamma} = 0.4$
dashed: $\rho = 0.3$, solid function: $\rho = 0.7$

The intuition for this is as follows: If a_{t-1} is small, productivity in the considered economy is low. This impedes vast realization of productivity advances. If in contrast, an economy is quite well developed in the sense of high values of a_{t-1}, the differential between the economy's productivity and productivity at the technology frontier is not very pronounced. Additionally, the relative importance of technological skills, which are strengthened by increases in ρ, diminishes as the economy converges to the technology frontier. Consequently, the more public expenditures are focused on the utilization of the high productivity at the technology frontier, the higher is the corresponding productivity gain of increasing the related technological skills. This gain is maximal for intermediate levels of development, namely if the state of development already allows for 'learning' from the technology frontier and when at the same time the distance to frontier is still significant

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enough to realize productivity gains.[15]

6.2 Assessment of alternative policies

From a policy view, the crucial question is to which extent each of the afore dis-
cussed instruments speeds up convergence and with this to assess alternative pub-
lic policies. In doing so, we derive productivity differentials thereby comparing
higher investment to higher budget sizes, higher budget sizes to restructuring a
given budget, and restructuring the public budget to reorganizing the shares of
specialists. In doing so, we assume that speeding up the process of convergence is
the pursued policy goal. Anyway, we do not assess the derived policy instruments
according to a social welfare function that is maximized by a political actor. To sup-
port the argumentation, the corresponding plots of the differentials are included
in Figures 5–7. It becomes apparent that policy recommendations depend upon
a country's state of development and that for certain parameter constellations a
policy switch with respect to the chosen instrument might be advised throughout
the process of convergence.

Investment size versus amount of public expenditure, $\frac{\partial a_t}{\partial s} - \frac{\partial a_t}{\partial \beta}$: As argued before,
both higher investment and a bigger government budget speed up convergence
though to different extents. Comparing the single effects via considering produc-
tivity differentials leads to the relationships displayed in Figures 5(a) – 5(c).

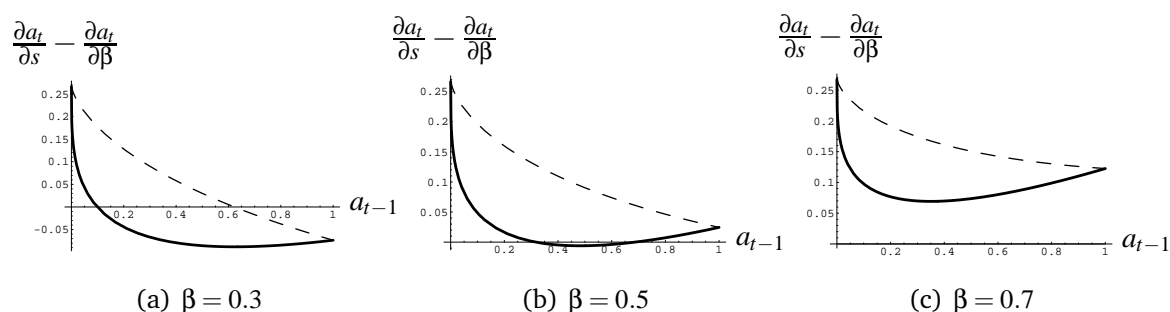(a) $\beta = 0.3$ (b) $\beta = 0.5$ (c) $\beta = 0.7$

Figure 5: Investment vs. amount of the governmental budget
parameters: $\tilde{s} = 0.75$, $g = 0.02$ (exogenous), $\bar{\eta} = 0.6$, $\underline{\eta} = 0.5$, $\bar{\gamma} = 0.6$, $\underline{\gamma} = 0.4$, $\lambda = 0.5$
dashed: $\rho = 0.3$, solid function: $\rho = 0.7$

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[15]Notice that the discussed results are independent of the shares of specialists.

