



## Public policies and convergence <sup>☆</sup>

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### ABSTRACT

This paper employs a dynamic framework to compare the effects of alternative government policies 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 implies 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 phenomenon 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 skills lying beyond pure technological knowledge, for being successful in innovation and growth. 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 where 'backwardness' as discussed, e.g. by [Gerschenkron \(1962\)](#) does not necessarily refer to a disadvantage if argued from a long-run perspective (see also [Acemoglu et al. \(2006\)](#), [King and Levine \(1993\)](#), [Audretsch and Thurik \(2001\)](#); [Aghion and Howitt \(2009\)](#) as well as [Acemoglu \(2009\)](#) provide recent overviews).

Especially in industrialized economies such as, e.g. OECD countries, but increasingly also in emerging economies, human capital is broadly seen as being the central determinant for innovation and growth. Based on the seminal work of [Lucas \(1988\)](#), the aforementioned distinction in skilled and unskilled workers already represents a refinement. But nevertheless, this distinction does not hit the mark underlying the European Paradox. It is reasonable to assume that the

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majority of individuals in these countries is highly skilled but that there exists a broad variety of skills, each contributing differently to catching-up. At the same time one might notice that the state of development among those countries that have available highly qualified workers also varies tremendously. Hence one has to take a closer look at the peculiarities of highly skilled workers, on the one hand, and the state of development, in which they are active, on the other hand. Throughout the process of convergence, aside from pure technological knowledge other skills also seem to gain importance. These could mostly be interpreted, e.g. as a basic understanding of the timing of an innovation, societal acceptance of a new technology or just a feeling for the applicability of an idea within a certain economic environment.

Usually, these skills are the outcome of specific education policies which likewise 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). An instrument available, among others, is public spending on education and it is not only the absolute amount, but also its composition with respect to various applications, that has an impact on the success of spending in education and henceforth on convergence. Consequently, the government might choose among a large variety of possible policies. The question that has to be addressed in this context includes how to determine which policy shall be carried out to enhance education and thus productivity.

Based on this reasoning this paper may be linked to the existing literature as follows. Education investments are of interest in the work of Blankenau (2005) or Blankenau et al. (2007) who find a positive relationship between public education expenditure and growth for developed countries. Benhabib and Spiegel (2005) provide an overview on the impact of human capital on growth. Krueger and Lindahl (2001) or Vandenbussche et al. (2006) present a more skeptical view on the impact of education policy for industrialized countries. A more general view on the impact of productive government expenditure on growth has been well recognized since the seminal work of Aschauer (1989, 1990) who focuses on infrastructure investment. But the overall valuation of the studies is mixed. The basic theoretical framework that introduced productive public inputs in a growth framework was provided by Barro (1990) and has been extended to include, amongst others, aspects related to our paper regarding development (e.g. Chatterjee et al., 2003) or the splitting up of the government budget in consumptive and productive expenditure which has been addressed, e.g. by Turnovsky and Fisher (1995). 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 in Romp and deHaan (2007) or Irmen and Kuehnel (2009). Nevertheless, the relationship between productive government expenditure, human capital and convergence still remains an unresolved puzzle.

Being conscious about the growth enhancing effect of productive public spending, the main question addressed in this paper is to determine those policies that speed up convergence of an economy to the world 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). In contrast to them, we focus exclusively on highly skilled specialists and thus there exists no clear productivity ranking between the two agents that is independent of the economy's state of development. Each specialist is endowed with two types of skills though to different extents. Accordingly, we distinguish between technological specialists whose productivity is mostly related to productivity at the world technology frontier and systemic specialists whose productivity is closely related to their regional embeddedness. We introduce productive government activity thereby focusing on the amount and structure of government expenditure and correspondingly on the resulting impact on individual productivity and hence on the development of the economy. In this context it is also shown that public education policy may have the same implication as those policies that tend to mitigate credit market imperfections for young firms. Finally, 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. These policies include increasing the specialists' investment opportunities, the choice of the size and composition of the public input as well as the overall composition of specialists. We carry out policy analysis thereby comparing the contexts of isolated public policies. In doing so it is assumed that successful policies will not be copied by other countries. 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 paper is organized as follows. Section 2 describes the setup of the model which includes the determinants of individual productivity, the choice of the project size and the implementation of the government. The macroeconomic equilibrium is derived in Section 3. Sections 4 and 5 distinguish the consequences of public policies for the two frameworks of isolated and coordinated policies and provide some selected simulations. Section 6 briefly concludes.

## 2. The model

### 2.1. Two-sector economy

The basic framework is given by a two-sector economy which is composed of a perfectly competitive final good 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

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

where  $A_t(i)$  is productivity of firm  $i$  in the intermediate good sector at time  $t$ . Each intermediate good is produced by a leading specialist who is endowed with certain skills. We detail this aspect throughout the following discussion. The specialist acts as a monopolist and produces the intermediate good 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 specialist. She faces a competitive fringe of imitators that can produce the same intermediate good but at higher cost. This forces the specialists to charge a limit price,  $p_t(i) = \xi > 1$ , in order to avoid competition by imitators. At the same time it allows for positive profits. To ensure that only one specialist is active for each intermediate good it is assumed that  $1/\alpha \geq \xi > 1$ . Given inverse demand (2) and the limit price,  $\xi$ , equilibrium profits in the intermediate good sector are<sup>1</sup>

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

where  $\delta \equiv (\xi - 1)\xi^{-1/(1-\alpha)}$ . Aggregate final output results as  $y_t = \alpha^{-1} \xi^{-\alpha/(1-\alpha)} A_t$ , with  $A_t$  representing the average level of (local) knowledge in the considered economy at time  $t$  according to

$$A_t \equiv \int_0^1 A_t(i) di \tag{4}$$

We assume  $A_t \leq \bar{A}_t$ , where  $\bar{A}_t$  is determined by the most productive country which represents productivity at the world technology frontier (global knowledge). Productivity at the technology frontier grows at rate  $g$  and evolves according to<sup>2</sup>

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

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

$$a_t \equiv A_t/\bar{A}_t \in [0, 1] \tag{6}$$

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 convergence is provided by those factors that affect the productivity of the specialists as well as their overall distribution. Hence, any governmental policy which affects these parameters becomes essential for convergence.

## 2.2. Individual productivity in the intermediate product sector

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

$$A_t(i) = s_t(i)[\eta(i)\bar{A}_{t-1} + \beta\bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \gamma(i)A_{t-1}], \quad \rho \in [0, 1] \tag{7}$$

Here,  $s_t(i)$  is investment size of specialist  $i$  at time  $t$ ;  $\eta(i)$  and  $\gamma(i)$  denote two types of time-invariant skills in the following sense: (i) *Technological skills*,  $\eta(i)$ , 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 who work at universities or in research labs thereby having access to the most advanced knowledge worldwide. (ii) *Systemic skills*  $\gamma(i)$ , 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 a sound background 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.<sup>3</sup> 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, e.g. engineers and managers have different skill advantages, while at the same time having a minimum understanding of the respective other skill advantage. As a consequence specialists are heterogenous in the sense that they are characterized by different sources of productivity.

Government activity enters productivity of the specialist via the individually available amount of (uncongested)<sup>4</sup> productive spending,  $\beta$ , and its composition as determined by the structural parameter  $\rho \in [0, 1]$ . The latter parameterizes

<sup>1</sup> Broadly speaking, one can think of the parameter  $\delta$  as capturing competitive policies. Higher values of  $\delta$  correspond to a less competitive market for intermediates and imply higher profits for the monopolist. A more detailed discussion of the corresponding implications can be found in Acemoglu et al. (2006).

<sup>2</sup> Throughout the paper, the growth rate  $g$  is initially assumed to be exogenous. However, in the context of the macroeconomic equilibrium in Section 3 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.

<sup>3</sup> We abstract from imperfect substitutability of the two skills. A paper that addresses this issue in the context of catching-up is given by Caselli and Coleman II (2006).

<sup>4</sup> This paper does not address issues of congested public inputs as discussed, e.g. by Fisher and Turnovsky (1998) or Eicher and Turnovsky (2000). Instead, it is assumed that the government's spending enters productivity as a pure public good.

