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Corrupt bureaucrats, bad managers, and the slow race between education and technology

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Abstract

We study a developing economy in which the representative firm's production function exhibits complementarities between human capital and the available level of technology. The firm invests in the acquisition of new technology, while employees decide how much human capital to acquire. The rate of human capital accumulation positively affects the economy's growth rate, and therefore in our baseline case a reform that improves the educational system boosts growth. An important caveat, however, is that the absence of robust institutions may lead to lax enforcement of property rights and limit the incentives for firms to invest in new technology. The lack of investment in technology constrains demand for human capital and undermines the success of the education reform. It can even lead to a brain drain as individuals take advantage of the education reform and then move to an economy with higher demand for their acquired skills. We also consider our model findings with respect to the real-world case of Russia. Our main conclusion is that measures to improve the school system need to be accompanied by other institution-building measures that enhance property rights, promote good management practices and reduce incentives to engage in corrupt behaviors.

JEL classification codes: O43, P16
Keywords: reforms, education, institutions, growth diagnostics.

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1 Introduction

A vast literature emphasizes the role of human capital as a key determinant of long-term growth (e.g. Mincer, 1984; Lucas, 1988; Stokey, 1991; Barro and Lee, 1993; Barro, 2002). Quantitative estimates by Barro (1998) suggest that one additional year of upper-level schooling for males on average raises the growth rate by 1.2% per year. According to Hanushek and Woessman (2015), a one standard deviation increase in PISA test scores, also a measure of human capital stock, adds 1.3% to the per capita growth rate.[1]

Papers on developing economies indicate that provision of educational services operates relatively far from the efficient frontier of resource allocation (e.g. Hanushek, 1995; Glewwe, 1999). Such countries may even spend hundreds of billions of dollars a year supporting and improving their educational systems without having much to show for the investment (Glewwe, 2002). PISA (OECD, 2010) results indicate that the vast majority of developing countries performed below the OECD average in all three main PISA categories (reading, mathematics and natural sciences). This implies significant potential for improvement in educational standards in developing countries, and indeed much attention in the literature is devoted to this issue. Glewwe (2002), for example, attempts to identify the cognitive skills most relevant to individual income growth. The World Bank (2001) argues that investment in education should be a policy priority in these countries as it results in better educational infrastructure, properly training of teaching staff and well-equipped classrooms and laboratories.

Thus, a reform of the educational system which is aimed at dealing with the variety of inappropriate practices impeding the transfer of knowledge to young generations and at improving education standards has the potential to be a solution to these problems. In this paper, we argue though that this type of reform taken in isolation does not necessarily lead to the desired outcomes, and that the results highlighted in the existing literature are driven by a partial equilibrium focus.

To capture the interaction of demand and supply of human capital, we develop a general equilibrium model in which the equilibrium level of education may fail to adjust to positive changes introduced through an education reform. In other words, removing the most restricting constraints in the education sector does not increase the demand for education.

[1] "PISA (the Programme for International Student Assessment) is an international study launched by the OECD in 1997. It aims to evaluate education systems worldwide every three years by assessing 15-year-olds' competencies in the key subject areas: reading, mathematics and science. To date, over 70 countries and economies have participated in PISA." http://www.oecd.org/pisa/

What aspects of an economy might suppress educational demand in a developing economy? Some authors suggest that liquidity constraints may make it impossible for individuals to choose their education optimally (e.g. Morley and Coady, 2003; World Bank, 2001). We argue, however, that even where liquidity constraints are not binding, educational opportunities might go unexploited.

Rodrik (2007), in prescribing a framework for efficient growth policies, points to the lack of economic opportunity, a common problem in developing countries, as a factor that can scuttle the benefits of an education reform:

> "...For quite a while, policymakers thought that the solution to poor human capital lay in improving infrastructure of schooling – more schools, more teachers, more textbooks, and more access to all three. These interventions did increase the supply of schooling, but when the results were in, it became evident that the increase in schooling did not produce the productivity gains that were anticipated. The reason is simple. The real constraint was the low demand for schooling – that is the low propensity to acquire learning – in environments where the absence of economic opportunities depresses the return to education..."

Rodrik's conclusion is closely related to the empirical observations of Pritchett (2004), who detects that the return on schooling might be low due to the lack of economic development. Pritchett does not specify the impediments to development, however, and thus provides an opening for us to contribute to the literature by analyzing how individuals might deliberately choose not to seek higher education and thereby slow economic development even further.

The issue of education avoidance is raised in the study of Goldin and Katz (2008) on income inequality in the United States. They apply Tinbergen's (1974,1975) metaphor of a race between education and technology to the evolution of income inequality in the US during the 20^{th} century. As modern long-term growth is driven by technological development, they argue, a society optimizes the benefits of evolving technology by assuring its individuals are capable of using new technology as it emerges. A society competent with new technology enjoys higher economic growth as more economic agents are using frontier technology to produce output. If, on the contrary, the education level lags the rate of technological advance, a gap appears over time as individuals fail to acquire sufficient skills.

Now suppose technological development is slow, but the education system produces a large pool of overqualified talent. In such case, the incentive for individuals to accumulate more human capital declines as there may be no technology applicable to their skills. In this case, increasing the supply of education does not result in higher economic growth.

We argue therefore that an individual's demand for education depends indirectly on a variety of institutional features, including the quality of property right protections, the risk of expropriation and quality of management. When property rights are weakly enforced, or when top managers are incapable of, in the words of Acemoglu and Autor (2010), "completing difficult tasks," the return on investment declines and firms tend to acquire less new capital and technology. Assuming factors of production are complements, employees prefer to invest less in education and the level of the corresponding complementary factor remains low. If an economy is characterized by weak property right protections or tolerates poor managerial standards, then high levels of education only matter if there is a possibility for the educated individual to move to another economy with a sufficiently high level of technology to justify that demand. Thus, successful encouragement of higher growth implies that any education reform should be accompanied by institutional reforms to improve the quality of property rights protections and management quality.

This coordination of policy reform follows the more general prescription of Rodrik (2007), as it relates to the notion of binding constraints on economic growth. In terms of the present paper, poor institutions constitute a more tightly binding constraint on the economy than the lack of educational capacity. Our policy recommendation therefore is that measures to deal with weak institutions need to be tackled in tandem with education reform. This is consistent with Rodrik's prescription that the most tightly binding constraints should be dealt with at the same time as other reforms, if not first.

The mechanics of our paper are closely related to the literature emphasizing the importance of complementarity between production factors. Following Acemoglu (1994) and Redding (1996), we argue that investment in one factor of production affects the decision to invest in another. Unfortunately, neither paper pays particular attention to what might restrain the accumulation of complementary factors. Our contribution thus lies in modeling the role of weak institutions as an obstacle to investment in a complementary factor.

This work also relates to the broad literature on the linkage of institutional quality to investment and growth. For instance, Mauro (1995) and Mo (2001) provide quantitative estimates of the negative influence of corruption on growth rates. Works by Clarke

(2001) and Keefer and Knack (1997) show that R&D expenditures increase when the rule of law is enhanced and the risk of expropriation declines. Hanushek and Woessmann (2008) provide empirical evidence on the complementarity of skills and quality of economic institutions. None of these papers, however, provide theoretical analysis on how imperfect institutions affect human capital accumulation.

To fill this gap we develop a model which describes how this complementarity works. In our setting, identical firms combine technology and human capital to produce output. Following Redding (1996), we consider a non-overlapping generations economy where output is shared between firms' owners and employees. When a new generation arrives, firms produce output and invest part of it into the acquisition of a new technology. When young, the employees decide how to allocate their human capital stock, which they inherit from the previous generation, between production and investment in human capital. Education and investment in the new technology result, respectively, in a larger human capital stock and a higher level of technology, which are used to produce output when the generation becomes old. Firms and employees share the same information, and thus the employees can perfectly foresee how much output do the firms plan to invest in a new technology. When firms invest more into new technologies, employees also prefer to acquire more human capital, since the latter will earn a higher return. In this benchmark version of the model, the economy starts by imitating technologies from the leading frontier, and then converges to a steady-state.

Unfortunately, the empirical evidence suggests that convergence does not happen for many developing countries (see e.g. Acemoglu, 2008). Instead, it is common for developing economies to grow at relatively low rates and get stuck in a *non-convergence trap* (Acemoglu et al, 2006), or its variation, a *middle-income trap* (Eichengreen et al., 2013). To incorporate this possibility, we add imperfect institutions to our baseline model. Following Shleifer and Vishny (1993), we introduce corruption in the economy and assume that firms are required to share their profits with bureaucrats.[2] We show that corruption reduces the incentive of firms to invest in new technology, thereby affecting the economy's ability to catch up with the leading technological frontier. As production factors are complements, employees reduce their investment in human capital in response to the slow pace of technological advancement. Therefore, when an education reform brings about new opportunities to acquire human capital, it may hap-

[2]Alternatively, we could introduce a manager to the model and assume that he pockets some of the representative firm's profit on the knowledge that the regulators and judiciary are too weak or corrupt to punish him. This argument has been pursued by e.g. Boycko, Shleifer and Vishny (1993), Boycko, Shleifer and Vishny (1994) and Shleifer and Vishny (1997).

pen that the level of demand for these opportunities is low.[3] To induce the employees to avail themselves of these opportunities, the government must encourage firms to invest more in acquisition of new technology.