For low levels of the government budget ($\beta = 0.3$), no unambiguously dominating policy recommendation may be derived (see Figure 5(a)): Poorly developed economies benefit more from higher investment, whereas more developed regions display a faster convergence process if public expenditures are extended in order to enhance skills. This result basically holds for both displayed structures of the public budget, $\rho = 0.3$ and $\rho = 0.7$. Both the dashed and the dotted functions intersect the horizontal axis thereby implying that after having passed a certain state of development, as indicated by the intersection of the non-linear functions with the horizontal axis, the economy should realize a policy switch from increasing investment to increasing public expenditure. Such a switch in the preferable policy is due to the changing relative importance of technological and systemic skills throughout the process of convergence whereas higher investment enhances productivity uniformly throughout the process of convergence. As argued before, higher investments increase productivity with respect to both technological and systemic skills. Productive spendings instead augment productivity depending on the prevailing budget structure. Hence, the critical value of the technology level, which separates the ranges of dominance of any policy, decreases with an increase in ρ. The reason is that an increase in ρ means a restructuring of the government budget in favor of technological skills which become relatively less important as a country catches up. Figure 5(c) shows the impact of the same policy options on the convergence process but for a already high public budget. Since government expenditures are already high, the gain from an additional increase in the government share is smaller. Besides, the productivity gain which results from an increase in individual investment sizes is large, as it leads to relatively high individual productivity. Hence, for all states of development, an increase in investment induces a faster catching-up process than a corresponding increase in productive government spendings.

Amount versus structure of the government budget, $\frac{\partial a_t}{\partial \rho} - \frac{\partial a_t}{\partial \beta}$: Comparing the impact of a higher ρ vs. a higher β leads to the question if either a restructuring of an existing budget or its enhancement given a certain budget structure contributes more to speeding-up convergence. Figures 6(a)–6(c) plot the corresponding productivity differentials, $\frac{\partial a_t}{\partial \rho} - \frac{\partial a_t}{\partial \beta}$, again for alternative amounts of the governmental budget, β, and for different compositions, ρ. The underlying partial derivatives are only functions of investment, s_o and s_y, productivity growth at the technology frontier, g, as well as of the government budget parameter, ρ and β. Neither individual skills nor the overall composition of specialists affects these results and

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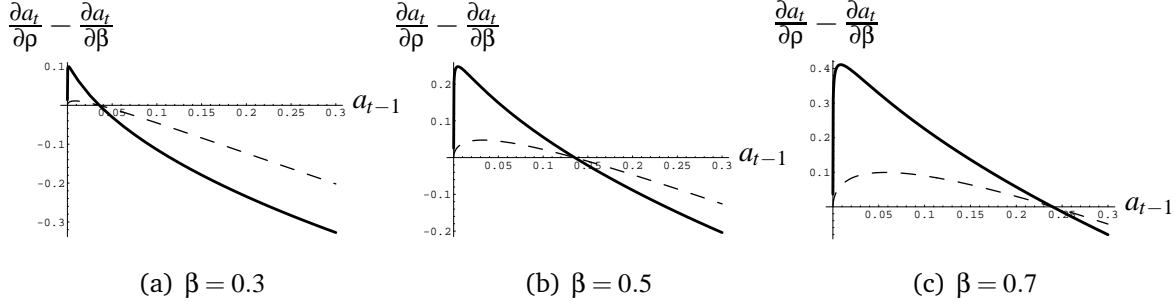non-monotonic relationships characterize the productivity differentials.

$$\frac{\partial a_t}{\partial \rho} - \frac{\partial a_t}{\partial \beta} \qquad\qquad \frac{\partial a_t}{\partial \rho} - \frac{\partial a_t}{\partial \beta} \qquad\qquad \frac{\partial a_t}{\partial \rho} - \frac{\partial a_t}{\partial \beta}$$

(a) $\beta = 0.3$ (b) $\beta = 0.5$ (c) $\beta = 0.7$

Figure 6: Structure vs. amount of the governmental budget
parameters: $\tilde{s}$, $\bar{\eta} = 0.6$, $\underline{\eta} = 0.5$, $\bar{\gamma} = 0.6$, $\underline{\gamma} = 0.4$, $\lambda = 0.5$ $g = 0.02$
dashed: $\rho = 0.3$, solid function: $\rho = 0.7$