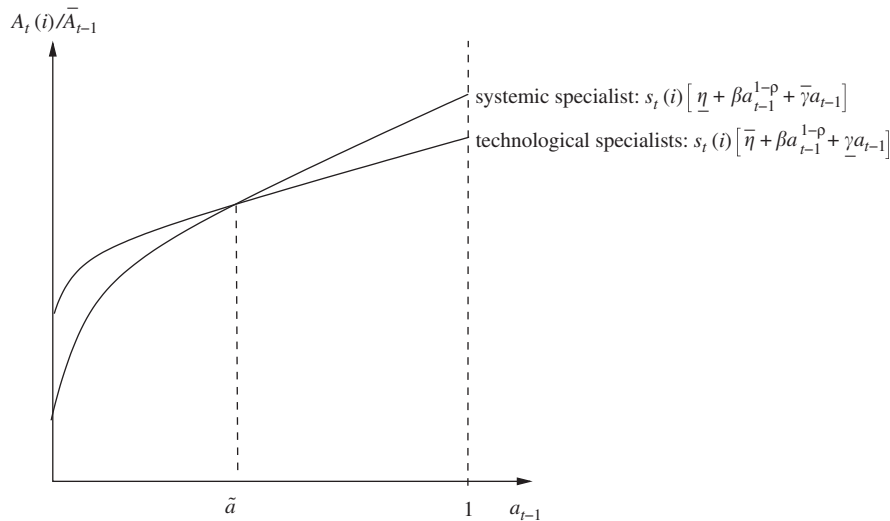


Fig. 1. Technological and systemic specialists.

to which extent government spending places emphasis on activities related to productivity at the technology frontier or on those skills that are more valuable in a regional/local context. Given the benchmark case of  $\rho = 0$ , the total amount of public expenditure enhances 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 global knowledge and thus productivity at the technology frontier ( $\bar{A}_{t-1}$ ). Intermediate values of  $\rho$  imply that the government's budget is divided in the sense that it supports both skills though to a varying extent.

For the sake of simplicity, we assume that there are two possible values for technological and systemic skill levels, respectively;  $\bar{\eta} > \underline{\eta}$  and  $\bar{\gamma} > \underline{\gamma}$ . Given these characteristics, two types of specialists may be identified whose productivity arises according to

$$A_t^{TS}(i) = s_t(i) [\bar{\eta} \bar{A}_{t-1} + \beta \bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \underline{\gamma} A_{t-1}] \quad (8a)$$

$$A_t^{AS}(i) = s_t(i) [\underline{\eta} \bar{A}_{t-1} + \beta \bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \bar{\gamma} A_{t-1}] \quad (8b)$$

Depending upon the prevailing skill advantage, the two types of actors are henceforth called *technological specialists* (see (8a)) and *systemic specialists* (see (8b)).

Fig. 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 is active. The horizontal axis  $a_{t-1}$  represents 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 on the vertical axis. Both functions are derived by dividing individual productivity in (8a) and (8b) by the productivity at the technology frontier,  $\bar{A}_{t-1}$ . In case of identical investment,  $s_t(i)$ , the curves intersect at the state of development<sup>5</sup>

$$a_{t-1} = \frac{\bar{\eta} - \underline{\eta}}{\bar{\gamma} - \underline{\gamma}} \equiv \tilde{a} \quad (9)$$

It becomes apparent that, as long as  $a_{t-1} < \tilde{a}$ , technological specialists are more productive while, in contrast, systemic specialists have a higher productivity if the state of development of the considered economy exceeds  $\tilde{a}$ . This reflects the fact that all other things being equal, the marginal productivity of technological specialists 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.<sup>6</sup>

<sup>5</sup> Given identical investment sizes of both technological and systemic specialists,  $\tilde{a} \leq 1$  only if  $\bar{\eta} - \underline{\eta} \leq \bar{\gamma} - \underline{\gamma}$ . This parameter restriction – which is assumed to hold throughout the paper – implies that technological skills are less spread than systemic skills, an assumption which is quite plausible within developed countries.

<sup>6</sup> 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, highly skilled and lowly skilled entrepreneurs might be distinguished, i.e. there exists a clear productivity ranking between the two agents which is independent of the economy's state of development.

From (4) and (7) the growth rate of the economy's aggregate technology is given by

$$\frac{A_t}{A_{t-1}} = \int_0^1 s_t(i) \left[ \eta(i) \frac{\bar{A}_{t-1}}{A_{t-1}} + \beta \left( \frac{\bar{A}_{t-1}}{A_{t-1}} \right)^\rho + \gamma(i) \right] di \tag{10}$$

Notice that this growth rate 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.<sup>7</sup> As long as it is far away from the technology frontier, technological skills are the major force that drives growth of national productivity and with this also convergence to the technology frontier. While catching-up, the growth rate of national productivity declines. At the same time, technological skills become relatively less important while systemic skills become relatively more important. The same logic applies to the impact of government spending on convergence which diminishes throughout the process of convergence.<sup>8</sup>

### 2.3. The specialists' decisions on the project size and the role of the government

The economy is populated by overlapping generations of risk-neutral agents, each of them living for two periods and discounting the future at rate  $r$ . Each generation is composed of highly skilled young and old specialists who are endowed with skills as detailed before. Hence, in each period there are four different types of agents: young technological specialists, young systemic specialists, old technological specialists, and old systemic specialists. Each of them seeks to maximize the value,  $V_t$ , of the corresponding firm thereby taking into account that higher project sizes indeed increase productivity but also induce higher capital costs,  $k_t(s(i))$ . The cost of investment has to be borne by the specialist and depends upon the project size according to

$$k_t(s_t(i)) \equiv \begin{cases} \phi \kappa \bar{A}_{t-1} & \text{if } s_t(i) = \underline{s} \\ \kappa \bar{A}_{t-1} & \text{if } s_t(i) = \bar{s} \end{cases} \tag{11}$$

with  $\phi < 1$ . The proportionality of investment costs to  $\bar{A}_{t-1}$  ensures balanced growth at the technology frontier, and capital costs are higher for the large project. In each period, the specialists have to decide on the size of investment. There exists a large literature which argues that mostly young firms are credit-constrained, e.g. because they have not yet proven to be successful. In contrast, old firms profit from reputation acquired from previous activities. As a consequence it is easier for old than for young firms to realize bigger projects.<sup>9</sup> Within this model we simplify the analysis in the sense that we allow for two project sizes,  $\underline{s}$  and  $\bar{s} > \underline{s}$ . In each period, specialists choose their project size according to the following reasoning. The firm's value of a young specialist  $i$  is

$$V_{t,y}(s_t(i), i) = \begin{cases} \delta \underline{s} \left[ \eta(i) \bar{A}_{t-1} + \beta \bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \gamma(i) A_{t-1} \right] - \phi \kappa \bar{A}_{t-1} & \text{if } s_t(i) = \underline{s} \\ \delta \bar{s} \left[ \eta(i) \bar{A}_{t-1} + \beta \bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \gamma(i) A_{t-1} \right] - \kappa \bar{A}_{t-1} & \text{if } s_t(i) = \bar{s} \end{cases} \tag{12}$$

Hence, independent of the skill advantage, a young specialist will undertake the small project whenever  $V_{t,y}(\underline{s}, i) > V_{t,y}(\bar{s}, i)$ . A technological specialist will choose the small project size  $\underline{s}$  if

$$\delta \underline{s} [\underline{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}] - \phi \kappa > \delta \bar{s} [\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}] - \kappa \iff \delta < \frac{(1-\phi)\kappa}{(\bar{s}-\underline{s})(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1})} \tag{13}$$

whereas a systemic specialist will decide in favor of the small project size if

$$\delta \bar{s} [\underline{\eta} + \beta a_{t-1}^{1-\rho} + \bar{\gamma} a_{t-1}] - \kappa > \delta \underline{s} [\bar{\eta} + \beta a_{t-1}^{1-\rho} + \bar{\gamma} a_{t-1}] - \phi \kappa \iff \delta < \frac{(1-\phi)\kappa}{(\bar{s}-\underline{s})(\underline{\eta} + \beta a_{t-1}^{1-\rho} + \bar{\gamma} a_{t-1})} \tag{14}$$

Both upper limits of rentability  $\delta$  given in (13) and (14) decrease in  $a_{t-1}$ , hence the sufficient condition

$$\delta < \frac{(1-\phi)\kappa}{(\bar{s}-\underline{s})(\underline{\eta} + \beta + \bar{\gamma})} \equiv \bar{\delta} \tag{15}$$

ensures that all young specialists will undertake the small project independent of the economy's prevailing state of development,  $a_{t-1}$ . Note that an increase in the individually available amount of government spending,  $\beta$ , enhances individual productivity. Hence, the threshold value  $\bar{\delta}$  is reduced and the large project is more likely to be profitable for young specialists. In other words, with sufficiently large government expenditure, the separation effect of capital market incompleteness may vanish. As a consequence, all specialists would run the large project. We refer to this aspect below.