To this end, the government can try to improve the quality of institutions through such measures as anti-corruption policies, so we argue that tackling corruption may be included as a potential solution to low investment in the acquisition of new technologies and human capital.[4] Similarly, policies that encourage top management to adopt practices that promote efficiency and good governance through e.g. a privatization program,[5] may also reduce the level of wasted income and thereby increase profits of firms, allowing them to invest more in acquisition of new technology. As the level of investment in new technology increases, employees have greater incentive to acquire more human capital and the education reform bears fruit.

We thus emphasize that the presence of persistent corruption and inappropriate management practices can hobble education reforms aimed at expanding supply of high-quality educational services. Corruption reduces incentives to invest in the acquisition of new technologies, and, as technology and human capital are complementary factors of production, the demand for education can fall below the available level of supply. Thus, to avoid a potential imbalance between supply and demand for high-quality education, the government should intervene to reduce the level of corruption. Similarly, if poor management is reducing the level of investment, the government should consider measures such as a privatization campaign to induce firms to invest more in new technology.

The remainder of the paper is organized as follows. Section 2 introduces our baseline growth model. In Section 3, we incorporate corruption into the model and show how does the latter affect the effectiveness of an education reform. In Section 4, we discuss the effect of an anticorruption policy on the acquisition of new technologies and human capital accumulation. We also consider how our main findings might apply in the real world, taking the Russian economy as an example. Section 5 concludes.

[3] Such a reform will result in a brain drain, whereby employees acquire more education on the assumption that they can transfer their acquired skills to another economy with a higher level of technology. Instead of increasing the stock of domestic human capital, the education reform leads to emigration of skilled individuals.

[4] We assume that corruption can be reduced, i.e. the authorities are actually motivated to fight corruption and possess adequate means to control the bureaucracy.

[5] The literature that focuses on possible avenues of reducing the level of corruption is vast (see, for instance, Reinikka and Svensson, 2005, or OECD, 2005), and therefore surveying it is beyond this paper's scope.

2 The Model

In the following presentation of our benchmark developing economy, we describe how economic agents invest in acquisition of new technology and accumulate human capital. Initially, the lack of an educated workforce is the impediment to economic growth, so the government introduces an education reform. As the workforce becomes educated, economic growth accelerates.

2.1 Production

Our baseline growth model builds upon Redding (1996). We consider a non-overlapping generations economy,[6] where each generation lives for two periods, $j = 1, 2$. In period 1, the new generation is born, produces output and makes its investment decisions. In period 2, the same generation is now old; it produces output and passes away.

Each generation is made up of M employees working at N identical firms, and N individuals, each owning one firm. Every firm combines technology and human capital to produce the final output. In each period $j = 1, 2$, a typical firm produces the following level of output:

$$Y_{t,j} = A_{t,j}^{\theta} \left(h_{t,j} m_t\right)^{1-\theta}, \tag{1}$$

where t represents a particular generation, $Y_{t,j}$ corresponds to the level of output which is produced in period $j = 1, 2$ by individuals belonging to generation t and employed at the representative firm, $A_{t,j}$ is the level of technology which is identical for every firm, and $h_{t,j}$ reflects the amount of human capital per employee. m_t denotes the number of employees per firm; it is also the same for every firm,[7] and for every period $j = 1, 2$. The importance of technology in production is described as $0 \leq \theta \leq 1$.

To produce output, the representative owner provides his workers with technology

[6] We use a non-overlapping generations framework to consider the co-evolution of two production factors. A key issue here is making sure that the levels of these factors evolve synchronically. In the presence of a standard overlapping generations framework, the young generation has incentive to accumulate a particular factor of production, while the old generation prefers to consume. Therefore, a standard overlapping generations model does not suit our goals.

We could, of course, use an overlapping generation framework in which each generation lives for three periods, but this increases the number of overlapping cohorts and number of production factors. As analysis of a three-period model is complicated, we prefer the simpler dynamic framework in which the economy is represented as a collection of non-overlapping two-period optimization problems. This is quite adequate for our purposes.

[7] As all firms are identical and equally attractive as employers, employees are uniformly distributed among the firms, implying that $m_t = \frac{M}{N}$, where M is a number of employees in the economy and N represents the number of firms.

$A_{t,j}$. He receives a payoff which is as large as a share $0 \leq \beta \leq 1$ of his firm's production level $Y_{t,j}$, $j = 1, 2$.[8] This sharing rule implies that owners and employees are stakeholders, so they all benefit when their firm produces a higher level of output.[9]

We assume that technology is transferred from the previous generation to its successor.[10] The presence of this intergenerational spillover effect implies that in period 1, a firm belonging to generation t uses the following technology to produce $Y_{t,1}$:

$$A_{t,1} = A_{t-1,2}, \tag{2}$$

where $A_{t-1,2}$ is the level of technology used by generation $t-1$ in period 2.

Following Lucas (1988) and Redding (1996), we assume that human capital is also transferred from the preceding generation to the next. Thus, a new generation t uses the following stock of human capital in period 1:[11]

$$H_{t,1} = H_{t-1,2} \tag{3}$$

We assume that all young members of generation t receive the same share in the aggregate human capital stock $H_{t-1,2}$, which is inherited from the previous generation $t-1$. This wealth is equally distributed among the employees.[12]

2.2 Investment

In period 1, the representative owner chooses whether to retain the inherited technology $A_{t,1}$ or to improve upon it. The owner can improve upon the old technology in the following way:

$$A_{t,2} = \eta\left(\alpha_t\right) A^L_{t,1} + \left(1 - \eta\left(\alpha_t\right)\right) A_{t,1}. \tag{4}$$

Equation (4) reflects a possibility of *adoption* from exogenously given frontier tech-

[8]The workers, instead, receive $(1-\beta)\, Y_{t,j}$.

[9]β could be interpreted as an outcome of a Nash bargaining problem. For a particular value of β, this sharing rule satisfies the conventional product sharing rule, whereby spending on factors of production reflects their marginal contributions.

[10]This intertemporal spillover effect can be interpreted as a bequest from one generation to its successor generation.

[11]Equation (3) corresponds to a particular case, belonging to a more general rule $H_{t,1} = (1-\delta)H_{t-1,2}$, where $0 < \delta < 1$, reflects the rate of intertemporal human capital depreciation. In the case of equation (3), the latter is taken equal to zero. We could alternatively assume that δ is sufficiently small, so when an employee from generation t invests in the acquisition of additional human capital, their final level of human capital is larger than that of a representative employee from generation $t-1$ in period $j = 2$.

[12]This assumption facilitates aggregation of the most important variables in our model. A different assumption would complicate aggregation, making analysis of the model more difficult without adding any important results.

nology. We therefore consider technology as a stock of knowledge that can be increased when the firm "buys" additional knowledge from the leading technological frontier. To see that this is truly the case, we rewrite $A_{t,2}$ as the sum of the old technology, represented by $A_{t,1}$, and part of the distance between the old technology and the leading frontier $\eta(\alpha_t)\left(A^L_{t,1} - A_{t,1}\right)$, where $0 \leq \eta(\alpha_t) \leq 1$, $\eta'(\alpha_t) > 0$, $\eta''(\alpha_t) < 0$, $\eta(0) = 0$, $A^L_{t,1}$ corresponds to the state of the world technological frontier in period 1, which evolves at an exogenously given rate g, and where $0 \leq \alpha_t \leq 1$ reflects the share of income the representative firm invests in new technology. The level of technology in period $j = 2$, i.e. $A_{t,2}$, can thus be represented as $A_{t,2} = A_{t,1} + \eta(\alpha_t)\left(A^L_{t,1} - A_{t,1}\right)$, which, after minor manipulations, transforms into equation (4).

In the presence of technological adoption, the level of local, i.e. domestic, technology $A_{t,1}$ can only approach the leading frontier, but never reach full convergence with the world frontier. Instead, the level of domestic technology always remains below the frontier level of technology.[13] To allow for convergence, we could suggest that the economy substitutes imitations with innovations when the level of $A_{t,1}$ becomes sufficiently high and, as a result of this shift to innovation, the growth rate remains higher than that of the world frontier $A^L_{t,1}$.[14] We do not, however, introduce innovations into the model at this point as the results are still insensitive to the presence of innovations. Finally, there is a storage technology which pays a return $r = 0$ in period 2 if the representative owner invests a part of his income in this technology in period 1.[15] A firm uses this alternative asset if investing in productive technology provides a negative payoff. In the latter case, the owner substitutes investment in a new technology with acquisition of a storage asset. Thus, the owner sticks with the same technology until

[13]To show that this is truly the case, we use the steady-state version of the adoption equation (4), which implies that as long as the imitation of the frontier technology remains the only source of technological evolution, the level of domestic technology in the steady state grows at the same rate as the leading frontier, i.e. at rate g (we prove this result below):

$A_{t,1}(1+g) = \eta(\alpha)A^L_{t-1}(1+g) + (1-\eta(\alpha))A_{t,1}$

where α is the steady-state level of α_t.

After rearranging, this equation transforms into the following expression:

$$A_{t,1} = \frac{\eta(\alpha) + g\eta(\alpha)}{g + \eta(\alpha)} A^L_{t-1},$$

which, as $\frac{\eta(\alpha)+g\eta(\alpha)}{g+\eta(\alpha)} < 1$, and as long as $g > 0$, implies that $A_{t,1} < A^L_{t-1}$.

