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The Spillover Effects of Innovative Ideas on Human Capital

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Abstract

This paper extends a two-period Overlapping Generations model of endogenous growth where the interactions between public infrastructure, human capital with R&D activities, and growth are studied. The paper makes two important contributions. First, it accounts for the spillover effect of the stock of ideas on learning which in turn promotes the production of innovative technologies. In doing so, it brings to the fore a two-way interaction between human capital and innovation. The paper then applies various econometric methods which confirm the above theoretical thesis. Second, the solutions of the model emphasise the important role public spending on infrastructure, human capital and R&D can play in promoting economic growth. In order to study the transitional dynamics of the model and to illustrate the impact of public policy, the model is calibrated using the average data for low-income countries and a sensitivity analysis is reported under different parameter configurations. The findings of the numerical analysis show that trade-offs in the allocation of public spending may inevitably emerge. In particular, investment in public infrastructure at the expense of spending on R&D is less likely to succeed in promoting economic growth, whereas it may be more effective to foster growth through an offsetting cut in another productive component, namely, education. In light of these potential trade-offs, governments in low-income countries need to use their limited budgets as part of holistic measures in order to achieve efficient outcomes.

Keywords

Infrastructure, Human Capital, Innovation, Government Policy

JEL Classification

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The Spillover Effects of Innovative Ideas on Human Capital*

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Abstract

This paper extends a two-period Overlapping Generations model of endogenous growth where the interactions between public infrastructure, human capital with R&D activities, and growth are studied. The paper makes two important contributions. First, it accounts for the spillover effect of the stock of ideas on learning which in turn promotes the production of innovative technologies. In doing so, it brings to the fore a two-way interaction between human capital and innovation. The paper then applies various econometric methods which confirm the above theoretical thesis. Second, the solutions of the model emphasise the important role public spending on infrastructure, human capital and R&D can play in promoting economic growth. In order to study the transitional dynamics of the model and to illustrate the impact of public policy, the model is calibrated using the average data for low-income countries and a sensitivity analysis is reported under different parameter configurations. The findings of the numerical analysis show that trade-offs in the allocation of public spending may inevitably emerge. In particular, investment in public infrastructure at the expense of spending on R&D is less likely to succeed in promoting economic growth, whereas it may be more effective to foster growth through an offsetting cut in another productive component, namely, education. In light of these potential trade-offs, governments in low-income countries need to use their limited budgets as part of holistic measures in order to achieve efficient outcomes.

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1 Introduction

Technological progress in developing countries has benefited greatly from the increase of globalisation due to the adoption and adaptation of pre-existing technologies imported from more advanced economies. Developing countries are, however, impeded in their ability to promote the growth of technological sectors due to lack of human capital and other complimentary factors. In recent years, there has been an increasing amount of literature on the link between human capital, innovation, and growth. Several studies, for instance, Romer (1990), Grossmann and Helpman (1991), Aghion and Howitt (1992), Redding (1996), Arnold (1999), Funke and Strulik (2000), Strulik (2005), Grossmann (2007), Iacopetta (2010), Gómez (2011), Sequeira (2011), Chen and Funke (2013), and Gómez and Sequeira (2013) have shown that innovation and human capital accumulation are essential instruments for growth, emphasising the complementarity between these two factors in the process of economic development.

So far, however, there has been little discussion on the link between public capital and human capital, innovation activities, and growth. In this paper, we argue that the interplay between these important factors is crucial. In fact, lack of access to physical infrastructure, including electricity, transport networks, and telecommunications, continues to impede the ability of, particularly, low-income countries to absorb foreign ideas and develop new ideas that would result in new and efficient technologies which could be disseminated nation-wide, and thereby fuelling their economies. Conversely, in many countries, governments have used information and communication technologies (ICTs) to promote innovation and human capital by upholding the free ideals of the Internet, thereby allowing other sectors to develop the ability to provide services, such as distance education and telemedicine etc.

The first systematic study in which education and innovation as well as public capital are all determinants of long-run growth was reported by Agénor and Neanidis (2015) within the context of a two-period Overlapping Generations (OLG) model. In their study, numerical calibrations and panel data regressions show that public capital has direct as well as indirect effects on growth through productivity, human capital accumulation, and innovation capacity.

The objectives of this paper are two-fold. First, we examine how the stock of technical knowledge or innovated ideas affects the accumulation of human capital.

In particular, we account for the spillover effects of the stock of ideas on learning, emphasising the important role previously innovated ideas can have in promoting human capital; in doing this, we bring to the fore a two-way interaction between human capital and innovation, confirming the existence of the so-called '*implementation innovation*'. In pursuing the above objective empirically, we extend the theoretical model presented in Agénor and Neanidis (2015), augmenting their human capital sector equation with a parameter capturing the stock of technical knowledge and thus the externality of innovative activities. We then test the central predictions emanating from the above theoretical model using recently developed panel cointegration techniques on a sample of 35 high-income economies over the period 1980 – 2014. Our empirical strategy takes into account issues such as cross-sectional heterogeneity and endogeneity concerns. Moreover, we estimate panel error correction model to ascertain the short- and long-run dynamics in the relationship. Finally, we rely on panel Granger causality tests to determine whether the relationship is of a causal nature.