<sup>7</sup> Formally, a quite distinct distance to frontier is reflected by values  $\bar{A}_{t-1}/A_{t-1}$  that strongly exceed unity. The term declines while catching-up.

<sup>8</sup> This holds basically for all values of  $\beta$  but the effect is more pronounced given high values of  $\rho$ .

<sup>9</sup> In their model, Acemoglu et al. (2006) argue that skills of young firms are still revealed and investors only know the borrower's probability of being highly or lowly skilled. In contrast the skills of old entrepreneurs are already known, hence highly skilled old entrepreneurs are less credit-constrained than young entrepreneurs.

Old specialists living in  $t$  who ran the small project when they were young in period  $t-1$  realized profits in  $t-1$  amounting to  $V_{t-1,y}(\underline{s},i)$  as defined in (12). With  $r$  denoting the interest rate, old specialists hold wealth  $(1+r)V_{t-1,y}(\underline{s},i)$  when they become old. Hence old specialists need less outside capital to run a project. The large project with size  $\bar{s}$  may be profitable for old specialists since their equity mitigates the credit market imperfection. Capital costs only accrue with respect to outside capital.<sup>10</sup>

The firm value of an *old* specialist  $i$  is

$$V_{t,o}(s_t(i),i) = \begin{cases} \delta \underline{s} [\eta(i) \bar{A}_{t-1} + \beta \bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \gamma(i) A_{t-1}] - \max\{\phi \kappa \bar{A}_{t-1} - (1+r)V_{t-1,y}, 0\} & \text{if } s_t(i) = \underline{s} \\ \delta \bar{s} [\eta(i) \bar{A}_{t-1} + \beta \bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + \gamma(i) A_{t-1}] - \max\{\kappa \bar{A}_{t-1} - (1+r)V_{t-1,y}, 0\} & \text{if } s_t(i) = \bar{s} \end{cases} \quad (16)$$

It might be shown that, independent of their respective skill advantage, all old specialists will undertake the large project, whenever  $V_{t,o}(\bar{s},i) > V_{t,o}(\underline{s},i)$ . A sufficient condition for profits to be large enough is<sup>11</sup>

$$\delta > \frac{\kappa \left(1 + \frac{1+r}{1+g} \phi\right)}{(\bar{s}-\underline{s})\eta + \frac{1+r}{1+g} \underline{s}\eta} \equiv \underline{\delta} \quad (17)$$

In the following, we restrict the discussion to the case  $\delta \in (\underline{\delta}, \bar{\delta})$  indicating the degree of market competitiveness and determining the profitability of the investment projects. One might summarize that for  $\delta \in (\underline{\delta}, \bar{\delta})$ , young specialists will decide to run the small project with size  $\underline{s}$ , whereas all old specialists will decide to run the large project with size  $\bar{s} > \underline{s}$ . If competitiveness would be lower ( $\delta > \bar{\delta}$ ), monopoly profits in the intermediate sector would be high and both young and old entrepreneurs would decide to run the large project. In contrast, if competitiveness would be even higher ( $\delta < \underline{\delta}$ ), both young and old specialists would decide to run the small project. Within Section 4 we detail how government activity affects these relationships.

With respect to government activity, we focus on the amount and structure of government expenditure, on the resulting impact on individual productivity and hence on the development of the economy. For the sake of simplicity it is assumed that the government budget is balanced in each period. Revenues are created by taxes levied on the firm value as given in Eqs. (12) and (16), respectively. In what follows we assume that in each period half of the specialists are old and half are young. Aggregate tax revenues in  $t$  are then given by  $\frac{1}{2} \tau_y V_{t,y} + \frac{1}{2} \tau_o V_{t,o}$ . Additionally, we impose a lump sum subsidy  $z_t$  which could be negative (lump sum tax) as well, in order to balance the government budget.

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 spending on education. Another component provides an indication for the emphasis as regards the content of public spending. This includes the structure of the budget as well as the determination of the respective shares of the heterogeneous 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.

### 3. Macroeconomic equilibrium and public policies

#### 3.1. Equation of motion and growth at the technology frontier

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 as determined by productivity at the firm level; (ii) the national level which focuses on the economy'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. Notice that policy implications differ depending on whether the growth rate of productivity at the world technology frontier is assumed to be exogenous or not. We detail this in Sections 4 and 5.

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 productivity increases. An initially given distance to the frontier vanishes over time due to the country's growth process thereby inducing convergence of the country to the technology frontier.

From an aggregate perspective, another policy variable which is not included in (10) 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  $\lambda$  of technological specialists and the share  $1-\lambda$  of systemic

<sup>10</sup> In any case, we exclude negative credits, so capital costs are not allowed to be negative.

<sup>11</sup> The derivation of this sufficient condition is given in the mathematical appendix.

specialists. Average productivity of young specialists arises according to

$$A_t^y = \lambda \int_0^1 A_t^{s^y}(i) di + (1-\lambda) \int_0^1 A_t^{s^o}(i) di \quad (18)$$

$$= \underline{s}[(\lambda\bar{\eta} + (1-\lambda)\underline{\eta})\bar{A}_{t-1} + \beta\bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + (\lambda\underline{\gamma} + (1-\lambda)\bar{\gamma})A_{t-1}] \quad (19)$$

Analogously one might derive average productivity of old specialists,  $A_t^o$ , with the sole difference that old specialists realize other project sizes,  $\bar{s} \geq \underline{s}$ , and<sup>12</sup>

$$A_t^o = \bar{s}[(\lambda\bar{\eta} + (1-\lambda)\underline{\eta})\bar{A}_{t-1} + \beta\bar{A}_{t-1}^\rho A_{t-1}^{1-\rho} + (\lambda\underline{\gamma} + (1-\lambda)\bar{\gamma})A_{t-1}] \quad (20)$$

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

$$A_t = \frac{1}{2}[A_t^o + A_t^y] \quad (21)$$

From (5) and (6), an economy's distance to the frontier results in

$$a_t = \frac{A_t}{(1+g)\bar{A}_{t-1}} \quad (22)$$

This, together with Eqs. (19)–(21) determines an economy's process of convergence according to the equation of motion

$$a_t = \frac{\bar{s}}{1+g}[\lambda\bar{\eta} + (1-\lambda)\underline{\eta} + \beta a_{t-1}^{1-\rho} + (\lambda\underline{\gamma} + (1-\lambda)\bar{\gamma})a_{t-1}] \quad (23)$$

where  $\bar{s} \equiv (\bar{s} + \underline{s})/2$  represents average investment of old and young specialists.

To close the model, equilibrium growth of productivity at the technology frontier has to be determined. It may be derived by evaluating (23) 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

$$g^* = \bar{s}[\lambda(\bar{\eta} + \underline{\gamma}) + (1-\lambda)(\bar{\gamma} + \underline{\eta}) + \beta] - 1 \quad (24)$$

It is a function of individual skills, the shares of technological and systemic specialists, investment size, and public spending. 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,  $\beta$ , but is independent of its composition,  $\rho$ . This is in strong contrast to an economy's path of convergence to the technology frontier,  $a_t$ , which is increasing in both  $\beta$  and  $\rho$  (see (23)).

### 3.2. Policy implications

Within the considered framework, the goal of government policy is catching-up of lagging economies to the technology frontier. This goal may be achieved by advancing the economy's labor force as determined by productivity of the heterogenous specialists and/or by affecting their overall distribution. From a formal point of view, the starting point of the analysis is (23).