[14]Starting from a particular instant, the pace of technological development should be larger than the one resulting from imitations. Otherwise, the economy ends up in a steady state, where it only grows as fast as the leading technological frontier and never converges. Note that, if the country sticks solely with a technological adoption strategy, the steady-state level of technology evolves at the rate g, which corresponds to the growth rate of frontier technology.

[15]We incorporate the storage asset into the model to capture a possibility of the non-convergence trap that results when local technology fails to evolve fast enough to converge on the world technological frontier.

the payoff from investing in new technology becomes positive.

2.3 Equilibrium

In period $j = 1$, the representative firm invests $\alpha_t \beta Y_{t,1}$ in a new technology, and the returns are realized in period 2. The representative owner thus receives $(1-\alpha_t)\,\beta Y_{t,1}$ in period 1 and $\beta Y_{t,2}$ in the following period 2. Note that the level of output in periods $j = 1, 2$ is as large as $Y_{t,j} = A^{\theta}_{t,j}\,(h_{t,j} m_t)^{1-\theta}$, so the owner's payoff function can be written as follows:

$$W_o = (1-\alpha_t)\,\beta A^{\theta}_{t,1}\,(h_{t,1} m_t)^{1-\theta} + \beta A^{\theta}_{t,2}\,(h_{t,2} m_t)^{1-\theta}\,. \tag{5}$$

Employees, in turn, receive as much as $(1-\beta)\,Y_{t,1}$ in period 1 and $(1-\beta)\,Y_{t,2}$ in the following period. In period 1, they have the option of investing a fraction φ_t of their human capital endowment $h_{t,1}$ to increase their human capital stock. For simplicity, we assume that human capital is created according to a one-to-one technology, so that in period 2 an employee receives $(1+\varphi_t)\,h_{t,1}$ if she invests $\varphi_t h_{t,1}$ in period 1.[16]

Adding the possibility of human capital accumulation to the model, we transform the owner's payoff functions (5) into the following expression:

$$W_o = (1-\alpha_t)\,\beta A^{\theta}_{t,1}\,(h_{t,1}\,(1-\varphi_t)\,m_t)^{1-\theta} + \beta A^{\theta}_{t,2}\,(h_{t,1}\,(1+\varphi_t)\,m_t)^{1-\theta}\,. \tag{6}$$

At the beginning of period 1, owners decide how much to invest in the acquisition of a new technology and employees decide how much human capital to acquire. The representative firm imitates new technology from the world frontier and maximizes the payoff function (6) s.t. equation (4), and thus chooses the optimal level of technological adoption.

The corresponding first-order condition for the owner is given by the following equation:

$$\eta'(\alpha^*_t) = \frac{1}{\theta\left(\frac{A^L_{t,1}}{A_{t,1}} - 1\right)}. \tag{7}$$

From equation (7),[17] it follows that when the economy adopts technology from the world technological frontier, the optimal share of income the representative firm invests in a new technology, i.e. the optimal α_t, is higher, when the difference between local

[16] A different assumption would cost us algebraic and geometric convenience without producing further tangible benefits or insights.

[17] See Appendix I for a detailed derivation of equations (7) and (10).

technology and the leading frontier $\frac{A_{t,1}^{L}}{A_{t,1}}$ is also larger, as is the measure of importance of technology for production θ.

While the representative firm improves upon its technology, the typical employee maximizes the following payoff function:

$$W_e = (1-\beta)\, A_{t,1}^{\theta} \left(h_{t,1} \left(1-\varphi_t\right) m_t\right)^{1-\theta} + (1-\beta)\, A_{t,2}^{\theta} \left(h_{t,1} \left(1+\varphi_t\right) m_t\right)^{1-\theta}. \quad (8)$$

Differentiating equation (8) with respect to φ_t results in the following first order condition:

$$\frac{1+\varphi_t^*}{1-\varphi_t^*} = \frac{A_{t,2}}{A_{t,1}} \quad (9)$$

or, alternatively

$$\varphi_t^* = \frac{A_{t,2} - A_{t,1}}{A_{t,2} + A_{t,1}}. \quad (10)$$

We can see that the right-hand side of equation (10)[18] is less than one and becomes smaller over time, since the difference between $A_{t,2}$ and $A_{t,1}$ decreases as long as the representative firm invests in new technology.[19]

From equation (7), it follows that the value of α_t^* increases if the level of domestic, i.e. local, technology $A_{t,1}$ is more remote from the leading frontier $A_{t,1}^{L}$. At the same time, from equation (4) we conclude that a larger value for α_t^* implies a higher level of technology in period 2, i.e. in a higher $A_{t,2}$.

Following equation (10), a larger distance between the level of technology in period 2, i.e. $A_{t,2}$, and its level in period 1, $A_{t,1}$, results in a higher fraction of human capital φ_t^* invested in human capital accumulation.

When firms do not invest in a new technology, i.e. when $\alpha_t^* = 0$, the level of technology remains constant $A_{t,1} = A_{t.2}$. From equation (10), we, therefore, obtain $\varphi(0) = 0$.

We are now ready to summarize our findings in the following proposition:

[18]See Appendix I for the detailed derivation of equations (7) and (10).

[19]We can use equation (10) to show that the latter is the case. After minor manipulations, we arrive at the following result:

$$\varphi_t^* = 1 - \frac{2A_{t,1}}{A_{t,2} + A_{t,1}}.$$

It follows that φ_t^* is going to 0 as $A_{t,2}$ approaches $A_{t,1}$. It is also close to 1 when $A_{t,2}$ is significantly larger than $A_{t,1}$.

Proposition 1.

1. *The economy converges to a unique steady state.*
2. *Increases in the relative distance to the leading technological frontier* $\frac{A_{t,1}^L}{A_{t,1}}$*, and the importance of technology for production* θ*, both increase incentives to invest in new technology. The resulting increased pace of technological evolution induces employees to acquire more human capital.*

Proof. We first establish uniqueness. To this end, we lag equation (4) back to $t-1$ and use equation (2) to show that $A_{t,1}$ is a function of α_{t-1}^*. Hence, the more previous generation $t-1$ invested in new technology, i.e. the larger the level of α_{t-1}^*, the higher the level of technology $A_{t,1}$ inherited by generation t from its predecessors. Given a larger $A_{t,1}$, the distance between the level of domestic technology $A_{t,1}$ and the leading technological frontier $A_{t,1}^L$ diminishes. From equation (7), it follows that the distance to frontier $\frac{A_{t,1}^L}{A_{t,1}}$ and the optimal share of income invested by the owner α_t^*, are positively related, and therefore as $\frac{A_{t,1}^L}{A_{t,1}}$ decreases, α_t^* falls as well. Therefore, the level of α_{t-1}^* exceeds α_t^*.

In the opposite case involving a low level of α_{t-1}^*,[20] the gap between the level of local. i.e. domestic, technology $A_{t,1}$ and the leading frontier $A_{t,1}^L$ widens. From equation (7), it follows that the value of α_t^* increases as well, implying that α_t^* becomes larger than α_{t-1}^*.

Finally, at a particular level of α_{t-1}^* the gap between the level of domestic technology $A_{t,1}$ and the leading technological frontier $A_{t,1}^L$ remains constant. As a result, the level of α_t^* also remains constant, implying that $\alpha_{t-1}^* = \alpha_t^*$.[21] As the right-hand side of equation (7) strictly diminishes as long as the economy catches up with the leading frontier, this equilibrium is unique.

We now focus on the equilibrium case. From the denominator of the right-hand side of equation (7) it follows that the optimal share of income invested by the owner α_t^* remains a constant when the distance between the level of domestic technology

[20]The level of α_{t-1}^* should be low enough to allow the pace of world frontier growth to exceed that of local technology.

[21]The economy does not necessarily end up growing at a constant rate. For example, the growth rate may oscillate around a unique equilibrium rate of growth. Whatever the case, it is not particularly important for our purposes to specify exactly where the economy ends up. What we need to know is that it is possible for domestic technology to attain a high level of development.

$A_{t,1}$ and the leading technological frontier $A^L_{t,1}$ does not change, which occurs when the local technology grows as fast as the leading frontier, i.e. at rate g.

The proof of the second part of the proposition follows directly from equations (7) and (10).

■

We can also represent this argument graphically.

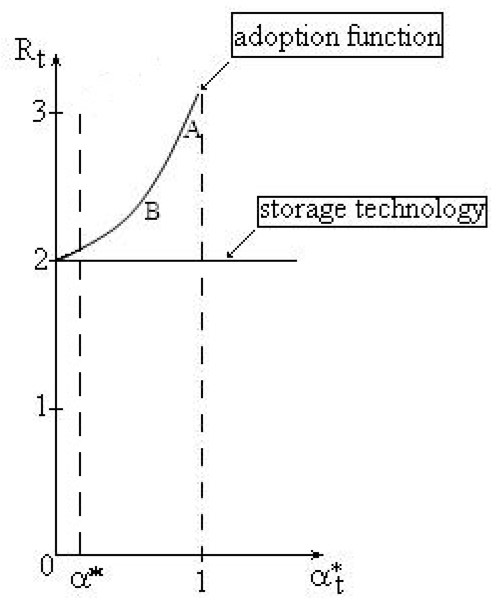

Figure 1. Investment into technological evolution in the economy without corruption.