The following becomes obvious: The productivity differentials are positive as long as an economy is poorly developed, and negative for economies close to the technology frontier. The according threshold state of development results from(19b) and (20) according to

$$a_{t-1} = \exp^{-\frac{1}{\beta(1-\rho)}} \tag{22}$$

It is graphically illustrated by the intersection between the non-monotonic functions and the horizontal axis in 6(a)–6(c). Accordingly, for lagging economies, restructuring the government budget according to a higher ρ is the preferred convergence policy whereas economies with a state of development beyond the threshold value should instead increase the budget size. This implies an unambiguous recommendation of a policy switch from restructuring a given governmental budget for poorly developed economies to then increasing higher public expenditures after having passed a certain threshold state of development as determined by (22).

Comparing Figures 6(a)–6(c) highlights that the corresponding threshold is increasing in β thereby making a restructuring of the public budget the favorite policy for even a wider range of states of development. To understand this result one must look at the mechanism that drives convergence: A higher value of ρ acts like enhancing technological skills. Their contribution to convergence is the higher the less developed a region is. After having passed a certain degree of development this productivity enhancing effect is reduced while the productivity enhancing effect of a higher β becomes relatively more important. If β is small the

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marginal contribution of a higher budget dominates the marginal contribution of a restructuring for most states of development since the threshold level of development is very small. Since it increases with β, restructuring the budget becomes than reasonable for a wider range of development.

For low levels of ρ as represented by the dashed function, the differentials are not so distinct as for high ρ as represented by the solid function. This implies that changes of both parameters have quite similar (positive) extents. However, for high levels of ρ a further increase even more fosters convergence compared to increasing the budget. This predominance is reinforced as the governmental budget increases. Again the reason for this result lies in the strong contribution of all activities that act as enhancing technological skills as long as a country is poorly developed.

Restructuring the public budget vs. restructuring the composition of specialists, $\frac{\partial a_t}{\partial \rho} - \frac{\partial a_t}{\partial \lambda}$: Figure 7 compares the impact of a change in the structure of the public budget to a change of the composition of specialists. For all states of development, an increase in ρ contributes more to speeding up convergence than an increase in λ. Economies far away from the technology frontier experience a productivity gain from both policy measures. Yet the productivity shift which results from a restructuring of the public budget is larger. Economies close to the technology frontier still profit from a rise in ρ. Simultaneously, as their state of development exceeds the threshold level $\tilde{a}$, convergence is slowed down by means of an increase in the share of technological specialists. Hence, an increase in the weight given to productivity at the technology frontier, ρ, is unambiguously preferable to an increase in the share of technological specialists.

7 Coordinated policies

The analysis in the preceding section assumes that only the considered economy realizes the respective policy. In this section we will contrast the outcomes with the setting where the policies of different countries are coordinated. For example, countries pertaining to the European Union could generate common policies in order to foster convergence. A common policy to increase government expenditure, for instance, then would enhance not only the productivity within a single country but if feedback effects the economies' policies are considered, also productivity
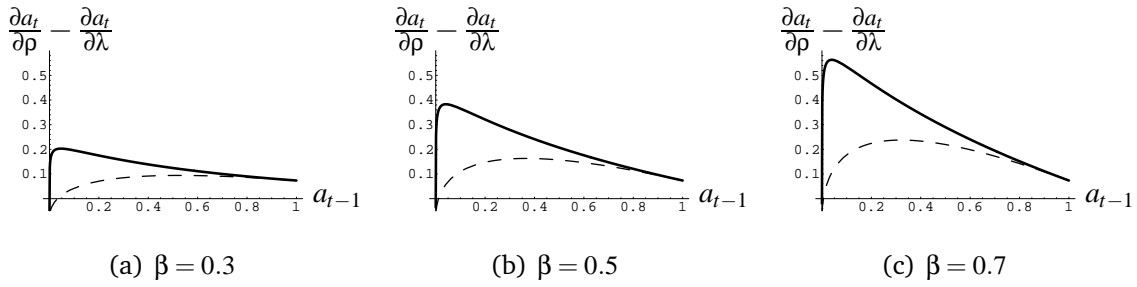
(a) $\beta = 0.3$	(b) $\beta = 0.5$	(c) $\beta = 0.7$