*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 (7)). Higher investment sizes (e.g. via easier access to private capital) unequivocally spur the specialists' productivity thereby affecting technological and systemic skills uniformly. Notice that enhancing private investment does not necessarily require fiscal instruments as, e.g. investment subsidies. Government intervention might also consist of institutional policies which at the end are targeted on relaxing possibly existing credit market imperfections. We do not detail this aspect here since emphasis is not placed on the sources of higher productivity but on the consequences of higher productivity on catching-up. Instead we focus on the impact of government expenditure, its amount and composition, as well as on the overall composition of the heterogenous specialists. This latter decision is independent of the amount and structure of the public budget. At an individual level, the analysis is interpreted as reflecting skill-enhancing education policies that result as a consequence of either higher public spending 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 placed by the government. This argument has been detailed before in Section 2.2.

From a formal point of view, the analysis conducts a sensitivity analysis of the equation of motion (23) with respect to the government parameters ( $\beta$ ,  $\rho$ ,  $\lambda$ ) and to investment ( $s$ ) in order to derive the single effect of any policy. Due to

<sup>12</sup> This assumption is in accordance with the fact that younger firms usually are more frequently credit-constrained than old and well-known firms. See also the discussion carried out before in the context of the microfoundation (Section 2.3) and in the mathematical appendix.

complementarity between the skills on the one hand and investment ( $s$ ) and the government budget ( $\beta$ ,  $\rho$ ) on the other hand, any policy unequivocally enhances the productivity of a single specialist, though to a different extent.

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,  $\lambda$ , will be analyzed thereby capturing the aggregate perspective of government policy.

In what follows, the focus will be on determining those policies that speed up convergence of an economy to the technology frontier. In doing so, no attention is paid to the costs that are induced by any policy. We are quite aware of the fact that an overall assessment of any governmental policy, especially in the context of welfare analysis, would imply to derive the net effect, i.e. including costs and benefits of such a policy. Nevertheless, following the arguing within the public choice literature, we think that it is quite reasonable to assume that governments do not always consider all relevant aspects when deciding on a certain policy.<sup>13</sup> Given a certain state of development,  $a_{t-1}$  within (23), that policy will be preferred that results in a higher level of  $a_t$ . 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 (24), 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 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.<sup>14</sup> To substantiate the line of argumentation, some selected simulation plots are provided.

## 4. Isolated policy

### 4.1. 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 (23) with respect to the considered parameter. Throughout this section we assume that productivity growth at the technology frontier,  $g$ , is exogenous. This allows us to interpret the consequences of choices of instruments as an isolated policy of the considered economy.

Besides, one has to bear in mind that government activity might affect the endogenously determined choice of the project sizes via changing the threshold levels  $\bar{\delta}$  in (15) and  $\underline{\delta}$  in (17). We detail this argument for the impact of an increase of public expenditure and shortly sketch the implications for the other mentioned policy instruments.

An illustration of the results is provided by Figs. 2–4 that 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 magnitudes of the public budget (see Figs. (a)–(c)) thereby indicating the positive impact of public expenditure on individual productivity.

*The impact of the budget size:* It is straightforward that productivity of the specialists increases with the amount of public expenditure and with this the speed of convergence increases as well. Formally, this results from

$$\frac{\partial a_t}{\partial \beta} = \frac{\tilde{s}}{1+g} \cdot a_{t-1}^{1-\rho} > 0 \quad (25)$$

The parameter  $g$  reflects productivity growth at the technology frontier which the specialists consider as being exogenous. Eq. (25) illustrates that the speed of convergence 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 is independent of the shares of specialists. The resulting effect on convergence increases with a country's state of development,  $a_{t-1}$ , but decreases as the economy approaches the technology frontier.<sup>15</sup> Hence, although the sign is unequivocally positive, the strength of the effect is weakened throughout the process of convergence thereby reflecting decreasing returns of the mentioned instrument,  $\beta$ . With the exceptions of  $a_{t-1} = 0$  and 1, where the dashed and dotted functions intersect, the effect is more pronounced for high values of  $\rho$ . In the extreme case of  $a_{t-1} = 0$ , enhancing public expenditure does not speed up convergence. Fig. 2(a) illustrates these considerations.

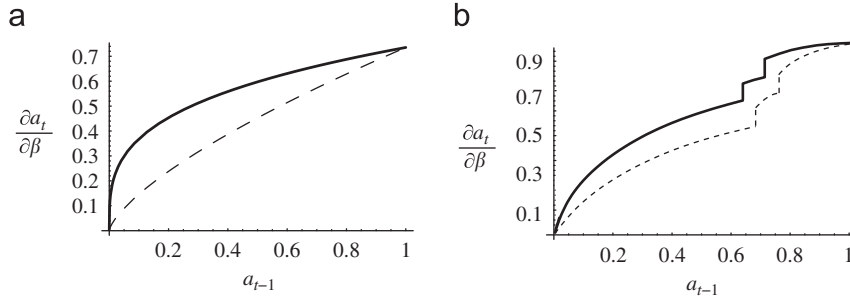
As long as the restriction  $\delta \in (\underline{\delta}, \bar{\delta})$  is fulfilled, this argumentation holds for all levels of  $\beta$ . But taking a closer look at the threshold values  $\underline{\delta}$ ,  $\bar{\delta}$  it becomes obvious that they react differently to an increase of the public budget size,  $\partial \bar{\delta} / \partial \beta < 0$  and  $\partial \underline{\delta} / \partial \beta = 0$ . Increasing the amount of public expenditure reduces the interval  $\delta \in (\underline{\delta}, \bar{\delta})$  in which investment sizes are separated between old and young firms in any case. This implies that it becomes more probable for young firms also to choose the large project size. It is possible to determine the critical level of public expenditure,  $\tilde{\beta}$ , that leads to  $\delta > \bar{\delta}$ , i.e. a situation in which the large project size may also become optimal for young specialists although it implies higher capital

<sup>13</sup> E.g. the rich literature on public choice explicitly abstracts from welfare maximizing agents.

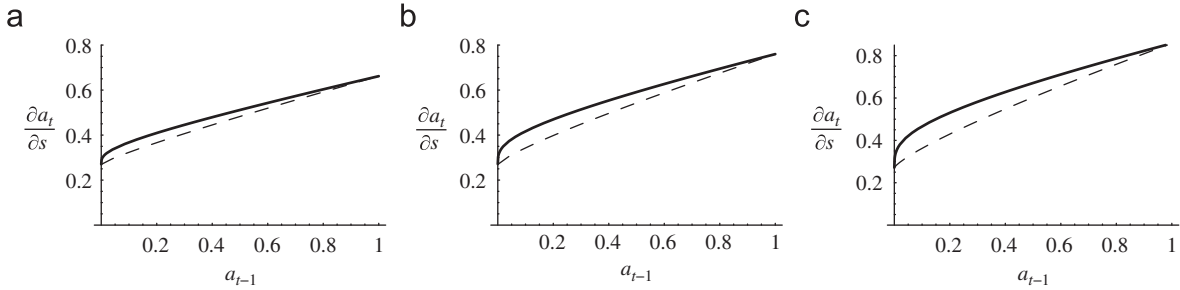
<sup>14</sup> Notice that this is a different perspective from the one discussed by Acemoglu et al. (2006) who compare the impact of innovation and imitation strategies that are carried out by the individual firms.

<sup>15</sup> It is easy to show that the derivative of (25) with respect to the state of development is negative.