Second, given the pressing need of low-income economies to improve their technological sectors, we explore whether there are possible trade-offs in the allocation of public expenditure between infrastructure investment and other productive components of public spending, that is, education and R&D activities. We illustrate this issue by applying numerical analysis using average data for low-income countries. Finally, unlike Agénor and Neanidis (2015) who only analyse the long-run balanced growth path, in this paper, we study the transitional dynamics of the model, which enable us to trace the path of the variables after a shock to the steady-state. Thus, we are able to fully capture the important interactions between public capital, human capital, and economic growth from the perspective of public policy.

Based on our empirical analysis, we find that the stock of ideas form a long-run equilibrium relation with human capital. Our panel error correction model indicates the existence of a long-run positive bidirectional relationship between innovation and education, confirming the so-called '*implementation innovation*'. These results remain robust when we extend the specification and apply other estimators such as pooled OLS, random effects, Feasible GLS as well as system GMM.

Our numerical analysis, where we use average data for low-income countries, indicates the existence of potential trade-offs associated with the provision of infrastructure and other productive components of public spending. The results suggest that government interventions may indirectly affect the capacity of sectors to innovate through spillover effects. However, investment in public infrastructure at the expense of spending on R&D is less likely to succeed in promoting economic growth, whereas it may be more effective to foster growth through an offsetting cut in another productive component of public spending, namely, education.

The remainder of the paper is organised as follows. Section 2 gives a brief review of the relevant literature. Section 3 lays out the theoretical framework of the paper, including the main equation in the human capital sector of the model presented in Agénor and Neanidis (2015) in which we incorporate the externality of the stock of technical knowledge. Section 4 calibrates the model, where we illustrate, through several experiments, the impact of public policy, including potential trade-offs between productive components of public spending. Section 5 empirically explores the relationship between the stock of knowledge and human capital. Finally, Section 6 offers some concluding remarks and policy implications.

2 Literature Review

A large body of research, particularly within the endogenous growth literature, has stressed the important role innovation and capital accumulation (both human and physical) play in explaining (long-run) economic growth (Romer, 1986; Rebelo, 1991; Grossmann and Helpman, 1991; and Aghion and Howitt, 1992). Innovation is associated with knowledge assets and processes, which can be converted into new resources that have economic payoffs (McCann and Ortega-Argiles, 2013). Innovative ideas (i.e. the stock of [technical] knowledge) and human capital are closely related through 'interactive processes'. In this context, a distinction is usually made between the creation of new knowledge and its diffusion (Schumpeter, 1943) which can result in knowledge spillovers and externalities (De Dominicis et al., 2013). At the heart of these informational spillovers is learning and, thus, human capital (Romer, 1986; Lucas, 1988; Dakhli and De Clercq, 2004). As argued by Aghion and Howitt (1998, ch.3), therefore, there is a close interaction between human capital and innovation.

The overwhelming majority of the literature focuses on how human capital influences innovation. This issue is theoretically straightforward in that human capital is an important input in the generation and diffusion of innovative ideas. For example, Dakhli and De Clercq (2004) explore the effects of two forms of capital, namely human capital and social capital, on innovation using a sample of 59 countries. Their results show that human capital has positive and significant effects on innovation unlike social capital. Focusing on the United States, Chellaraj et al. (2008) show that the presence of foreign graduate students has positive and significant impacts on both patent grants and applications. Other studies show that innovation is positively related to R&D, financial development and institutional quality (Bottazzi and Peri, 2007; Ang, 2011).

However, little research has been done on how the stock of technical knowledge (i.e. number of ideas innovated) affects the accumulation of human capital. As alluded to above, there are two broad reasons why human capital may benefit from innovation. First, new technological inventions have the tendency to create new economic opportunities which can change the incentive structures, enticing economic agents to improve their skills and expertise (Zeng, 2003). Second, as emphasised by the regional economics literature, geography and spatial proximity are important determinants of the creation and diffusion of new ideas (De Dominicis et al., 2013). This is because geographical proximity tends to encourage "learning processes through mechanisms of knowledge spillovers" (ibid, p.2). Hence, agents located in the same region tend to benefit more from dynamic information externalities given that information within the same locality tends to flow more smoothly. Therefore, a two-way link between innovation and human capital may exist.

One of our main objectives in this paper is to explore theoretically and empirically how the stock of knowledge influences human capital accumulation and whether there is indeed a two-way relationship between the two – i.e. the so-called '*implementation innovation*'. As far as we are aware, the only paper that has previously examined this issue is by Faggian and McCann (2009). In that study, the authors explore the relationship between graduate human capital and innovation in British regions. Their results indicate that there is indeed a two-way link; innovative regions tend to attract a high amount of graduate human capital while the inflow of graduate human capital tends to improve regional innovation. However, their result is only robust once London is included and Scotland is excluded. Moreover, they use a single cross section dataset.

In this paper, we apply recently developed panel cointegration techniques to examine the (long-run) relationship between the stock of ideas and human capital. Unlike the study by Faggian and McCann (2009), our empirical exercise is based on a tractable theoretical model based on the work by Agénor and Neanidis (2015). In particular, we augment their human capital sector equation with a parameter capturing the stock of (technical) knowledge. We retain the rest of their original model for consistency but also because we want to explore two more issues; (1) as we are interested in whether there is a two-way relationship between innovation and human capital, their R&D sector equation is of interest to us as it will be clearer later on, and (2) in light of our second objective, we want to study the transitional dynamics of their model given that we are interested in examining the potential trade-offs associated with public spending, particularly with respect to public infrastructure and other productive components of public expenditure (R&D investments and education). This issue is particularly important for low-income countries as our numerical analyses confirm.