To this end, we first compare the payoff from investing in new technology and investing in a storage asset. These two payoffs are identical when the following equation holds:

$$(1-\varphi(\alpha^*_t))^{1-\theta}\left[1-\alpha^*_t+\frac{1+\varphi(\alpha^*_t)}{1-\varphi(\alpha^*_t)}\right]=2. \tag{11}$$

In Figure 1, the share α^*_t is placed along the horizontal axis, and R_t, representing the normalized payoff from investment, corresponds to the vertical axis. The curve, our *adoption function*, represents the left-hand side of equation (11), and reflects the payoff from adopting a technology from the world frontier. In Appendix I, we show that the left-hand side of equation (11) is an increasing function of α^*_t, i.e.

$(1-\varphi(\alpha_t^*))^{1-\theta}\left[1-\alpha_t^*+\frac{1+\varphi(\alpha_t^*)}{1-\varphi(\alpha_t^*)}\right]$ becomes larger as α_t^* increases. As we know from equation (7), the greater the distance to the leading frontier $\frac{A_{t,1}^L}{A_{t,1}}$, the higher the value of α_t^*. Therefore, as the left-hand side of equation (11) increases when α_t^* becomes larger, it also increases as the distance to the leading frontier $\frac{A_{t,1}^L}{A_{t,1}}$ becomes larger. In contrast, when the distance to the leading frontier diminishes, both, α_t^* and $(1-\varphi(\alpha_t^*))^{1-\theta}\left[1-\alpha_t^*+\frac{1+\varphi(\alpha_t^*)}{1-\varphi(\alpha_t^*)}\right]$ get smaller. Consider a point on the adoption function that is close to the dashed line, say, point A. The dashed line intersects the horizontal axis at $\alpha_t^*=1$, corresponding to the largest possible value of α_t^*. Therefore, as point A is close to the dashed line that starts from point 1 on the horizontal axis, it reflects a comparatively large value of α_t^*, which, according to our discussion, corresponds to a greater distance to the world technological frontier $\frac{A_{t,1}^L}{A_{t,1}}$. Conversely, a point on the adoption function that is far from the dashed line on the right, say, point B, corresponds to a low level of α_t^*, and implies a smaller technological gap $\frac{A_{t,1}^L}{A_{t,1}}$.

When firms do not invest in new technology, i.e. when $\alpha_t^*=0$, the left-hand side of equation (11) is equal to 2. The horizontal line, which reflects the payoff from investing in the *storage technology*, also intersects the vertical axis in $R_t=2$. However, when $\alpha_t^*>0$, the left-hand side of equation (11) is larger than 2, which implies that as long as $\alpha_t^*>0$, the payoff from investing into the storage asset is lower than the payoff from acquiring a new technology. When the gap between the level of domestic, i.e. local, technology and the leading frontier is positive, i.e. when $\frac{A_{t,1}^L}{A_{t,1}}$ is larger than 1, the economy can imitate technologies from the leading frontier, and, as it follows from equation (7), α_t^* remains positive. Therefore, for $\alpha_t^*>0$, the adoption function is placed strictly above the horizontal line, representing the payoff from investing in the storage technology.

When α_t^* becomes equal to α^*, which is comparatively low but still positive and corresponds to the case when the distance to the leading technological frontier $\frac{A_{t,1}^L}{A_{t,1}}$ remains constant over the course of time, the economy grows at the same rate g as does the frontier technology. Since, according to equation (7), α^* is positive, it implies that the left-hand side of equation (11) is larger than 2 when $\alpha_t^*=\alpha^*>0$. It therefore follows that in this case the level of payoff from acquiring a new technology is also larger than choosing the storage asset.

2.4 Education in an economy with perfect institutions

In the previous subsection, we focused on the behavior of α_t^*, the optimal share of income the owner should invest in new technology. To see how an education reform might result in a higher level of human capital and higher economic growth, we now consider the behavior of $\varphi(\alpha_t^*)$, the optimal fraction of human capital endowment that should be invested in human capital accumulation.

Notably, as long as firms imitate technologies from the leading frontier, $\varphi(\alpha_t^*)$ remains a concave function of α_t^*.[22] We call $\varphi(\alpha_t^*)$ the *dynamic demand function* as it reflects the level of education demanded by each generation of employees.

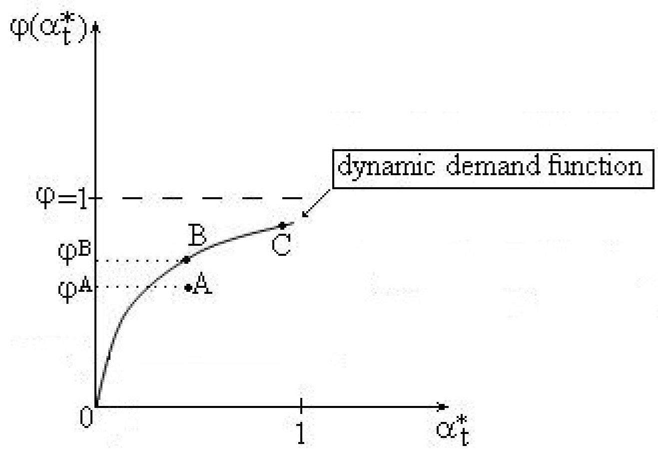

Figure 2. Educational reform in the economy without corruption.

In Figure 2, the *dynamic demand function* corresponds to the concave curve. We start considering the behavior of $\varphi(\alpha_t^*)$ from its right-hand part. We see from equation (7) that when the distance to the frontier technology $\frac{A_{t,1}^L}{A_{t,1}}$ is comparatively large, the value of α_t^* is also high. From equation (10) we further note that a large α_t^* results in a high level of $\varphi(\alpha_t^*)$. This is comparatively close to $\varphi(\alpha_t^*) = 1$, or the largest

[22]This result follows from two derivatives:

$$\frac{\partial\varphi(\alpha_t^*)}{\partial\alpha_t^*} = \frac{2A_{t,1}^2}{\theta\left(A_{t,2}(\alpha_t^*) + A_{t,1}\right)^2} > 0$$

$$\frac{\partial^2\varphi(\alpha_t^*)}{\partial\left(\alpha_t^*\right)^2} = -4\frac{A_{t,1}^3}{\theta^2\left(A_{t,2}(\alpha_t^*) + A_{t,1}\right)^3} < 0$$

possible value for $\varphi(\alpha_t^*)$ as depicted in Figure 2 as a dashed line. Hence, a point on the curve that is close to the dashed line, say, point C, reflects a high value of α_t^* and mirrors a large level of technological backwardness $\frac{A_{t,1}^L}{A_{t,1}}$. In contrast, a point belonging to a section of the *dynamic demand function* that is relatively far from the dashed line, as, say, point B, corresponds to a smaller value of α_t^* and thus closer to frontier technology $\frac{A_{t,1}^L}{A_{t,1}}$.

We now consider how a reform of the education system might result in a higher fraction of the human capital endowment actually being invested in education. We notice that point B on to the *dynamic demand function* curve represents the level of demand for education of generation t. If we assume that the supply of education corresponds instead to point A, which is located strictly below point B, it implies that for generation t, the available level of supply φ_t^A is lower than the demanded level of education φ_t^B. In this case, if the government intervenes and introduces an education reform to boost the supply of education φ_t^A from point A to point B, i.e. increase the human capital stock in the economy, so that economic growth accelerates.[23]

We are ready to formulate our next result:

Proposition 2. *As long as the quality of institutions in the economy is high and the level of demand for education exceeds the available supply, an education reform will result in an increase in the human capital stock.*

Proof. We first posit that the actual level of additional human capital is defined from the following expression:

$$\varphi_t = min\left\{\varphi_t^{S,1}, \varphi_t^D\right\}, \tag{12}$$

where $\varphi_t^{S,1}$ corresponds to exogenously given level of supply of education, while $\varphi_t^D = \varphi(\alpha_t^*)$. $\varphi(\alpha_t^*)$ as defined in equation (10), reflects the level of demand for education and belongs to *the dynamic demand function*. If the level of supply is lower than the level of education demanded by the employees, i.e. if $\varphi_t^{S,1} < \varphi_t^D$, then the actual level

[23]Such reform is relevant for developing countries with underdeveloped educational systems. A developing economy might suffer e.g. from poorly trained teaching staff or a lack of universities and vocational schools.

Many papers argue that improvements in the quantity of education, measured in terms of PISA scores (e.g. Hanushek and Woessmann, 2015), or the adult literacy rate (see Durlauf and Johnson, 1995) positively influence economic growth. Hanushek and Kimko (2000) and Hanushek and Kim (1995), report a strong and robust influence of the quality of education on economic growth. Thus, if an economy is characterized by a low level of human capital, growth can be raised by removing the most limiting constraints on education capacity. In this case, an education reform, comprising technical and financial assistance aimed to improve education standards, can be promising.

of investment in human capital is equal to $\varphi_t^{S,1} = min\left\{\varphi_t^{S,1}, \varphi_t^D\right\}$. An education reform that increases the level of supply from $\varphi_t^{S,1}$ to $\varphi_t^{S,2} = \varphi_t^D$ results in a higher level of investment in the acquisition of human capital $\varphi_t^{S,2} = \varphi_t^D = min\left\{\varphi_t^{S,2}, \varphi_t^D\right\}$, as $\varphi_t^{S,2} = \varphi_t^D > \varphi_t^{S,1}$. As a result, the level of human capital in the economy increases. ■

Therefore, according to our benchmark model, an education reform launched in the presence of a limited supply of education, ceteris paribus, results in an increase in the level of human capital. However, as we will see in the following section, this result does not necessary hold in the presence of corruption or poor management.