Figure 7: Structure of the government budget vs. composition of specialists
parameters: $\tilde{s}$, $\bar{\eta} = 0.6$, $\underline{\eta} = 0.5$, $\bar{\gamma} = 0.6$, $\underline{\gamma} = 0.4$, $\lambda = 0.5$
dashed: $\rho = 0.3$, solid function: $\rho = 0.7$

at the technology frontier. This can crucially affect the outcomes referring to the convergence speed discussed before.

Recall that the equilibrium growth rate at the technology frontier, is given by (18). Inserting this equilibrium growth rate into the equation of motion (17) gives

$$a_t = \frac{\lambda\bar{\eta} + (1-\lambda)\underline{\eta} + \beta a_{t-1}^{1-\rho} + \left(\lambda\underline{\gamma} + (1-\lambda)\bar{\gamma}\right) a_{t-1}}{\lambda\bar{\eta} + (1-\lambda)\underline{\eta} + \beta + \lambda\underline{\gamma} + (1-\lambda)\bar{\gamma}} \tag{23}$$

which describes an economy's distance to frontier given that all involved countries implement the same policy measures.

A coordinated policy concerning the investment size obviously does not influence the convergence process

$$\frac{\partial a_t}{\partial s_o} = \frac{\partial a_t}{\partial s_y} = 0 \tag{24}$$

Of course, relaxing capital market frictions still enhances productivity. But in the setting of coordinated policy, the positive productivity effect applies to all countries equally thereby leaving the convergence process unaffected.

The impact of a coordinated rise in productive government spendings, β, is displayed in Figures 8(a) to 8(c). Productivity is increased due to the rise in government expenditures. But again the productivity increase in the considered country is accompanied by a productivity increase in all other countries. Moreover, the positive productivity effect is less pronounced for less developed regions and more pronounced for higher ρ, see Figure 3. The overall effect on the convergence process hence depends on the country's state of development. Regions with low
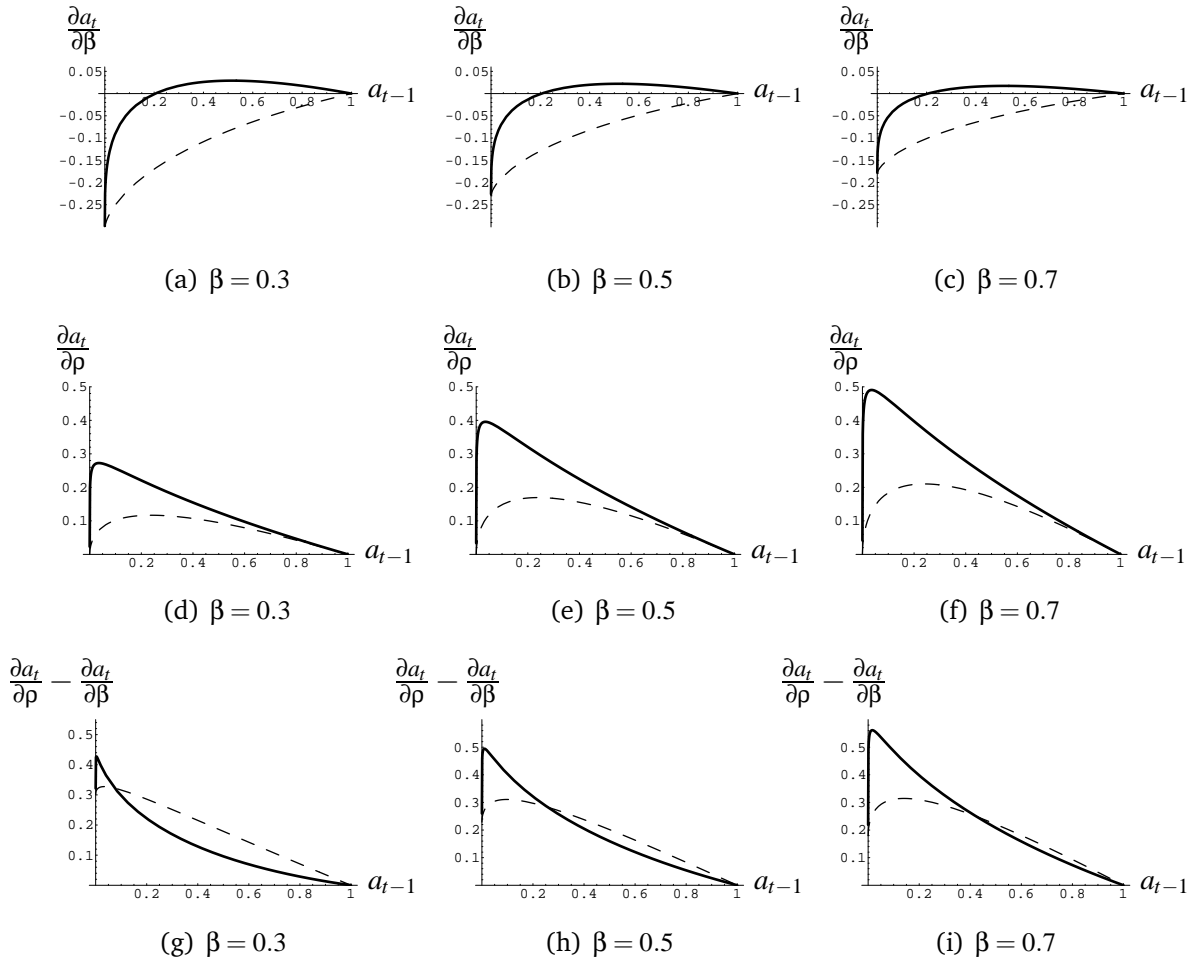
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Figure 8: Coordinated policies