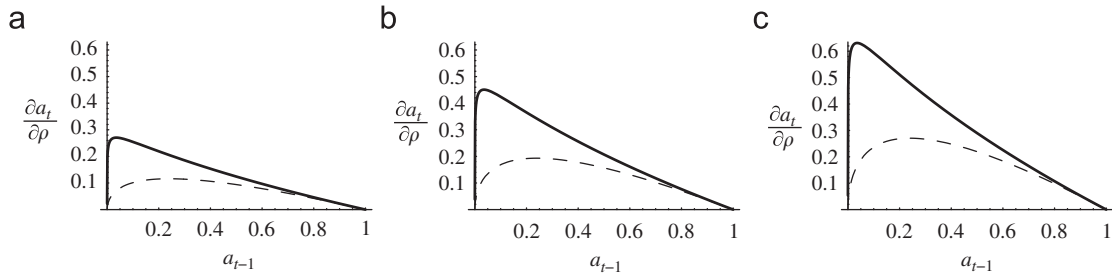




**Fig. 2.** Government expenditure and convergence parameters:  $\bar{s} = 0.75, g = 0.02$  (exogenous),  $\bar{\eta} = 0.6, \underline{\eta} = 0.5, \bar{\gamma} = 0.6, \underline{\gamma} = 0.4, \phi = 0.5, \kappa = 1, \delta = 0.75$ . Dashed function:  $\rho = 0.3$ , solid function:  $\rho = 0.7$ . (a)  $\beta = 0.2 < \tilde{\beta}$ ; (b)  $\beta = 0.5 > \tilde{\beta}$ .



**Fig. 3.** Investment and convergence parameters:  $\bar{s} = 0.75, g = 0.02$  (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:  $\rho = 0.7$ . (a)  $\beta = 0.3$ ; (b)  $\beta = 0.5$ ; (c)  $\beta = 0.7$ .



**Fig. 4.** Structure of the government budget and convergence parameters:  $\bar{s} = 0.75, g = 0.02$  (exogenous),  $\bar{\eta} = 0.6, \underline{\eta} = 0.5, \bar{\gamma} = 0.6, \underline{\gamma} = 0.4$ . Dashed:  $\rho = 0.3$ , solid function:  $\rho = 0.7$ . (a)  $\beta = 0.3$ ; (b)  $\beta = 0.5$ ; (c)  $\beta = 0.7$ .

costs. If government expenditure exceeds the threshold value  $\tilde{\beta}$ , as determined by

$$\beta > \frac{(1-\phi)\kappa - (\bar{s}-\underline{s})\delta(\underline{\eta} + \bar{\gamma})}{\delta(\bar{s}-\underline{s})} \equiv \tilde{\beta} \Rightarrow \delta > \bar{\delta} \tag{26}$$

Eq. (15) ceases to be fulfilled. Formally, this induces an additional and discontinuous effect which is due to capital market imperfection. Such a situation is displayed in Fig. 2(b). With an increase in the country's state of development,  $a_{t-1}$ , productivity rises and the threshold values given in (13) and (14) decline. Hence, young technological and young systemic specialists successively decide to run the large project.<sup>16</sup>

To summarize: In addition to the direct productivity impact of government expenditure presented within Fig. 2(a), there is a discontinuous effect resulting from the switch in the specialists' investment decision, i.e. if the rise in government expenditure is sufficiently high. Since this enhances individual productivity of young firms, public education policy in the sense of an increased budget may have the same implication as those policies that tend to mitigate credit market imperfections for young firms. Consequently, there exists a feedback effect of governmental policy to the choice of investment size of young firms which is the outcome of optimizing specialists. Besides, more ample policies also speed up convergence.

<sup>16</sup> Which type of specialist switches first to the large project depends on the magnitude of government expenditure which together with the other parameters mentioned in (13) and (14) determine the threshold values of the state of development. If these threshold values are below  $\tilde{a}$  as given in (9), technological specialists switch first, if they are above  $\tilde{a}$ , systemic specialists switch first.

*The impact of investment:* Higher investment of either old or young specialists enhances productivity equally.<sup>17</sup> The impact results from

$$\frac{\partial a_t}{\partial s} = \frac{1}{2(1+g)} [\lambda \bar{\eta} + (1-\lambda) \underline{\eta} + \beta a_{t-1}^{1-\rho} + (\lambda \underline{\gamma} + (1-\lambda) \bar{\gamma}) a_{t-1}] > 0 \quad (27)$$

A positive effect already arises for an initial state of development equal to  $a_{t-1} = 0$ . With the exceptions of the two boundary values  $a_{t-1} = 0$  and 1, where the dashed and dotted functions intersect, the extent is stronger for high values of  $\rho$ . 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 (7). Since investment and government spending are complementary, the impact of more investment on the speed of convergence increases with the size of the government budget. This can be seen from the derivative in (27) which is a function of the budget size,  $\beta$ , and illustratively by comparing Figs. 3(a) and (b).

With respect to the endogenous choice of the project size one might state the following impact of increasing the investment size. Basically, jump points as seen within Fig. 2(b) may arise if the public policy affects  $\bar{s}$  and  $\underline{s}$  to a different extent. The reasoning is analogous to the discussion carried out in the context of the enhanced public budget. Contrarily, any policy which enlarges both investment sizes to the same extent, will leave the young specialists' ranking of the project sizes unaffected, as only the difference in the project sizes is relevant.<sup>18</sup> Increasing both project sizes then immediately leads to a rise in aggregate investment. The impact of an increase in the project sizes on productivity is positive, hence convergence is speeded up.

*The impact of the budget structure:* Considering the impact of the government budget structure and its contribution to convergence, a positive but non-monotonic relation arises, which results from<sup>19</sup>

$$\frac{\partial a_t}{\partial \rho} = -\frac{\bar{s}}{1+g} \cdot \beta a_{t-1}^{1-\rho} \underbrace{\ln a_{t-1}}_{> 0} > 0 \quad (28)$$

From (28) and the illustrations in Fig. 4 it becomes obvious that increasing  $\rho$  has a positive but non-monotonic impact on the speed of convergence. Generally speaking, higher levels of  $\rho$  imply a stronger emphasis on technological skills that are linked to productivity at the technology frontier and which increase with the budget size. Increasing  $\rho$  thus enhances productivity in the considered economy and the effect is strongest for intermediate states of development.

The intuition 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  $\rho$ , diminishes as the economy converges to the technology frontier. Consequently, the more public expenditure is focused on the utilization of 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 the frontier is still significant enough to realize productivity gains.<sup>20</sup>

*The impact of the overall composition of specialists:* 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  $\lambda$ . Again it turns out that the state of development of a country is of major importance for the corresponding effect on convergence.<sup>21</sup> It follows that

$$\frac{\partial a_t}{\partial \lambda} \geq 0 \iff a_{t-1} \leq \frac{\bar{\eta} - \underline{\eta}}{\bar{\gamma} - \underline{\gamma}} \equiv \tilde{a} \quad (29)$$

The state of development  $\tilde{a}$  from (9) 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 Fig. 1. Applying this (individual) argument to the (aggregate) level of the economy highlights that increasing the share of technological specialists,  $\lambda$ , 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.<sup>22</sup>

<sup>17</sup> Aggregate investment changes according to  $d\bar{s} = (\partial\bar{s}/\partial\bar{s}) d\bar{s} + (\partial\bar{s}/\partial\underline{s}) d\underline{s}$ . With  $d\bar{s} = d\underline{s} = ds$  the change in aggregate investment is given by  $d\bar{s} = ds$ . In order to simplify the presentation, we just talk about an increase in investment size,  $ds$ .

<sup>18</sup> Compare Eqs. (13), (14) and (17).

<sup>19</sup> Again the discussion is restricted to those parameter constellations that are in accordance with  $\delta \in (\underline{\delta}, \bar{\delta})$ . But in contrast to investment size or  $\beta$  there exists no level of  $\rho$  which leads to values of  $\delta$  outside of this interval.

<sup>20</sup> Notice that the discussed results are independent of the shares of specialists.

<sup>21</sup> Again the discussion is restricted to those parameter constellations that are in accordance with  $\delta \in (\underline{\delta}, \bar{\delta})$ . This is fulfilled for all levels of  $\lambda$ .

<sup>22</sup> However, if one thinks about  $\lambda$  as reflecting a certain existing education system, it becomes obvious that the corresponding effects would only become effective in the intermediate run and hence one might doubt the reasonability of such a policy.

4.2. Assessment of alternative policies

From a policy view, the crucial question is to which extent each of the previously discussed instruments speeds up convergence and with this to assess alternative public 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. We assume that speeding up the process of convergence is the pursued policy goal but as argued before, we do not assess the derived policy instruments according to a social welfare function that is maximized by a political actor. It is impossible to assume particular cost functions for this wide variety of possible public policies, which range from mitigating capital market imperfections to rearranging the education structure in favor of one kind of specialists. Therefore, we focus on the comparison of benefits arising from the different public policies. Depending on the country's state of development we indicate policy instruments which induce major contributions to convergence. To weigh the benefits of these policy instruments against their costs would be a next step in order to derive the optimal level of the respective instrument.