3 Imperfect Institutions

In this section, we introduce low-quality institutions into the model by assuming that the owners are required to pay a share of their income to receive a license, permit, etc.[24] We consider an extreme case of corruption in which the bureaucrat completely avoids prosecution by the state when he extracts some of the owner's income and that the owner has no other recourse to punish the corrupt bureaucrat. We further assume that the diverted income is not invested in new technology, but simply pocketed by the bureaucrat. Alternatively, we can introduce this problem in the context of corporate mismanagement. If a firm is managed by an individual who systematically makes incorrect decisions regarding the firm's investment strategy, the return on investment in new technology declines.

We show that the presence of weak institutions reduces the incentives for firms to invest in new technology. As a low level of investment in the acquisition of new technology retards the pace of technological development, it becomes harder for the economy to catch up to the world technological frontier and it becomes more likely that the economy will be caught a non-convergence trap,[25] whereby the gap between the level of domestic technology and the leading technology frontier remains large and

[24]Our assumption about the presence of weak institutions in a developing economy has been used widely (e.g. Mauro, 1995; Shleifer and Vishny, 1993; and Svensson, 2005).

[25]Alternatively, we could consider the case of income diversion or corporate mismanagement within the representative firm. The owners (shareholders) entrust the duties of running the firm to a manager, who can use the position to pursue interests other than enriching shareholders. As property rights are comparatively weakly protected in developing and transitional economies, powerful managers who follow their own interests may reduce shareholders' benefits (e.g. Boycko, Shleifer and Vishny, 1993; Boycko, Shleifer and Vishny, 1994); Shleifer and Vishny, 1997); and Black (1998).

In our setting, managers would thus be able to expropriate a part of the owners' income therefore reducing firms' incentives to invest in new technologies.

never narrows. In response, employees have less incentive to invest in human capital, so the likelihood of an education reform succeeding decreases.

3.1 Model with imperfect institutions

Assume that part of the representative owner's income can be stolen by bureaucrats at no cost. The latter, however, occurs only if the owner runs an investment project. In other words, if the representative firm takes no action to adopt new technology, there are no transactions from which the bureaucrat can extract income. The official's extracted share is $0 < \gamma < 1$ of the owner's income, leaving the owner with $1 - \gamma$.

In contrast to the previous section, where the owner's payoff function corresponded to equation (8), corruption reduces the owner's income, such that:

$$W_o = (1-\gamma)\left[(1-\alpha_t)\,\beta A_{t,1}^{\theta}\,(h_{t,1}m_t)^{1-\theta} + \beta A_{t,2}^{\theta}\,(h_{t,2}m_t)^{1-\theta}\right]. \tag{13}$$

Before the owner begins a new project, the owner must make sure that the project provides a higher payoff than investing in the storage technology. This is only the case if the following inequality holds (see Appendix II for more details):

$$1-\gamma \geq \frac{2}{(1-\varphi(\alpha_t^*))^{1-\theta}\left[1-\alpha_t^* + \frac{1+\varphi(\alpha_t^*)}{1-\varphi(\alpha_t^*)}\right].} \tag{14}$$

In the previous section, which dealt with the case without corruption, γ equaled 0. In the presence of corruption, however, γ must be positive. As a result, the left-hand side of condition (14) is less than 1. We also showed in the previous section that the denominator of the right-hand side of inequality (14), which is identical to the left-hand side of equation (11), converges on its lowest value, 2, as α_t^* approaches 0. Therefore, if the latter is the case, the value of the entire right-hand side of inequality (14) is close to its maximum value of 1. For comparatively high values of γ and low values of α_t^*, condition (14) does not hold, as in this case its left-hand side is substantially lower than 1, while its right-hand side is instead close to 1. In the presence of corruption, the owner is less willing to invest in new technology.

We assume that a bureaucrat chooses the level of γ exogenously, and the owner invests in new technology as long as inequality (14) holds. The lowest level of α_t^*

satisfying inequality (14) also satisfies equation (15):

$$\gamma = 1 - \frac{2}{(1-\varphi(\widehat{\alpha}^*))^{1-\theta}\left[1-\widehat{\alpha}^* + \frac{1+\varphi(\widehat{\alpha}^*)}{1-\varphi(\widehat{\alpha}^*)}\right]}, \tag{15}$$

where $\widehat{\alpha}^*$ reflects the value of α_t^* at which the payoff levels from investing into a new technology and acquiring the storage asset are identical. We notice that in the benchmark version of our model both γ and $\widehat{\alpha}^*$ were equal to zero.

Returning to Figure 1, we observe that as the vertical distance between a point on the adoption function and the payoff from the storage technology represented as a horizontal line increases, so does the value of α_t^*.

Thus, even after the bureaucrat extracts share γ from the owner's income, as long as α_t^* remains comparatively large, the owner's income from investing in new technology is still greater than his payoff from acquiring the storage asset. However, as α_t^* becomes smaller, the difference between these two payoffs decreases. When it reaches zero, α_t^* reduces to $\widehat{\alpha}^* > 0$. As $\widehat{\alpha}^* > 0$ results in a positive level of investment in new technology, the distance to the leading frontier $\frac{A_{t,1}^L}{A_{t,1}}$ declines. For the next generation, in accordance with equation (7), the value of α_t^* is less than $\widehat{\alpha}^*$, implying that condition (14) no longer holds.[26] At this point, it becomes prudent for the owner if he starts investing in the storage asset rather than new technology. The owner will only resume investment in new technology when the gap between the payoff from investment in new technology and that of investing in a storage asset becomes positive again. For this to happen, the level of α_t^* should increase, which, according to equation (7), is a consequence of a larger value of $\frac{A_{t,1}^L}{A_{t,1}}$, the measure of technological backwardness.

We now consider the above argument in detail. Assume that generation t invests $\alpha_t^* = \widehat{\alpha}^*$ in new technology, and that α_t^* satisfies inequality (14), implying that the actual level of investment in the acquisition of new technologies will be positive. As we know from Proposition 1, the optimal share for the next generation $t+1$ will be equal to α_{t+1}^*, which is lower than $\widehat{\alpha}^*$. This is because the economy is converging on the world technological frontier. From equation (7) it follows that for generation $t+1$ investing $\alpha_{t+1}^* = \widehat{\alpha}^*$ is no longer optimal. However, if the value of γ does not also decline, and instead remains constant, then α_{t+1}^* does not satisfy inequality (14), as it is lower than $\widehat{\alpha}^*$, i.e. the lowest value satisfying this inequality. In this case, given the optimal $\alpha_{t+1} = \alpha_{t+1}^*$, which is defined from (7), and a positive level of γ, the payoff from investing in the storage asset becomes larger than the payoff from investing in new

[26] This is because $\widehat{\alpha}^*$ corresponds to the lowest value of α_t^* for which inequality (14) holds.

technology. This implies that the representative owner will not invest in technological adoption, and therefore the actual value of α_{t+1} will be equal to zero. At the same time, as the level of leading technology increases at rate g, so the distance between the local technology and the world frontier becomes greater. If, for generation $t+2$, the distance to the leading frontier $\frac{A^L_{t+2,1}}{A_{t+2,1}}$ becomes sufficiently large, the optimal value of α_{t+2} will satisfy inequality (14) and therefore the owner will start investing in new technology again. While investing in new technology shortens the distance to the technological frontier $\frac{A^L_{t+3,1}}{A_{t+3,1}}$, it also reduces α^*_{t+3} such that it might no longer satisfy inequality (14). This process reduces the payoff from investing in a new technology below the payoff from investing in the storage asset.

From this discussion, it follows that in the presence of corruption, the economy does not converge to the technological frontier. Instead, the distance to the leading technology, on average, remains relatively large and constant. The latter implies that in general the level of domestic technology and the world technological frontier rise at the same rate g. We label the latter result as a *non-convergence trap*.[27]

From equation (15) it follows that a larger share of income γ that the bureaucrat extracts from the owner's income, the higher the threshold fraction of income $\widehat{\alpha}^*$ that the owner invests in the acquisition of new technology before investing in storage technology. At the same time, according to equation (7), a higher $\widehat{\alpha}^*$ corresponds to a larger distance to the leading frontier $\frac{A^L_{t,1}}{A_{t,1}}$. If the distance to technological frontier can be considered as a measure of development, then, as a larger γ results in a higher value of $\frac{A^L_{t,1}}{A_{t,1}}$, it follows that a higher γ implies greater technological backwardness, i.e. a lower level of development. We summarize the detrimental effects of corruption on technological evolution in the following expression:

$$\frac{A^L_{t,1}}{A_{t,1}} = f(\gamma). \tag{16}$$

Equation (16) implies that as long as the level of corruption γ does not change, the technological gap $\frac{A^L_{t,1}}{A_{t,1}}$ remains constant. We can rewrite equation (16) as follows:

$$z_\gamma = \frac{A^L_{t,1}}{A_{t,1}} = f(\gamma), \tag{17}$$

[27]"There is also a group of middle income countries which appear to have become trapped and are either not converging with the rich countries or converging very slowly. The 'middle income trap' (which is a particular case of the non-convergence trap) is a name for countries that appear squeezed between low wage, poor developing countries that can outcompete them in standardized manufacturing exports, and high-skilled, rich countries that grow through innovation." OECD (2010).

where z_γ reflects the level of technological backwardness as a function of the level of corruption. Thus, when the level of corruption does not change, domestic technology remains a constant fraction $\frac{1}{z_\gamma}$ of the leading technology level. We summarize our finding in the following proposition:

Proposition 3. *The higher the share of income γ that the bureaucrat diverts from the representative owner, the larger the non-reducible gap between local technology and the world technological frontier.*

Proof. From equation (15), it follows that the larger the share γ that the bureaucrat diverts from the representative owner, the greater the threshold optimal share of income $\widehat{\alpha}^*$ the owner must invest in new technology. From equation (7), it follows that a larger $\widehat{\alpha}^*$ corresponds to a greater distance to the world technological frontier $\frac{A^L_{t,1}}{A_{t,1}}$. ■

Therefore, we conclude that corruption can slow the pace of technological evolution and even ensnare the economy in a *non-convergence trap*.