3 Theoretical Framework

In line with Agénor and Neanidis (2015, p.253), we consider a two-period (adulthood and old age) OLG model of endogenous economic growth where the economy is populated by nonaltruistic individuals, firms and a government. The economy has four sectors: final good, intermediate inputs, human capital, and R&D. The government cannot borrow but runs a balanced budget in each period. However, it finances its spending on investment in infrastructure, education, R&D activities, and other items by taxing only wage incomes of adult workers. Wages in the second period of life are the source of income and savings are in the form of physical capital. Agents are only endowed with an initial stock of physical capital at the beginning of each period. Total population is assumed to be constant and the number of adult workers is set to $\bar{N}$. And finally, all markets clear in equilibrium.

We now turn our attention to the detailed description of the theoretical model developed by Agénor and Neanidis (2015, pp.253-256) in which we incorporate the externality of the stock of technical knowledge, as noted earlier: individuals, final good sector, intermediate goods sector, human capital accumulation, research and development sector, government, market-clearing conditions, and dynamic equilibrium respectively.

Individuals:

The discounted utility of an individual born at t is given by

$$U_t = \eta_C \ln c_t^t + \frac{\ln c_{t+1}^t}{1+\rho}, \tag{1}$$

where c_{t+j}^t denotes consumption at period $t+j$ of a person born at the beginning of period t, with $j = 0, 1$, $\rho > 0$ is the subjective discount rate and the parameter $\eta_C > 0$ is the individual's preference for current consumption.

The period-specific budget constraints are given by

$$c_t^t + s_t = (1-\tau)e_t w_t, \tag{2}$$

$$c_{t+1}^t = (1 + r_{t+1})s_t, \tag{3}$$

where w_t is the economy-wide wage rate, e_t individual human capital, $\tau \in (0, 1)$ a constant tax rate, s_t the savings, and r_{t+1} the rate of return on holding (physical) assets between periods t and $t+1$. Individuals maximise equation (1) subject to their intertemporal budget constraint with respect to c_t^t and c_{t+1}^t, taking prices as given.

Final Good Sector:

The final good is produced by using effective labour, $E_t N_{i,t}^Y$, where E_t, the product of average human capital of individuals born in $t-1$ and $N_{i,t}^Y$, employment, private capital, $K_t^{P,i}$, public infrastructure, K_t^I, and a combination of M_t intermediate inputs, $x_{s,t}^i$, where $s = 1, ...M_t$:

$$Y_t^i = [\frac{K_t^I}{(K_t^P)^{\zeta_K}(N_t^Y)^{\zeta_N}}]^{\varepsilon}(K_t^{P,i})^{\alpha}(E_t N_{i,t}^Y)^{\beta}[\sum_1^{M_t}(x_{s,t}^i)^{\eta}]^{\gamma/\eta}, \tag{4}$$

where $\varepsilon > 0, \alpha, \beta, \gamma \in (0, 1)$; the elasticities with respect to public-private capital ratio, private capital, effective labour, and intermediate goods respectively, and $\alpha + \beta + \gamma = 1$ (assuming constant returns to scale in private inputs), $\eta \in (0, 1)$ the parameter that determines the demand elasticity and therefore $1/(1-\eta) > 1$ is the absolute value of the elasticity of demand for each intermediate good, the parameters $\zeta_K, \zeta_N > 0$ measure the strength of congestion effects for the aggregate private capital stock and the total number of workers in the final good sector respectively, $K_t^P = \int_0^1 K_t^{P,i} di$ the aggregate private capital stock, and $N_t^Y = \int_0^1 N_{i,t}^Y di$ total employment in the final good sector.

Assuming constant returns to scale, the aggregate output of the final good is

$$Y_t = \int_0^1 Y_t^i di = (N_t^Y)^{\beta - \varepsilon\zeta_N} (\frac{K_t^I}{K_t^P})^{\varepsilon} (\frac{M_t}{K_t^P})^{\gamma/\eta} (\frac{E_t}{K_t^P})^{\beta} x_t^{\gamma} (K_t^P)^{\alpha+\gamma/\eta+\beta+\varepsilon(1-\zeta_K)}, \quad (5)$$

or by implication,

$$Y_t = (k_t^I)^{\varepsilon} m_t^{\gamma/\eta} z_t^{\beta} x_t^{\gamma} K_t^P, \quad (6)$$

where $K_t^P = K_t^{P,i}$, $\forall i$, $\alpha + \gamma/\eta + \varepsilon(1-\zeta_K) = 1$ and $\beta - \varepsilon\zeta_N = 0$, $k_t^I = K_t^I/K_t^P$ is the ratio of public capital to private capital, $m_t = M_t/K_t^P$ is the knowledge-capital ratio, and $z_t = E_t/K_t^P$ is the human capital-private capital ratio.

Intermediate Goods Sector:

Profit of each intermediate-good producer, $\Pi_{s,t}^I$, is

$$\Pi_{s,t}^I = (p_t^s - \theta) x_{s,t}, \quad (7)$$

where p_t^s a fee monopolistically competitive firms in the intermediate sector should pay to use the patent of each input s to R&D sectors, θ unit of the final good that is required for production of each unit of an intermediate good s, and $x_{s,t}$ the optimal quantity of each intermediate good demanded by producers of the final good.