To support the argumentation, the corresponding plots of the differentials are included in Figs. 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,  $\partial a_t / \partial s - \partial a_t / \partial \beta$ :* As argued before, both higher investment and a bigger government budget speed up convergence though to a different extent. Comparing the single effects via considering productivity differentials leads to the relationships displayed in Figs. 5(a)–(c).

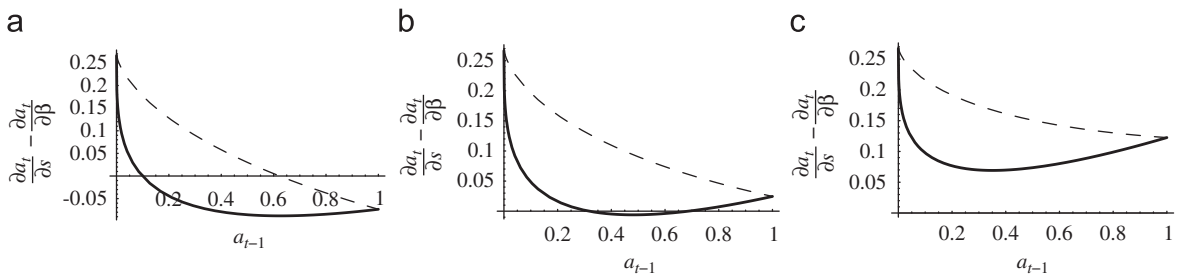


Fig. 5. Investment versus amount of the government budget parameters:  $\bar{s} = 0.75$ ,  $g = 0.02$  (exogenous),  $\bar{\eta} = 0.6$ ,  $\underline{\eta} = 0.5$ ,  $\bar{\gamma} = 0.6$ ,  $\underline{\gamma} = 0.4$ ,  $\lambda = 0.5$ . Dashed:  $\rho = 0.3$ , solid function:  $\rho = 0.7$ . (a)  $\beta = 0.3$ ; (b)  $\beta = 0.5$ ; (c)  $\beta = 0.7$ .

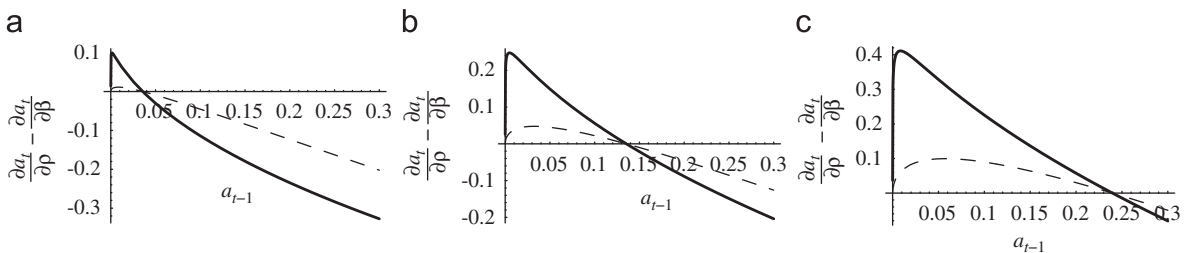


Fig. 6. Structure versus amount of the government budget parameters:  $\bar{s} = 0.75$ ,  $\bar{\eta} = 0.6$ ,  $\underline{\eta} = 0.5$ ,  $\bar{\gamma} = 0.6$ ,  $\underline{\gamma} = 0.4$ ,  $\lambda = 0.5$ ,  $g = 0.02$ . Dashed:  $\rho = 0.3$ , solid function:  $\rho = 0.7$ . (a)  $\beta = 0.3$ ; (b)  $\beta = 0.5$ ; (c)  $\beta = 0.7$ .

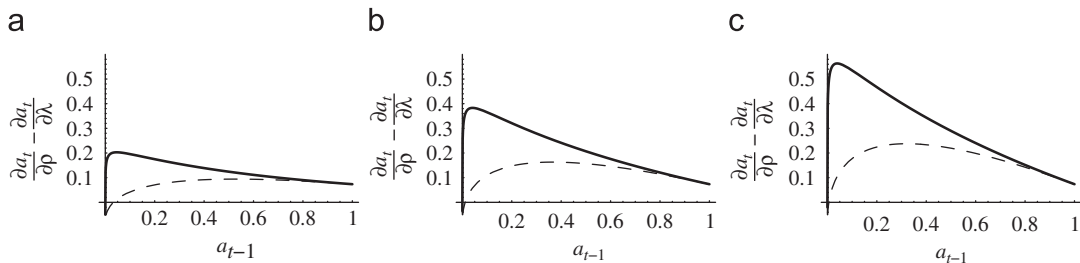


Fig. 7. Structure of the government budget versus composition of specialists parameters:  $\bar{s} = 0.75$ ,  $\bar{\eta} = 0.6$ ,  $\underline{\eta} = 0.5$ ,  $\bar{\gamma} = 0.6$ ,  $\underline{\gamma} = 0.4$ ,  $\lambda = 0.5$ . Dashed:  $\rho = 0.3$ , solid function:  $\rho = 0.7$ . (a)  $\beta = 0.3$ ; (b)  $\beta = 0.5$ ; (c)  $\beta = 0.7$ .

For low levels of the government budget ( $\beta = 0.3$ ), no unambiguously dominating policy recommendation may be derived (see Fig. 5(a)): Poorly developed economies benefit more from higher investment, whereas more developed regions display a faster convergence process if public expenditure is extended in order to enhance skills. This result basically holds for both displayed structures of the public budget,  $\rho = 0.3$  and 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. As argued before, higher investments increase productivity with respect to both technological and systemic skills. Productive spending instead augments 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  $\rho$ . The reason is that an increase in  $\rho$  means a restructuring of the government budget in favor of technological skills which become relatively less important as a country catches up. Fig. 5(c) shows the impact of the same policy options on the convergence process but for an already high public budget. Since government expenditure is 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 spending.

*Amount versus structure of the government budget,  $\partial a_t / \partial \rho - \partial a_t / \partial \beta$ :* Comparing the impact of a higher  $\rho$  versus a higher  $\beta$  leads to the question if either restructuring an existing budget or its enhancement given a certain budget structure contributes more to speeding-up convergence. Figs. 6(a)–(c) plot the corresponding productivity differentials,  $\partial a_t / \partial \rho - \partial a_t / \partial \beta$ , again for alternative amounts of the government budget,  $\beta$ , and for different compositions,  $\rho$ . The underlying partial derivatives are only functions of investment,  $\bar{s}$  and  $\underline{s}$ , productivity growth at the technology frontier,  $g$ , as well as of the government budget parameters,  $\rho$  and  $\beta$ . Neither individual skills nor the overall composition of specialists affect these results. 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 (25) and (28) according to

$$a_{t-1} = \exp^{-1/\beta} \quad (30)$$

It is illustrated by the intersection between the non-monotonic functions and the horizontal axis in Figs. 6(a)–(c). Accordingly, for lagging economies, restructuring the government budget in favor of a higher  $\rho$  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 government budget to enhancing it as an economy develops. The corresponding threshold state of development is given by (30). Comparing Figs. 6(a)–(c) highlights that the corresponding threshold is increasing in  $\beta$  thereby making a restructuring of the public budget the favorite policy for an even wider range of states of development. To understand this result one must look at the mechanism that drives convergence: A higher value of  $\rho$  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  $\beta$  becomes relatively more important. If  $\beta$  is small, the 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 this threshold increases with  $\beta$ , restructuring the budget becomes then reasonable for a wider range of development.

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

*Restructuring the public budget versus restructuring the composition of specialists,  $\partial a_t / \partial \rho - \partial a_t / \partial \lambda$ :* Fig. 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  $\rho$  contributes more to speeding-up convergence than an increase in  $\lambda$ . Economies far away from the technology frontier experience a productivity gain from both policy measures. Yet the productivity shift which results from restructuring the public budget is larger. Economies close to the technology frontier still profit from a rise in  $\rho$ . 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,  $\rho$ , is unambiguously preferable to an increase in the share of technological specialists.