We illustrate these results in Figure 3:

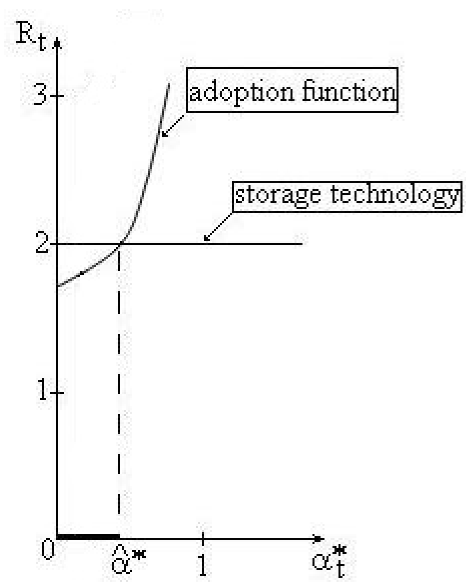

Figure 3. A non-convergence set in the economy with corruption.

This is similar to Figure 1 with one important difference – the presence of corruption shifts the adoption function downward. Unlike the case without corruption, the set of optimal values α_t^* for which the storage asset provides a higher payoff than investing in new technology is no longer empty. In Figure 3, we can see a set of values $0 \leq \alpha_t^* \leq \widehat{\alpha}^*$ (represented as a bold section of the horizontal axis) for which the horizontal line, reflecting the payoff from the storage asset, is located strictly above the adoption function, corresponding instead to the payoff from investing in a new technology. Whenever α_t^* belongs to this set, which we call the *non-convergence set*, the firm prefers to retain the old technology rather than acquire a new one. The larger the value for γ, the larger the *non-convergence set* and the greater the gap between domestic technology and the leading frontier. In the presence of corruption, the economy will attain the level $\alpha_t^* = \widehat{\alpha}^*$, which corresponds to the intersection between the adoption function and the horizontal line representing the payoff from investing in the storage asset. Its technology will evolve at a pace g, reflecting the growth rate of the world technological frontier. Although the level of domestic technology increases at a constant rate g over the long term for economies with and without corruption, the distance between the level of local technology and the leading frontier is greater in the corrupt economy.

3.2 Education in an economy with weak institutions

As more corruption slows technological evolution, we also expect it to depress the rate of human capital accumulation. From equation (10), it follows that the optimal fraction of human capital endowment invested in the acquisition of human capital φ_t^* equals zero whenever $\alpha_t = 0$. In other words, employees have no reason to acquire human capital if the representative owner does not invest in new technology. In the previous subsection, we showed that, in the presence of corruption, an economy can end up in a non-convergence trap. Once trapped, the economy only grows as fast as the world technological frontier, i.e. at rate g, which is lower than the economy's potential growth rate in its early stage of development. From equation (10), it follows that if the average growth rate of technology $A_{t,1}$ is similar to g, then the level of investment in human capital becomes constant and equals $\varphi_t^* = \frac{g}{2+g}$, which again is below potential. It thus follows that individuals acquire less human capital when corruption reduces the level of investment in technology adoption.

We can also present the argument that the presence of corruption reduces the effectiveness of education reform in graphic form.

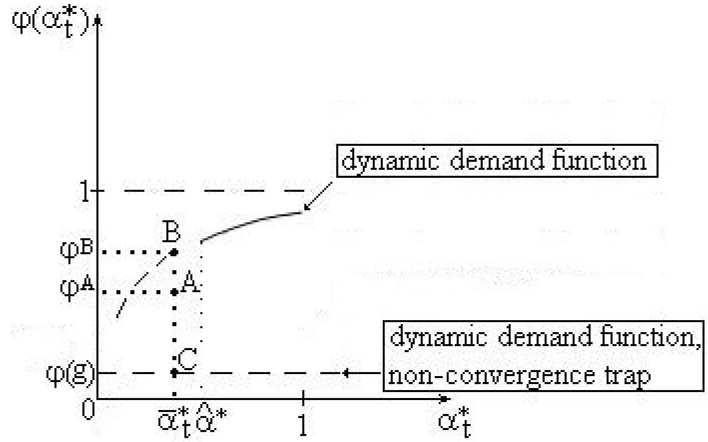

Figure 4. Educational reform in the economy with corruption

Note that, as long as $\alpha_t^* \geq \widehat{\alpha}^*$, the *dynamic demand function* in Figure 4 is represented by the same curve as in Figure 2. When the optimal α_t, i.e. α_t^*, is less than $\widehat{\alpha}^*$, the representative owner stops investing in new technology. In other words, α_t equals zero, so the owner turns to investing in the storage technology; when the value of α_t^* is less than $\widehat{\alpha}^*$, it no longer satisfies the inequality (14). As shown in the previous subsection, the level of domestic technology increases, on average, at a rate g if the economy has become caught in a non-convergence trap. The latter implies that the level of aggregate human capital stock H_t also grows at a constant rate determined by g. Thus, after the economy reaches $\alpha_t^* = \widehat{\alpha}^*$, the dynamic demand function becomes a constant $\varphi(g)$ represented as point C on the dashed line which we denote as *dynamic demand function, non-convergence trap*.

Also note that point C on the dashed line $\varphi(g)$ is located substantially below point B, which corresponds to the level of demand for education in the economy without corruption. As corruption has depressed the pace of technological development, it follows from equation (10) that $\varphi(g) < \varphi^B$. Thus, the impact of corruption is mirrored in both slower technological evolution and a lower pace of human capital accumulation.

Consider point C corresponding to $\overline{\alpha}_t^*$ on the horizontal axis, which is lower than $\widehat{\alpha}^*$, the lowest value of α_t^* satisfying inequality (14). As soon as the economy reaches $\widehat{\alpha}^*$, it transits from the *dynamic demand function* curve to point C, which lies on the *dynamic demand function, non-convergence trap* line. On one hand, as $\overline{\alpha}_t^* < \widehat{\alpha}^*$does not satisfy inequality (14), so at $\overline{\alpha}_t^*$ the owner prefers to acquire the storage asset rather than invest in new technology. On the other hand, $\overline{\alpha}_t^*$ also reflects the average share of income α_t that the representative owner invests in the acquisition of new technology while the economy is caught in the *non-convergence trap*. As we showed in the previous subsection, in the presence of corruption, the actual level of α_t is zero when α_t^* is too low to satisfy the inequality (14). However, $\alpha_t = \alpha_t^* > 0$ when, as a result of the increased distance to the leading frontier $\frac{A_{t,1}^L}{A_{t,1}}$, the optimal value of α_t, as defined in equation (7), increases, and thus satisfies inequality (14). On average, the level of technology evolves at rate g, thereby determining the level of $\overline{\alpha}_t^*$. As the pace of technological advancement is as fast as at the world technological frontier, it follows that the gap between local technology and the leading frontier remains unaltered. Moreover, this width of the gap remains relatively large as the economy shifts to a lower investment path, i.e. it invests less in acquisition of new technology than in the case without corruption. According to equation (10), the aggregate human capital stock H_t also grows at a constant rate, corresponding to the dashed line, designated *dynamic demand function, non-convergence trap*, i.e. to $\varphi(g)$.

As we did in subsection 2.4, assume that the government plans to implement a reform to improve the level of education in the economy. Again, the authorities believe that a low level of supply of education is the central obstacle to achieving higher economic growth. As in our benchmark model, we assume that the available supply of educational services corresponds to point A. However, unlike the case of Figure 2, where the level of demand for education corresponded to point B, the actual level of demand for education is now represented by point C. Thus, the level of demand for education is lower than the level of supply, so an education reform that increases the level of supply to point B does not lead to an increase in the human capital stock.

We are now ready to formulate our key result:

Proposition 4.