assumed parameters: $s_o = 1$, $s_y = 0.5$, $\bar{\eta} = 0.6$, $\underline{\eta} = 0.5$, $\bar{\gamma} = 0.6$, $\underline{\gamma} = 0.4$, $\lambda = 0.5$; dashed: $\rho = 0.3$, solid function: $\rho = 0.7$

technology levels will loose from a coordinated rise in β, where as the convergence speed of regions with higher technology levels will increase.

With respect to the structure of governmental activity, ρ, the essential results remain unchanged. The gain from restructuring the governmental budget in favor of high productivity at the technology frontier is largest for intermediate levels of development, as can be seen in Figures 8(d) to 8(f). The reason is that growth at the technology frontier is not influenced by the composition of governmental activity. Nevertheless, the comparison between the effectiveness of restructuring the governmental budget, ρ, versus an enlargement of governmental activity, β, now is unambiguous: Figures 8(g) to 8(i) show that for all levels of development, a coordinated increase in ρ unequivocally induces higher convergence speed than a

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coordinated increase in governmental activity. This outcome is due to the fact that a coordinate increase in β has less effect on convergence than an isolated increase in β as explained above.

In contrast to the ambiguous impact of an isolated increase in the share of technological specialists analyzed in the previous section, a coordinated increase in λ unambiguously accelerates convergence. As already mentioned above, productivity of countries with development levels below $\tilde{a}$ is increased. Simultaneously, productivity of countries with development beyond $\tilde{a}$ is decreased. Since the slowdown in growth is the larger, the more developed a country is, a coordinated increase in the share of technological specialists unambiguously increases convergence speed as displayed in figures 9(a) to 9(c). Correspondingly, figures 9(d) to 9(f) compare a change in the structure of the governmental budget with a change in the composition of specialists. The result is the same as already achieved above: An increase in ρ unambiguously leads to an increase in convergence speed, independent from the development level of the considered country.