## 5. 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 also if feedback effects on the economies' policies are considered, also productivity at the technology frontier. This can crucially affect the outcome referring to the convergence speed discussed before.

Recall that the equilibrium growth rate at the technology frontier is given by (24). Inserting this equilibrium growth rate into the equation of motion (23) gives

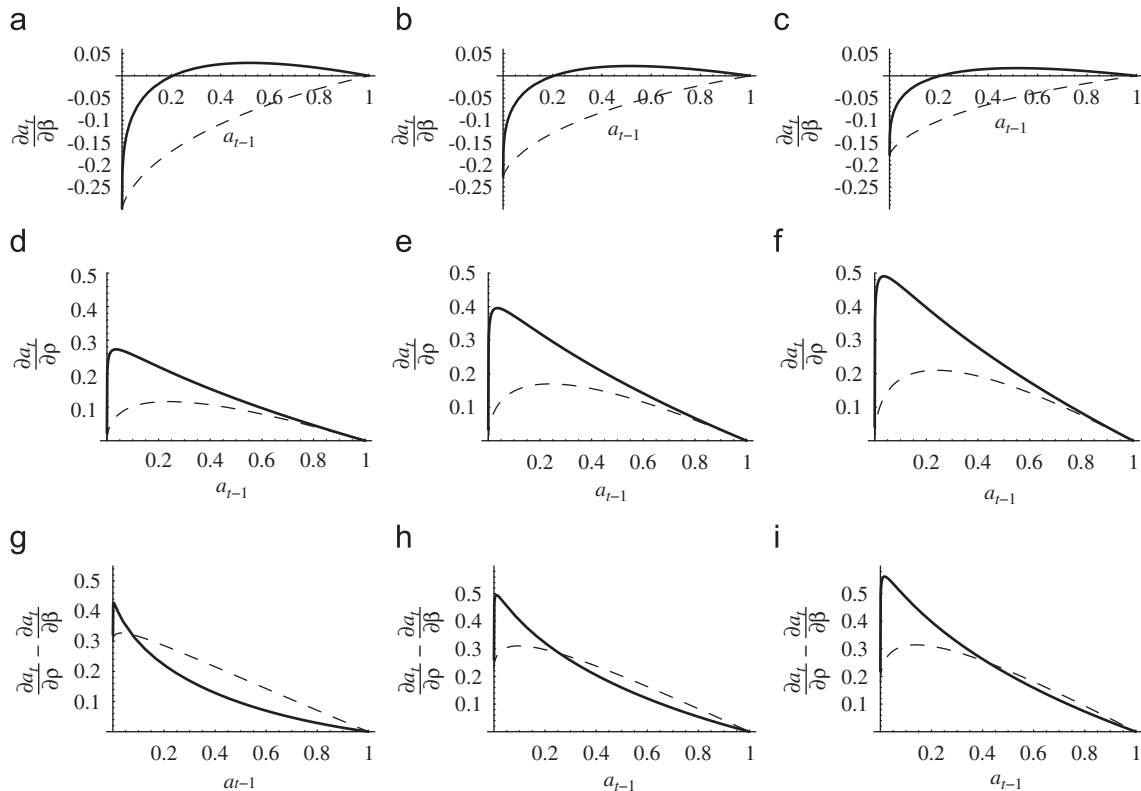
$$a_t = \lambda \bar{\eta} + (1-\lambda) \frac{\eta + \beta a_{t-1}^{1-\rho} + (\lambda \underline{\gamma} + (1-\lambda) \bar{\gamma}) a_{t-1}}{\lambda \bar{\eta} + (1-\lambda) \underline{\eta} + \beta + \lambda \underline{\gamma} + (1-\lambda) \bar{\gamma}} \tag{31}$$

which describes an economy's distance to frontier given that all involved countries implement the same policy measures. Coordinated policies concerning the investment size obviously do not influence the convergence process

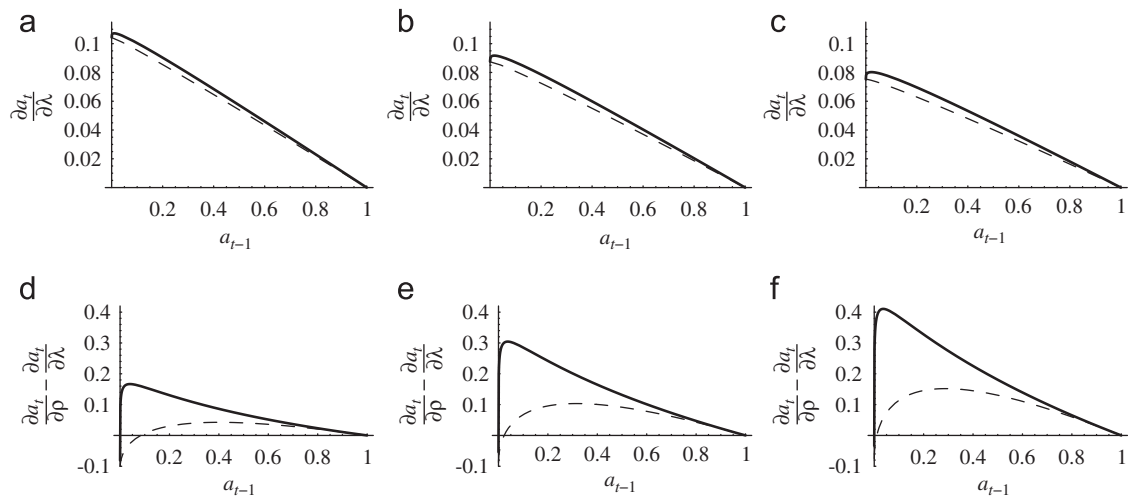
$$\frac{\partial a_t}{\partial \bar{s}} = \frac{\partial a_t}{\partial \underline{s}} = 0 \tag{32}$$

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 spending,  $\beta$ , is displayed in Figs. 8(a)–(c). Due to coordination, any productivity increase resulting from a bigger public budget within the considered country is accompanied by a simultaneous productivity increase in all other countries. This feeds back to convergence since catching-up requires a growth rate of national productivity (see (10)) that exceeds those of the other countries. Moreover, from the perspective of a single country, the positive productivity effect is less pronounced for less developed regions and more pronounced for higher  $\rho$  (recall Fig. 2). In case of coordinated policies, the overall effect on the convergence process thus depends upon the economy's state of development as well as upon the composition of the public budget. Given low values of  $\rho$  (i.e. emphasis is laid on systemic skills), a higher public budget even decreases the speed of convergence (compare also the dashed functions in Figs. 8(a)–(c)). Increasing the public budget only enhances the speed of convergence given high levels of  $\rho$  and after having passed a certain state of development as indicated by the intersection of the solid functions in Figs. 8(a)–(c) with the horizontal axis. To summarize, economies with low



**Fig. 8.** Coordinated policies assumed parameters:  $\bar{s} = 0.75$ ,  $\bar{\eta} = 0.6$ ,  $\eta = 0.5$ ,  $\bar{\gamma} = 0.6$ ,  $\underline{\gamma} = 0.4$ ,  $\lambda = 0.5$ . Dashed:  $\rho = 0.3$ , solid function:  $\rho = 0.7$ . (a)  $\beta = 0.3$ ; (b)  $\beta = 0.5$ ; (c)  $\beta = 0.7$ ; (d)  $\beta = 0.3$ ; (e)  $\beta = 0.5$ ; (f)  $\beta = 0.7$ ; (g)  $\beta = 0.3$ ; (h)  $\beta = 0.5$ ; (i)  $\beta = 0.7$ .



**Fig. 9.** Structure of the government budget versus composition of specialists parameters:  $\bar{s} = 0.75$ ,  $\bar{\eta} = 0.6$ ,  $\bar{\eta} = 0.5$ ,  $\bar{\gamma} = 0.6$ ,  $\bar{\gamma} = 0.4$ ,  $\lambda = 0.5$ . Dashed:  $\rho = 0.3$ , solid function:  $\rho = 0.7$ . (a)  $\beta = 0.3$ ; (b)  $\beta = 0.5$ ; (c)  $\beta = 0.7$ ; (d)  $\beta = 0.3$ ; (e)  $\beta = 0.5$ ; (f)  $\beta = 0.7$ .

states of development probably will slow down their pace of convergence if they increase their budget size as a consequence of coordinated policies.