Human Capital Accumulation:

Our main contribution in this paper is that we incorporate the role innovative ideas or stock of technical knowledge play in the human capital sector. We follow Agénor and Neanidis (2015) in that we assume that individuals devote their time to education in the first period of their lives and that their human capital is produced using a combination of government spending on education per worker, $G_t^E/\bar{N}$, where $\bar{N}$ the number of adults, the average human capital of the previous generation, E_t, and access to public capital or public infrastructure, k_t^I, which is subject to congestion measured by the aggregate private capital stock. Assuming constant returns to scale for tractability, human capital of individuals is

$$e_{t+1} = (\frac{G_t^E}{\bar{N}})^{\nu_1} M_t^{\nu_2} E_t^{1-\nu_1-\nu_2} (k_t^I)^{\nu_3}, \quad (8)$$

where $\nu_1 \in (0,1)$ and $\nu_2, \nu_3 > 0$; the elasticities with respect to public spending on education, externality of technical knowledge and public-private capital ratio respectively, and in a symmetric equilibrium, $e_t = E_t$.

However, as can be seen from equation (8) and unlike Agénor and Neanidis (2015), in this paper we account for the spillover effect of the existing stock of ideas, M_t on learning. This creates a positive externality for future R&D activities although it is subject to diminishing returns. Hence, as shown later, the production of new designs is positively correlated with average human capital of individuals in the economy. Thus, there is a two-way interaction between human capital and innovation or the so-called '*implementation innovation*', as noted earlier.

In our empirical section (Section 5), we test the above theoretical proposition using mainly a reduced form model which links the accumulation of human capital to the stock of (technical) knowledge in the long run. However, we also examine how the stock of knowledge affects human capital, controlling for per capita education expenditure, public infrastructure and the average human capital of the previous generation, as postulated by equation (8).

Research and Development Sector:

The production of new designs that firms generate for new intermediate inputs is given by:

$$M_{t+1} - M_t = (\frac{G_t^R}{E_t})^{\phi_1}(\frac{M_t}{E_t})^{\phi_2}(k_t^I)^{\phi_3}\frac{E_t N_t^R}{\bar{N}}, \tag{9}$$

where G_t^R government spending on R&D, $E_t N_t^R$ effective labour which is scaled by total population $\bar{N}$ to capture a dilution effect as in Dinopoulos and Thompson (2000), k_t^I public-private capital ratio which is subject to congestion, as noted earlier, $\phi_1, \phi_2 \in (0,1)$, $\phi_3 > 0$; the elasticities with respect to government spending on R&D, existing stock of ideas and public-private capital ratio respectively. Both government spending and the existing stock of ideas are scaled by the average human capital. This is because, as general knowledge increases, the marginal benefit of an increase in government spending or existing stock of ideas becomes less relevant for innovation activities, as discussed in Agénor and Neanidis (2015, p.256). Hence, human capital is critically important for the production and diffusion of new technologies. Using dynamic panel causality analysis, we later test this thesis empirically.

Government:

Government cannot borrow and finances its expenditure through taxes on wages, and its balanced budget:

$$G_t = \sum G_t^h = \tau e_t w_t \bar{N}, \quad h = E, I, R, U \tag{10}$$

where G_t^E spending on education, G_t^I on infrastructure investment, G_t^R on R&D activities and G_t^U on unproductive items, τ constant tax rate, w_t the economy-wide wage, e_t individual human capital, and $\bar{N}$ the number of adults, as noted earlier.

It is assumed that each share of public spending is set as a constant fraction of government revenues:

$$G_t^h = \upsilon_h \tau e_t w_t \bar{N}, \quad h = E, I, R, U \tag{11}$$

where $\upsilon_h \in (0, 1)$ for all j.

Equations (10) and (11) give

$$\sum_h \upsilon_h = 1. \tag{12}$$

Public capital in infrastructure:

$$K_{t+1}^I = G_t^I, \tag{13}$$

where for simplicity full depreciation is assumed.

Market-Clearing Conditions:

The asset market clearing condition is

$$K_{t+1}^P = \bar{N} s_t, \tag{14}$$

where s_t is savings per household, $\bar{N}$ is the number of adults, and for simplicity full depreciation is assumed.

Labour market equilibrium condition is

$$N_t^R + N_t^Y = \bar{N}, \tag{15}$$

where perfect labour market mobility, $w_t^Y = w_t^R$, and full employment are assumed.

Dynamic System:

Appendix A shows that the public-private capital ratio, k_t^I, is constant over time and the dynamic system is comprised of two first-order difference equations in $m_t = M_t/K_t^P$, the knowledge-capital ratio and $z_t = E_t/K_t^P$, the human capital-private capital ratio, as in Agénor and Neanidis (2015). The dynamic system behaves in a complex nonlinear fashion, therefore its stability cannot be studied analytically; however, the stability can be verified numerically once the model is calibrated.