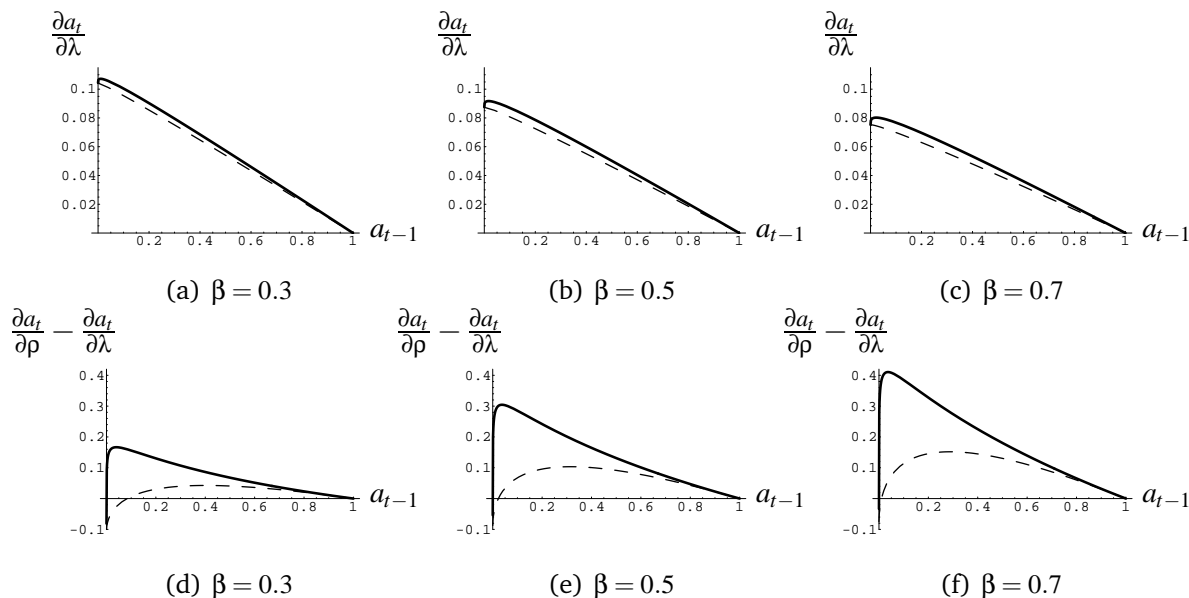

Figure 9: Structure of the government budget vs. composition of specialists
parameters: $\tilde{s}_0 = 1$, $s_y = 0.5$, $\bar{\eta} = 0.6$, $\underline{\eta} = 0.5$, $\bar{\gamma} = 0.6$, $\underline{\gamma} = 0.4$, $\lambda = 0.5$
dashed: ρ = 0.3, solid function: ρ = 0.7

8 Conclusions

In a model with different types of highly skilled specialists we show that convergence can be supported by various government policies. We focus on easier access to investment, an increase in government spendings, a restructuring of the government budget and a change in the composition of specialists. An increase in productive public expenditure fosters productivity of both types of specialists thereby increasing growth of the considered economy. The structure of the government budget determines the weight of productivity at the technology frontier versus productivity in the respective economy. More weight on the productivity at the technology frontier unambiguously accelerates convergence. An increase in the share of technological specialists, e. g. via a change in the education system, induces ambiguous effects on the catching up process. If the development level is below a threshold value, convergence is accelerated. If the development level is relatively high, convergence speed is reduced.

In comparing the effectiveness of the different policy measures we find several parameter settings in which policy switches are preferable. A country with a quite low development level can realize a faster convergence process by an increase in the investment size than by an increase in government budget. If the government share is not too high, this preferable policy changes as the economy approaches the technology frontier. Countries with a higher development level will gain more from an increase in government activity than from a rise in investment size. The same argument applies to the amount and the structure of government expenditures. Poorly developed economies gain more from restructuring an existing public budget whereas economies close to the technology frontier will profit from an expansion of government expenditures.

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