1. *In the presence of corruption, demand for education declines as a consequence of lower investment in new technology.*
2. *An education reform that aims to increase the supply of education in order to increase the human capital stock can still fail to increase the equilibrium level of human capital.*

Proof. The first part of Proposition 4 follows directly from equation (10).
As for the second part of Proposition 4, we again note that the level of investment in

the acquisition of additional human capital before the education reform takes place can be defined as:

$$\varphi_t = min\left\{\varphi_t^{S,1}, \varphi_t^D\right\}, \quad (18)$$

where $\varphi_t^{S,1}$ corresponds to the initial level of supply of education. $\varphi_t^D = \varphi(\alpha_t^*)$, where $\varphi(\alpha_t^*)$ is determined in equation (10), reflects the level of demand for education. If the latter corresponds to the *dynamic demand function* curve, then, as we showed in the proof for Proposition 2, the education reform has been successful. If *the dynamic demand function* instead falls along the *dynamic demand function, non-convergence trap* line, the level of education demanded by employees is lower than the initial level of supply, i.e. $\varphi_t^D < \varphi_t^{S,1}$. In such case, the actual level of investment in the acquisition of human capital is $\varphi_t^D = min\left\{\varphi_t^{S,1}, \varphi_t^D\right\}$. Thus, an education reform that increases the level of supply from $\varphi_t^{S,1}$ to $\varphi_t^{S,2}$, where $\varphi_t^{S,2} > \varphi_t^{S,1}$, does not result in higher level investment in acquisition of human capital, as $\varphi_t = min\left\{\varphi_t^{S,2}, \varphi_t^D\right\} = \varphi_t^D$. ■

We therefore conclude that corruption can diminish demand for education and limit the efficacy of the education reform.[28]

As we show in the following section, an education reform is more likely to succeed if it is carried out in conjunction with an anti-corruption campaign. Anti-corruption measure reduces the level of γ, and shifts the adoption function in Figure 3 upward. As a consequence, the non-convergence set becomes smaller and it becomes more likely that domestic technology can converge on the world technological frontier. As a result, employees invest a higher level of φ_t in the acquisition of human capital, and thus an education reform becomes potentially more effective.

As previously concluded, weak institutions can reduce the level of investment in

[28]When individuals can transfer their human capital to another economy, migrating to an economy with less corruption becomes an attractive option.

To show this result is the case, we consider two otherwise identical economies with different levels of corruption. Generation t in the less-corrupt economy, A, invests in new technology and acquires human capital, implying that $\alpha_t^A > 0$ and $\varphi_t^A > 0$. The same generation in more-corrupt economy B chooses instead to invest in the storage asset, reflecting that corruption reduces the return on investment in new technology.

Assume that individuals from economy B can freely transfer their human capital to country A, and vice versa. In equilibrium, a typical employee should earn the same income in both countries, implying that:

$$\frac{m_A}{m_B} = \frac{1}{1-\varphi_t^A}, \quad (19)$$

where m_j, is the number of employees who work at the representative firm in country $j = A, B$. As $0 \leq \varphi_t^A \leq 1$, it follows that $m_A \geq m_B$, so the number of employees increases in economy A and falls in country B. Thus, employees who plan to transfer their human capital to economy A will benefit from the implementations of an education reform in country B as they can acquire human capital for later use in economy A.

acquisition of new technology, which, in turn, dampens incentives to acquire more human capital. As a result, an education reform aimed at increasing human capital is rendered ineffective. Similarly, an education reform is more likely to achieve its purpose of enhancing economic growth when implemented in tandem with a policy that encourages firms to invest more in the acquisition of new technology and induces individuals to acquire more human capital. In this section, we will briefly review the effect of an anti-corruption campaign designed to reduce the negative impact of corruption on the level of investment in new technology and human capital.

As an effective anti-corruption campaign reduces the level of γ, it follows from equation (15) that the threshold fraction of income $\widehat{\alpha}^*$ that the owner invests in the acquisition of new technology also falls. From equation (7), we see that a lower level of $\widehat{\alpha}^*$ corresponds to a lower gap between domestic technology and the leading frontier $\frac{A_{t,1}^L}{A_{t,1}}$. Therefore, if γ decreases, the level of domestic technology moves closer to the leading frontier. As a consequence of a higher level of investment in a new technology, the level of demand for education increases. Thus, a reform that expands the level of supply of education becomes more effective when measures to deal with corruption are taken.

The literature on various methods of reducing the level of corruption is vast (see, for instance, Reinikka and Svensson, 2005, or OECD, 2005), and therefore we do not survey this literature in our paper. Instead, we only note here that anti-corruption campaigns can themselved be compromised. For example, Persson, Rothstein and Teorell (2012) discuss the failure of anti-corruption reforms in Africa. Bertucci and Armstrong (2000) and Hanna et al. (2011) survey possible reasons for the failure of anti-corruption campaigns.

4 Russia: a real-world case of low investment levels

To flesh out the theoretical discussion, we now consider the case of Russia. According to a group of internationally recognized measures used in cross-country comparisons,[29] the economy of Russia suffers from a variety of drawbacks, including weak institutional protections and an underperforming education system.Russian authorities have long recognized the need to diversify and increase the level of complexity of the

[29]These include the Transparency International's Corruption Perception Index, which has been calculated and published annually since 1995, as well as PISA scores, which measure of general education quality among 15-year-olds in OECD countries, as well as in a sample of less developed economies.

economy of Russia,[30] which even today is still dominated by low value-added sectors such as oil and gas extraction. According to the Atlas of Economic Complexity, a study that aims at making cross-country comparisons in terms of the level of production complexity, Russia ranked 50th of the 124 countries covered in its 2014 survey.[31] This finding suggests that Russia largely exports ubiquitous goods similar to those exported by many nations. This could simply indicate the technological backwardness of the Russian economy. If so, Russia needs to develop new production capabilities so that it can export sophisticated value-added products to take its rightful place among global technology leaders. However, as many of these production capabilities require a large and sophisticated supply of human capital, the quality of domestically supplied education, at least to some extent, influences this possibility.

Should Russia improve its education system to pursue its diversification goal? The 2012 PISA results gave Russia low marks in all three general categories of student performance (reading, mathematics and natural sciences).[32] While the overall performance of students in the United States was even worse than Russia's, the US still had the largest collection of world-class universities. Russian tertiary education at best may have some regional importance.[33] In other words, the system of education in Russia provides little opportunity to acquire advanced skills, and seems largely oriented to transferring medium-level skills to its labor force. Even though medium-level skills are valuable in performing routine, bureaucratic tasks, they do not demand the skillsets needed to establish potent research and development capabilities.

As indicated in Acemoglu and Autor (2010), an oversupply of medium-skilled workers results in a larger skill premium and, consequently, in a higher level of income inequality. Apart of its inequality effects, poor education also constrains economic growth. Hanushek and Woessmann (2015) directly point at education as a key ingredient for economic growth. As is discussed by Rodrik (2007), even where it might be possible to imitate frontier technology, the lack of a sufficiently educated workforce can substantially limit growth opportunities.[34] Thus, if more sectors of the Russian economy are to catch up with the world level of technology, it needs to change its system of education in ways that produce more engineers, programmers and managers –

[30] See e.g. this Reuters article: http://www.reuters.com/article/russia-crisis-putin-diversify-idUSR4N0QD05X20141218 .

[31] Entire rankings posted at http://atlas.cid.harvard.edu/rankings/.

[32] https://www.oecd.org/pisa/keyfindings/pisa-2012-results.htm

[33] For a distribution of top universities: http://www.shanghairanking.com/

[34] https://www.project-syndicate.org/commentary/innovation-impact-on-productivity-by-dani-rodrik-2016-06?utm_source=June+Newsletter&utm_campaign=June+Newsletter&utm_medium=email

and fewer clerks.

Indeed, the current state of Russian education may partly explain Russia's relative weakness in exporting sophisticated value-added products or services (as captured by the Hausmann-Hidalgo index of economic complexity mentioned above), but it is by no means the sole explanation. There are many problems that constrain Russia's capability to accumulate more human capital. To even gain the incentive to acquire more human capital, individuals need to be exposed to skill-intensive work, i.e. they need opportunities to interact with advanced technology in professional settings. When such opportunities are rare, education appears to offer not so much reward in the local job market, meaning that individuals developing high-end skillsets must eye opportunities elsewhere in advanced economies.

Why are advanced-skill jobs so rare in Russia? One reason may be the incompetence of corporate management. Russia's giant state-owned enterprises are notorious for poor management,[35] as well as systematically demanding bailouts[36] whenever demand on international commodity markets is down. Top management in Russia is hierarchical and undersupervised. Russian CEOs at big companies are free to sponsor soccer clubs, surround themselves with luxurious offices, unencumbered by the checks on their authority that restrain CEOs in more advanced economies from diverting company assets away from investment in productive activity. Shareholders and supervisory boards in Russia are not motivated or empowered to monitor CEOs. The consequence of CEO extravagance is that offices often lack competent lower level staff, or the appropriate equipment and technology required for high-skilled employees to make substantial contributions. Many CEOs in Russia themselves lack the key skills and experience need to run a large company. They have been installed in the the CEO position not because they were talented enough to climb the corporate ladder, but because they were entitled to control of company assets. When companies, banks or universities are managed by ex-bureaucrats instead of MBAs, they tend to stick with the technological status quo, as they might not have skills and incentives to advance the enterprise technologically or guarantee sound management practices.