4 Calibration and Policy Experiments

To study the transitional dynamics of the model and the steady-state effects of public policies, the model is calibrated. For households, the annual discount rate, ρ is set at 0.04, which is standard in the literature. Interpreting a period as 25 years in this OLG framework yields the intergenerational discount factor $[1/(1+0.04)]^{25} = 0.375$. The family's propensity to save, $\sigma = 1/[1+\eta_C(1+\rho)]$ is set at 0.12, as in Agénor and Dinh (2015). Using this definition, $\eta_C = (\sigma^{-1}-1)/(1+\rho)$ can be calibrated at 2.75. The elasticity of production of final goods with respect to public-private capital ratio, ε is set equal to 0.17 which is consistent with the value reported by Bom and Ligthart (2014, Table 4), whereas the elasticity with respect to effective labour, β is assumed to be 0.65, as in Agénor and Dinh (2015). However, the elasticity with respect to private capital, α is set equal to 0.2 and thus, the elasticity with respect to intermediate inputs, $\gamma = 1-\alpha-\beta$ is equal to 0.15.

Unlike Agénor and Neanidis (2015), in this paper the parameter $\eta = 0.61$ which determines the elasticity of substitution between intermediate goods is similar to the value reported by Iacopetta (2011) and Chen and Funke (2013, Table 1). In the R&D sector, the elasticity with respect to existing stock of ideas, ϕ_2 is slightly lower than their value; it is set equal to 0.6 to begin with, whereas in the human capital sector, the elasticity with respect to public-private capital ratio, ν_3 is set equal to 0.0 in the benchmark case; a sensitivity analysis with respect to both parameters is reported later on.

The tax rate on final output is equal to 0.151, which corresponds to the average ratio of tax revenues to GDP for low-income countries (see Baldacci et al. (2004, Table 1)). To match the model's definition, this value is divided by the average share of labour income in final output, $\beta = 0.65$ so the effective tax rate on wages is $\tau = 23.2$ percent. The initial share of government spending on education, υ_E is set at 17.1 percent which is consistent with the value used by Agénor and Alpaslan (2013).

The values of the remaining parameters used in this paper are consistent with the values reported by Agénor and Neanidis (2015). The benchmark values for the parameters are summarised in Table 1. Using these values and starting values for the dynamic variables; the technical knowledge-private capital ratio, $m_t = M_t/K_t^P$ and human capital-private capital ratio, $z_t = E_t/K_t^P$, the dynamic system is solved numerically and the model proved to be stable. A multiplicative constant is introduced in the growth equation and the steady-state growth rate of final output is calibrated at 3.3 percent per annum, the average growth rate of low-income countries over the period 1975-2000 (see Baldacci et al. (2004)). Figure 1a;b shows that the technical knowledge-human capital ratio and growth rate of final output, both of which have a monotonic pattern, converge to a steady-state value in the benchmark case, and therefore all experiments are conducted from the period where the economy is initially in a steady-state equilibrium.

Table 1: Calibrated Parameter Values: Benchmark Case

	Parameters
Individuals	$\rho = 0.04, \sigma = 0.12, \eta_C = 2.75$
Final good	$\varepsilon = 0.17, \alpha = 0.2, \beta = 0.65, \gamma = 0.15$
Intermediate goods	$\theta = 1.0, \eta = 0.61$
Human capital	$\nu_1 = 0.3, \nu_2 = 0.3, \nu_3 = 0.0$
R&D sector	$\phi_1 = 0.2, \phi_2 = 0.6, \phi_3 = 0.0$
Government	$\tau = 0.232, \upsilon_I = 0.061, \upsilon_E = 0.171, \upsilon_R = 0.05$
Transportation costs	$\varphi_0 = 0.2, \varphi_1 = 0.0$

[**Figure 1(a,b) about here**]

To characterise the results of the policy experiments, we focus on the following variables: public-private capital ratio, technical knowledge-human capital ratio, and growth rate of final output. Consider first the public policy aimed at promoting access to infrastructure, by investing in rural roads, power grids, etc. This is captured by considering a budget-neutral increase in the share of public expenditure on infrastructure investment, υ_I, from an initial value of 0.061 to 0.081, under alternative assumptions: first, financed by a cut in unproductive spending in which case there are no trade-offs ($d\upsilon_I + d\upsilon_U = 0$); second, financed by a cut in other productive components of public spending, namely, either education ($d\upsilon_I + d\upsilon_E = 0$) or R&D activities ($d\upsilon_I + d\upsilon_R = 0$), the case where we consider trade-offs that policymakers face. We first critically discuss the long-run effects then go on to the transitional dynamics.

4.1 The Long-run Effects of Public Policy

Table 2 shows the findings of these experiments for the benchmark case, as shown in red bold in the table, as well as alternative values of some key parameters. Consider first the benchmark results in the case where an increase in υ_I is financed by a cut in unproductive spending, υ_U. With the initial values of $\nu_3 = 0.0$ and $\phi_3 = 0.0$, in the long run, the results indicate that the direct effect of an increase in infrastructure investment is of course an increase in the public-private capital ratio J (which is constant over time and rises overall from an initial value of 0.1538 to 0.2042), thereby promoting growth through its effect on the productivity of private inputs in the final good sector; the solution of the model gives a steady-state (long-run) growth rate of 4.2 percent, that is, an increase of 0.98 percentage points in comparison with the baseline value. Table 2 also shows higher values of $\nu_3 = 0.1$ and $\phi_3 = 0.1$, both of which generate a positive growth rate of final output; in the case where $\nu_3 = 0.1$, the net impact on growth is equal to about 1.9 percentage points, whereas it is in the order of 1.6 percentage points when $\phi_3 = 0.1$.