*Assessment of various policies:* With respect to the structure of governmental activity,  $\rho$ , the essential results as highlighted in the context of (28) remain unchanged. The gain from restructuring the government budget in favor of high productivity at the technology frontier is the largest for intermediate levels of development, as can be seen in Figs. 8(d)–(f). Nevertheless, the comparison between the effectiveness of restructuring the government budget,  $\rho$  versus its enlargement,  $\beta$ , now becomes unambiguous: Comparing Figs. 8(g)–(i) (coordinated policies) to Figs. 6(a)–(c) (isolated policies) makes clear that for all states of development, a coordinated increase in  $\rho$  unequivocally induces faster convergence than a coordinated increase in the public budget. This outcome is due to the fact that a coordinated increase in  $\beta$  has less or even a negative effect on convergence than an isolated increase in  $\beta$  as explained above.

In contrast to the ambiguous impact of an isolated increase in the share of technological specialists analyzed in the previous Section 4, a coordinated increase in  $\lambda$  unambiguously accelerates convergence. As already mentioned above, the productivity of countries with development levels below  $\tilde{a}$  increases with the share of technological specialists,  $\lambda$ , whereas the productivity of countries with development states beyond  $\tilde{a}$  decreases. 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 Figs. 9(a)–(c). An assessment of alternative policies can be found in Figs. 9(d)–(f) which compare a change in the structure of the government budget to a change in the composition of specialists. In contrast to an isolated policy (compare Figs. 7(a)–(c)), the overall effect becomes now ambiguous. For low levels of  $\rho$  enhancing the share of technological specialists becomes preferable for economies with poor states of development. This effect vanishes as the public budget increases.

## 6. 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 spending, 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 expenditure. 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 expenditure.

**Appendix**

Due to  $\bar{A}_{t-2} = \bar{A}_{t-1}/(1+g)$ , the firm value (16) of *old technological specialists* running the small or the large project, respectively, is given by

$$V_{t,0}^{tS}(\underline{s}) = \delta \underline{s}(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}) \bar{A}_{t-1} - \max \left\{ \phi \kappa - \frac{(1+r)}{1+g} (\delta \underline{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) \cdot \phi \kappa), 0 \right\} \bar{A}_{t-1} \tag{33}$$

$$V_{t,0}^{tS}(\bar{s}) = \delta \bar{s}(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}) \bar{A}_{t-1} - \max \left\{ \kappa - \frac{(1+r)}{1+g} (\delta \bar{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) - \phi \kappa), 0 \right\} \bar{A}_{t-1} \tag{34}$$

Technological specialists will decide to run the large project if  $V_{t,0}^{tS}(\bar{s}) > V_{t,0}^{tS}(\underline{s})$  hence if

$$\begin{aligned} \delta(\bar{s} - \underline{s})(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}) &> \max \left\{ \kappa - \frac{(1+r)}{1+g} (\delta \bar{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) - \phi \kappa), 0 \right\} \\ &- \max \left\{ \phi \kappa - \frac{(1+r)}{1+g} (\delta \underline{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) - \phi \kappa), 0 \right\} \end{aligned} \tag{35}$$

In the following, we derive a minimum level for  $\delta$  implying a sufficient condition for old specialists to undertake the large project. Note that

$$\begin{aligned} \delta(\bar{s} - \underline{s})(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}) &> \kappa - \frac{(1+r)}{1+g} (\delta \bar{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) - \phi \kappa) \\ \Leftrightarrow \delta &> \frac{\kappa \left( 1 + \frac{1+r}{1+g} \phi \right)}{(\bar{s} - \underline{s})(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}) + \frac{1+r}{1+g} \delta (\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2})} \equiv \delta^{tS} \end{aligned} \tag{36}$$

$\delta > \delta^{tS}$  is a sufficient condition for inequality (35) to hold, because

$$\begin{aligned} \phi \kappa - \frac{(1+r)}{1+g} (\delta \underline{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) - \phi \kappa) &= \kappa - \frac{(1+r)}{1+g} (\delta \bar{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) - \phi \kappa) - (1-\phi) \kappa \\ &< \delta(\bar{s} - \underline{s})(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}) - (1-\phi) \kappa \quad \forall \delta > \delta^{tS} \\ &< \bar{\delta}(\bar{s} - \underline{s})(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}) - (1-\phi) \kappa \quad \forall \delta < \bar{\delta} \\ &< \bar{\delta}(\bar{s} - \underline{s})(\bar{\eta} + \beta + \underline{\gamma}) - (1-\phi) \kappa \quad \forall a_{t-1} < 1 \\ &= (1-\phi) \kappa \left( \bar{\eta} + \beta + \frac{\underline{\gamma}}{\underline{\eta} + \beta + \bar{\gamma} - 1} \right) < 0 \end{aligned} \tag{37}$$

and because

$$\kappa - \frac{(1+r)}{1+g} (\delta \bar{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) - \phi \kappa) = \delta(\bar{s} - \underline{s})(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1}) > 0 \quad \text{for } \delta = \delta^{tS} \tag{38}$$

together with the fact that  $\delta(\bar{s} - \underline{s})(\bar{\eta} + \beta a_{t-1}^{1-\rho} + \underline{\gamma} a_{t-1})$  increases faster in  $\delta$  than  $\max\{\kappa - ((1+r)/(1+g))(\delta \bar{s}(\bar{\eta} + \beta a_{t-2}^{1-\rho} + \underline{\gamma} a_{t-2}) - \phi \kappa), 0\}$ .

Similar considerations lead to the result that *old systemic specialists* will choose  $\bar{s}$ , if

$$\delta > \frac{\kappa \left( 1 + \frac{1+r}{1+g} \phi \right)}{(\bar{s} - \underline{s})(\underline{\eta} + \beta a_{t-1}^{1-\rho} + \bar{\gamma} a_{t-1}) + \frac{1+r}{1+g} \delta (\underline{\eta} + \beta a_{t-2}^{1-\rho} + \bar{\gamma} a_{t-2})} \equiv \delta^{sS} \tag{39}$$

where for all  $a_{t-1}, a_{t-2} > 0$

$$\delta^{tS} < \frac{\kappa \left( 1 + \frac{1+r}{1+g} \phi \right)}{(\bar{s} - \underline{s}) \bar{\eta} + \frac{1+r}{1+g} \delta \bar{\eta}} \quad \text{and} \quad \delta^{sS} < \frac{\kappa \left( 1 + \frac{1+r}{1+g} \phi \right)}{(\bar{s} - \underline{s}) \underline{\eta} + \frac{1+r}{1+g} \delta \underline{\eta}} \tag{40}$$

Since  $\bar{\eta} > \underline{\eta}$ , a common sufficient condition for both technological and systemic specialists is

$$\delta > \frac{\kappa \left( 1 + \frac{1+r}{1+g} \phi \right)}{(\bar{s} - \underline{s}) \underline{\eta} + \frac{1+r}{1+g} \delta \underline{\eta}} \equiv \underline{\delta} \tag{41}$$

The interval  $(\underline{\delta}, \bar{\delta})$  is nonempty, if the difference between the cost of investment of the small and the large project is sufficiently pronounced:

$$\underline{\delta} < \bar{\delta} \Leftrightarrow \phi < \frac{\underline{s} \left( \frac{1+r}{1+g} \eta + \beta + \bar{\gamma} \right) - \bar{s}(\beta + \bar{\gamma})}{\frac{1+r}{1+g} (\bar{s} - \underline{s})(\eta + \beta + \bar{\gamma}) + (\bar{s} - \underline{s})\eta + \frac{1+r}{1+g} \underline{s} \eta} \equiv \bar{\phi} \quad (42)$$

$$\text{with } \bar{\phi} > 0 \Leftrightarrow \underline{s} \left( \frac{1+r}{1+g} \eta + \beta + \bar{\gamma} \right) > \bar{s}(\beta + \bar{\gamma}) \quad (43)$$

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