Finally, Russia suffers from over-involvement of the state in the economy and poor property right protections. Even if the level of management were to improve to the highest international standards, companies might still have low incentives to invest as the risks of racketeering and nationalization remain substantial. According to Trans-

[35] https://www.bloomberg.com/view/articles/2013-06-09/gazprom-s-demise-could-topple-putin

[36] http://www.nytimes.com/2015/03/10/business/dealbook/in-russia-the-well-for-corporate-bailouts-might-run-dry.html?_r=0

parency International, Russia in 2015 was as corrupt as Sierra Leone, Guyana and Madagascar, countries with far lower levels of GDP per capita, education and technological development.[37]

Thus, to re-engage with the race between education and technology and to catch up with advanced economies, Russia needs to consider the mechanisms that affect the outcome of reforms, perhaps in the form of a Leontief function. There might be no improvement unless all important ingredients are addressed. Successful reform must proceed on multiple fronts. Such a reform package may be part of a long-term development strategy, but due to financial and administrative restrictions, implementing a collection of reforms at the same time may prove a difficult, if not impossible, task. This is why it is important to tackle the most restrictive constraint first. Here, identifying the most binding constraint in itself is the critical task, and for this a proper methodology is still lacking.

5 Conclusions

We considered an economy in which a typical firm combines technology and human capital to produce output. In our baseline version of this economy, a representative firm initially invests a part of its income in the acquisition of new technology using an adoption strategy. That is, the new technology is adopted from what is in use on the world technological frontier. As all firms in the economy do this, it brings the economy closer to the frontier level of technology. Employees, in turn, use their human capital stock to produce output and to acquire more human capital. As technology and human capital are complementary factors of production, a faster pace of technological evolution encourages the employees to allocate more of their investment to acquisition of additional education.

We assume that our imagined economy starts out with a limited supply of educational services relative to the existing demand for education. When the government implements a reform to enhance the availability of educational services, it helps the economy increase the human capital stock and promotes economic growth.

A common issue with developing economies is the weakness of institutional settings. We thus incorporate corruption into our baseline model. Corruption reduces the incentives for firms to invest in acquisition of new technology, so employees adjust their investment in human capital and acquire less education. Therefore, an education

[37] http://www.transparency.org/cpi2015

reform can lose efficacy if individuals are unwilling to partake of the benefits offered by the education reform.

To overcome this unwillingness to invest in the acquisition of human capital, we note that measures to reduce the level of corruption may result in an accelerated pace of technological evolution and a higher rate of human capital accumulation.

We also consider our model findings with respect to the real-world case of Russia.

This theory can be extended to show how an education reform might also promote a brain drain, i.e. outflow of human capital. For instance, if the level of corruption in the economy remains high, individuals are incentivized to transfer their human capital to a less corrupt country that offers higher levels of technology and income. Thus, individuals planning to transfer their human capital to a less corrupt economy will take advantage of the skills provided through an education reform in their home country on the assumption that they can use their new skill later in the more developed economy. This process iscsimilar to the "knowledge leaks" discussed in Easterly (2001). When the average level of knowledge in a particular society is high, individuals are motivated to invest in education. Conversely, when the level of knowledge is low, individuals have little incentive to invest in human capital, and if they do so, they may have an ulterior purpose such as emigration.

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Appendix I

Derivation of equations (7) and (10).

Each firm owner maximizes his income by choosing the share α_t optimally:

$$W_o = (1-\alpha_t)\,\beta A_{t,1}^{\theta}\left(h_{t,1}(1-\varphi_t)\,m_t\right)^{1-\theta} + \beta A_{t,2}^{\theta}\left(h_{t,1}(1+\varphi_t)\,m_t\right)^{1-\theta}.$$

Employees search for the optimal share of their human capital endowment φ_t to maximize their labor income

$$W_e = (1-\beta)\,A_{t,1}^{\theta}\left(h_{t,1}(1-\varphi_t)\,m_t\right)^{1-\theta} + (1-\beta)\,A_{t,2}^{\theta}\left(h_{t,1}(1+\varphi_t)\,m_t\right)^{1-\theta}.$$

The respective FOCs are:

$$-\beta A_{t,1}^{\theta}\left(h_{t,1}(1-\varphi_t)\,m_t\right)^{1-\theta} + \theta\beta A_{t,2}^{\theta-1}\frac{\partial A_{t,2}}{\partial \alpha_t}\left(h_{t,1}(1+\varphi_t)\,m_t\right)^{1-\theta} = 0$$

$$(1-\beta)(1-\theta)\left[A_{t,1}^{\theta}\left(h_{t,1}(1-\varphi_t)\,m_t\right)^{-\theta}h_{t,1}m_t - A_{t,2}^{\theta}\left(h_{t,1}(1+\varphi_t)\,m_t\right)^{-\theta}h_{t,1}m_t\right] = 0.$$

After rearranging, we obtain the following result:

$$\frac{\partial A_{t,2}}{\partial \alpha_t} = \frac{A_{t,1}}{\theta} \tag{20}$$

$$\frac{A_{t,2}}{A_{t,1}} = \frac{1+\varphi_t}{1-\varphi_t} \tag{21}$$

One can combine equation (4) and equation (20) to derive equation (7). Equation (10) follows from equation (21).

Dynamics of α_t^*.

Rewriting equation (7), we obtain:

$$\eta'(\alpha_t^*) = \frac{1}{\theta\left(\frac{A_{t-1,1}^{L}(1+g)}{A_{t-1,1}+\eta(\alpha_{t-1}^*)\left(A_{t,1}^{L}-A_{t-1,1}\right)} - 1\right)} \tag{22}$$

From equation (22), we note that when the denominator of the following expression

$$\frac{A_{t-1,1}^{L}(1+g)}{A_{t-1,1}+\eta(\alpha_{t-1}^*)\left(A_{t-1,1}^{L}-A_{t-1,1}\right)}$$

increases more than its numerator as a result of investing the share of income α^*_{t-1}, i.e. when the domestic level of technology grows faster than g, the economy approaches the leading technological frontier, narrowing the gap between the level of local technology and the leading frontier, i.e. $\frac{A^L_{t,1}}{A_{t,1}}$. As $\frac{A^L_{t,1}}{A_{t,1}}$ positively affects the level of α^*_t, this implies that α^*_talso get smaller, so $\alpha^*_t < \alpha^*_{t-1}$.

When, in contrast, the denominator of

$$\frac{A^L_{t-1,1}(1+g)}{A_{t-1,1} + \eta(\alpha^*_{t-1})\left(A^L_{t-1,1} - A_{t-1,1}\right)}$$

increases less than its numerator, i.e. the growth of domestic technology lags the world frontier and the distance to the technological frontier increases, this reverses the inequality, i.e. α^*_t becomes larger than α^*_{t-1}.

Finally, when the numerator of

$$\frac{A^L_{t-1,1}(1+g)}{A_{t-1,1} + \eta(\alpha^*_{t-1})\left(A^L_{t-1,1} - A_{t-1,1}\right)}$$

increases as fast as its denominator, i.e. at a rate g, the gap between the level of local technology and the leading frontier remains constant, it follows that $\alpha^*_t = \alpha^*_{t-1}$.

Adoption function increases in α^*_t.

To show that the following expression

$$R_t = (1 - \varphi(\alpha^*_t))^{1-\theta}\left[1 - \alpha^*_t + \frac{1+\varphi(\alpha^*_t)}{1-\varphi(\alpha^*_t)}\right]$$

is increasing with respect to α^*_t, we first rewrite

$$R_t = \left(\frac{A_{t,2} + A_{t,1}}{A_{t,1}} - \alpha^*_t\right)\left(\frac{2A_{t,1}}{A_{t,2} + A_{t,1}}\right)^{1-\theta}$$

and then differentiate the expression with respect to α^*_t to obtain:

$$\left(\frac{1}{\theta} - 1\right)\left(\frac{2A_{t,1}}{A_{t,2} + A_{t,1}}\right)^{1-\theta} -$$

$$-(1-\theta)\left(\frac{2A_{t,1}}{A_{t,2} + A_{t,1}}\right)^{-\theta}\left(\frac{2A_{t,1}}{A_{t,2} + A_{t,1}}\right)\frac{A_{t,1}}{\theta\left(A_{t,2} + A_{t,1}\right)}\left(\frac{A_{t,2} + A_{t,1}}{A_{t,1}} - \alpha^*_t\right) =$$

$$= \left(\frac{1}{\theta} - 1\right) \left(\frac{2A_{t,1}}{A_{t,2} + A_{t,1}}\right)^{1-\theta} \alpha_t^* \frac{A_{t,1}}{A_{t,2} + A_{t,1}} > 0.$$

Appendix II.

In the case of corruption, we consider the following inequality:

$$(1-\gamma) \left[(1-\alpha_t^*)\, \beta A_{t,1}^{\theta} \left(h_{t,1} \left(1 - \varphi(\alpha_t^*)\right) m_t\right)^{1-\theta} + \beta A_{t,2}^{\theta} \left(h_{t,1} \left(1 + \varphi(\alpha_t^*)\right) m_t\right)^{1-\theta}\right] \geq$$

$$\geq \beta A_{t,1}^{\theta} \left(h_{t,1} m_t\right)^{1-\theta} + \beta A_{t,1}^{\theta} \left(h_{t,1} m_t\right)^{1-\theta}$$

which reduces to

$$(1-\gamma) \left(1 - \varphi(\alpha_t^*)\right)^{1-\theta} \left[1 - \alpha_t^* + \frac{1 + \varphi(\alpha_t^*)_t}{1 - \varphi(\alpha_t^*)}\right] \geq 2.$$

From this result inequality (14) follows immediately.

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