[Table 2 about here]

In the second scenario, as shown in Table 2, an increase in the share of spending on infrastructure investment, υ_I, financed by a cut in spending on education, υ_E, has a net, negative effect on steady-state growth; growth falls by 0.19 percentage points. Although an increase in the share of spending on public infrastructure has a direct, positive effect on human capital accumulation, financing higher spending on infrastructure investment through a cut in the share of spending on education hampers growth because the fall in the level of human capital lowers the private capital stock.

In order to illustrate the potential trade-offs that may arise in the reallocation of spending across productive outlays, two key parameters are focused on: the elasticity of human capital with respect to public-private capital ratio, ν_3 and the elasticity of the flow of new ideas with respect to public-private capital ratio, ϕ_3. When the elasticity of human capital with respect to public-private capital ratio, ν_3 is set equal to a relatively higher value, 0.1, an increase in the share of public spending on infrastructure investment, υ_I financed by a cut in υ_E helps to mitigate the trade-off; in fact, the growth rate of final output turns positive because infrastructure is more productive than spending on education; growth increases by 0.70 percentage points. The positive effect on steady-state growth (higher spending on infrastructure generates) dominates the reduction in human capital accumulation because spending more on infrastructure leads to the production of productive inputs and therefore the offsetting cut in the share of spending on education is beneficial in terms of growth. Regarding the elasticity of the flow of new ideas with respect to public-private capital ratio, ϕ_3, a higher value, 0.1 is also displayed in Table 2; the growth rate of final output is also positive and equal to 0.53 percentage points yet less than in the case where υ_I is financed by a cut in υ_E.

Besides, the table shows two alternative values of ν_2 (0.4 and 0.6), which measures the response of human capital with respect to technical knowledge. Depending on the relative strength of the parameter ν_2, financing higher share of spending on infrastructure through a cut in education leads to a fall in the rate of human capital accumulation, therefore mitigating the benefit associated with the externality of technical knowledge. However, a higher value of $\nu_2 = 0.6$ may generate a positive growth rate even if an increase in spending on infrastructure is offset by a reduction in education; growth increases by 0.05 percentage points, whereas when ν_2 is set equal to a relatively lower value, 0.4, the trade-off still persists and it cannot generate a positive growth rate.

Figure 2 shows the impact of changes in the elasticity of human capital with respect to the externality of technical knowledge, ν_2 and the elasticity of R&D activities with respect to the existing stock of ideas, ϕ_2, either individually or in combination, on the steady-state growth rate of final output. In other words, in response to a permanent increase in infrastructure investment financed by a cut in education, the figure shows absolute deviations of the steady-state growth rate of final output from baseline for alternative values of ν_2 and ϕ_2, which range from 0.1 to 0.65.

[Figure 2 about here]

Table 2 also shows that for a combination of higher values of $\nu_2 = 0.6$ and $\phi_2 = 0.7$, despite the offsetting cut in education, as a result of complementarity effect, the growth rate of final output in the long run may actually turn positive and is equal to 0.11 percentage points. Or alternatively, a higher value of $\nu_2 = 0.65$, together with a reasonably lower value of $\phi_2 = 0.65$, may also achieve the same result. In fact, the externality of technical knowledge associated with human capital accumulation and its spillover effects on R&D sector may mitigate or even eliminate the initial adverse effects on the growth rate of final output in the long run despite an offsetting cut in education.

In the last case scenario where a budget-neutral increase in the share of public expenditure on infrastructure investment, υ_I, is financed by a cut in another productive share of public spending, υ_R, the growth rate of final output falls by 0.26 percentage points when compared to the baseline value. Despite the fact that better access to infrastructure has a direct, positive effect on the ability to innovate, higher share of spending on infrastructure at the expense of R&D discourages growth not only directly through its effect on R&D activities but also indirectly through lower government revenues which may also dampen human capital accumulation. In turn, the lower level of human capital further discourages R&D activities through the externality of technical knowledge, thereby impeding growth because spending less on R&D hampers the production of new designs. An increase either in ν_3 or in ϕ_3 has a positive impact on growth; growth increases by 0.61 percentage points per annum in the case where $\nu_3 = 0.1$, whereas it increases by 0.52 percentage points when $\phi_3 = 0.1$. Despite an offsetting cut in R&D activities, spending more on infrastructure leads to the production of productive inputs and dominates the reduction in the production of new designs, therefore the net impact on the growth rate of final output turns out to be a positive value.

4.2 Transitional Dynamics and Public Policy

Turning now to the experimental evidence on the transitional dynamics of the model, given that public-private capital ratio is constant over time, Figures 3,4,5 (a,b) show the time path of technical knowledge-human capital ratio and growth rate of final output in the benchmark case where an increase in the share of spending on investment infrastructure is offset by a cut unproductive spending, education, and R&D activities respectively. For instance, Figure 4 (a,b) shows that in the case where υ_I is financed by a cut in υ_E, on impact, a cut in spending on education leads to the lower level of human capital which hampers R&D activities through the externality of technical knowledge. However, at the same time, higher government spending on public infrastructure has a direct, positive impact on human capital accumulation, thereby promoting R&D activities. As a result, the ratio of technical knowledge to human capital increases. Nevertheless, the trade-off persists and the net impact on the growth rate of final output is negative. Over time, a positive externality associated with human capital accumulation promotes R&D activities more. Consequently, the ratio of technical knowledge to human capital increases by more. However, due to an offsetting cut in education, the trade-off still persists and therefore the net impact on growth remains negative yet the initial adverse effect is considerably mitigated.

[Figures 3,4,5 (a,b) about here]

According to Figure 5 (a,b), on impact, an offsetting cut in another productive component of public spending, υ_R, discourages R&D activities, therefore the stock of technical knowledge falls. At the same time, the lower level of production of new designs results in lower government revenues, which also leads human capital ratio to fall. As a result, the ratio of technical knowledge to human capital falls. However, despite the adverse effect of government spending on education, higher share of spending on infrastructure investment through its effects on the productivity of private inputs in the final good sector promotes growth. Over time, the technical knowledge-human capital ratio falls by more and the initial increase in growth is reversed. Despite higher spending on infrastructure, this offsetting cut in R&D activities dampens growth not only through its effects on R&D activities but also through lower government revenues, which adversely affects human capital accumulation. In turn, the lower level of human capital further discourages R&D activities through the externality of technical knowledge, thereby impeding growth.

4.3 Summary

To sum up, the model demonstrates the role public infrastructure, human capital and innovation play in encouraging economic growth. Moreover, it tries to show the beneficial effects public investments can have in augmenting the above determinants of growth. For instance, the solution of the model clearly indicates that public infrastructure investments can promote economic growth in the long run via increases in productivity. However, because most governments, especially those in low-income countries, face budget constraints that may be binding, potential trade-offs arise in the allocation of public expenditure. In particular, increases in public capital financed by a reduction in education spending or R&D spending hampers economic growth; however, higher share of spending on public infrastructure at the expense of spending on R&D is less likely to succeed in promoting growth in the long run.

Having established the beneficial effects of, among others, innovation and human capital on growth, in what follows, we empirically examine the relationship between these important variables.

5 Stock of Knowledge and Human Capital: Empirical Evidence

Our interest centres primarily on the empirical estimation of equation (8). To this end, we use a balanced panel of 35 high income economies over the period 1980 – 2014. The sample selection is based on the availability of consistent data. As we are interested in the (long-run) relationship between the stock of knowledge and human capital, we estimate the following parsimonious specification:

$$HC_{it} = \alpha_i + \beta SK_{it} + \varepsilon_{it} \tag{16}$$

where HC_{it} is human capital for countries $i = 1, ...N$ and time periods $t = 1, ...T$, α_i is a country specific fixed effect and ε_{it} is the error term. Our dependent variable is a relatively new measure of human capital based on the average years of schooling as well as an assumed Mincerian rate of return to education sourced from version 8.1 of the Penn World Tables. SK_{it} is a measure of the production of innovative ideas. We follow the existing literature and use patent count as a proxy for the stock of knowledge (see for example, Bottazzi and Peri, 2007; Madsen, 2008; Chellaraj et al., 2008; Ang, 2011). We apply perpetual inventory method with a depreciation rate of 10% as in Ang (2011). The initial level of patent stocks are estimated as $SK_0/(g+\delta)$, where SK_0 denotes the knowledge stock in the first available year, g is the average annual geometric growth rate over the sample period, and δ is the depreciation rate. The patent data comes from the World Intellectual Property Organisation, World Development Indicators and the OECD. Summary statistics as well as the list of countries in the sample can be found in Appendix B.

To estimate (16), we rely on recently developed panel cointegration methods that are robust to endogeneity issues, omitted variable bias, and measurement issues (Baltagi and Kao, 2000; Phillips and Moon, 2000). However, for specification (16) to be valid, we need to establish that both variables are nonstationary or, more precisely, integrated of the same order. In that case, they would constitute a cointegrating vector as they would have a stationary error term; any relevant omitted variable would be captured by the errror term, leading to a failure to reject the null hypothesis of no cointegration (Asteriou and Hall, 2007). Provided there is a cointegration between the stock of knowledge and human capital, therefore, such (long-run) relationship should remain even if equation (16) is augmented with additional variables (for a discussion on this, see for example, Herzer, 2012).

5.1 Integration and Cointegration Analyses

The integration analysis begins with an investigation of the properties of the variables. For this purpose, we employ three different types of panel unit root tests, namely, the Fisher-type ADF test developed by Maddala and Wu (1999) (MW), the Im, Pesaran and Shin (2003) (IPS) test, and the cross-sectionally augmented ADF test statistic developed by Pesaran (2007) (CIPS). While all three tests assume individual unit root processes, the IPS test allows for serial correlation in the error term while the CIPS allows for cross-sectional dependence as well. All the tests assume the non-stationarity of the series under the null hypothesis. The results, which are shown in panel A of Table 3, suggest that we cannot reject the null hypothesis of a unit root in levels, implying that the series are non-stationary. However, the series attain stationarity in first-differences, indicating that they are integrated of order one, $I(1)$. It should be noted that the human capital variable does not achieve stationarity once we control for cross-sectional dependence (CIPS test) among the countries stemming from, for example, common shocks. With this in mind, we go ahead with our panel cointegration analyses.

[**Table 3 about here**]

To confirm whether the long-run relationship captured in equation (16) exists, we apply two panel cointegration tests. The first is the Pedroni (2004) test which allows for heterogeneity in the long-run cointegrating vectors while capturing both the within- and between-dimensions of the panel via seven different test statistics. The second is the test proposed by Westerlund (2007) which can account for any potential cross-sectional dependence. The results which are summarised in panel B of Table 3 show that the null hypothesis of no cointegration is strongly rejected. Thus, the evidence points to a long-run relationship between the stock of knowledge and human capital.

5.2 Long-run Estimates

Given that we found a cointegration between the stock of knowledge and human capital, we now attempt to shed light on the nature of the relationship captured in equation (16). For this purpose, we employ the within-dimension dynamic OLS (WD-DOLS) estimator proposed by Kao and Chiang (2000). Even though this estimator overcomes issues such as serial correlation and endogeneity concerns, it pools the slope coefficients across countries. This homogeneity assumption, if not justified, can lead to a serious bias (Asteriou and Hall, 2007). Hence, we also apply the mean-group DOLS (MG-DOLS) estimator developed by Pedroni (2001) which allows for heterogeneous slopes whilst having better small sample properties. Finally, we use the two-step estimator of Breitung (2005) which is based on a VAR set-up and thus allows for dynamic effects.

[**Table 4 about here**]

The results on the long-run effects of the stock of knowledge on human capital are reported in Table 4. Across all the estimators, we consistently find that the stock of knowledge has a positive impact on the accumulation of human capital. This effect is statistically significant at the 5% level and the long-run elasticities range between 0.020 and 0.045. Hence, these results are consistent with the predictions of our theoretical proposition that the spillover effects of the stock of ideas can have beneficial influences on human capital accumulation. As we argued previously, this could suggest that new technological inventions create new incentive structures, enticing economic agents to improve their skills and expertise. Alternatively, the creation and diffusion of new ideas can promote learning through knowledge spillovers and dynamic information externalities.

5.3 Dynamic Panel Causality

Having established that the stock of knowledge has a positive and significant long-run effect on human capital, our interest lies in examining whether there is indeed a two-way interaction between innovation and human capital – the so-called '*implementation innovation*'. Some of the literature reviewed in Section 2 as well as our theoretical model (see equations [8] and [9]) postulate the existence of such a two-way relationship.

To examine this, we set up a dynamic panel error correction model (Engle and Granger, 1987; Pesaran et al. 1999; Ali and Alpaslan, 2013) of the type:

$$\Delta HC_{it}= \alpha_{1j}+\sum\nolimits_{k=1}^{p}\gamma_{11ik}\Delta HC_{it-k}+\sum\nolimits_{k=1}^{p}\gamma_{12ik}\Delta SK_{it-k}+\lambda_{1i}\varepsilon_{it-1}+u_{1it}, \quad (17)$$
$$\Delta SK_{it}= \alpha_{2j}+\sum\nolimits_{k=1}^{p}\gamma_{21ik}\Delta SK_{it-k}+\sum\nolimits_{k=1}^{p}\gamma_{22ik}\Delta HC_{it-k}+\lambda_{2i}\varepsilon_{it-1}+u_{2it}, \quad (18)$$

where Δ is the first-difference operator; p is the optimal lag length determined by Schwarz information criterion. The null hypothesis of no short-run causality can be examined, respectively, based on $\mathrm{H}_0{:}\gamma_{12ik} = 0$ and $\mathrm{H}_0{:}\gamma_{22ik} = 0$ for all ik. However, long-run causality can be tested by the statistical significance of, respectively, λ_{1i} and λ_{2i} (the error correction terms) using standard t-statistics.

[Table 5 about here]

The results are reported in Table 5. As can be seen, we fail to find any statistically significant relationship between human capital and the stock of knowledge in the short run. However, there is a significant two-way causal link between the two in the long run. This is consistent with the so-called '*implementation innovation*' and the predictions of the human capital and R&D sector equations of the theoretical model.

5.4 Robustness

The parsimonious specification we adopted in our empirical estimations so far is wholly informed by the super consistent properties of the panel cointegration methods we employ. Given that these are, under cointegration, robust to omitted variable bias, reduced-form models such as equation (16) are valid. In addition, since the theoretical OLG model we use has a long-term time horizon, the empirical methods we have employed so far are appropriate.

In this section, however, we attempt to fully estimate our human capital sector equation (Eq. 8). In particular, we re-examine how the stock of knowledge influences human capital – controlling for per capita education expenditure, public infrastructure (proxied by per capita transport and communication expenditure), and the average human capital of the previous generation (proxied by the average human capital values of the first 5 years of the sample period). Our dataset is slightly reduced as the public spending data is only available until 2012. The source of this data is the Statistics of Public Expenditure for Economic Development (SPEED) which has been compiled by IFPRI (2015). All the explanatory variables are expressed in natural logarithm.

[Table 6 about here]

We first estimate the empirical counterpart of equation (8) using the pooled ordinary least squares (POLS) estimator. As shown in column [1] of Table 6, all the variables carry the expected positive sign and are all significant at conventional levels (5%). However, since the POLS estimator is biased in the presence of unobserved country-specific effects, we report in column [2] estimates based on the random effects estimator. On the whole, the results remain largely similar.

Given that macroeconomic data series tend to be plagued by panel heteroscedasticity and serial correlation, we test for group wise heteroscedasticity and serial correlation using the modified Wald test (Greene, 2000) and the Wooldridge (2002) test, respectively. While the RE estimator can handle the first, neither it nor the POLS can handle serial correlation. This can lead to consistent but inefficient estimates (Baltagi, 2006). The Wooldridge test suggests that the within country residuals are serially correlated while the Wald test confirms heteroscedasticity. Hence, to overcome these potential biases, we use Feasible GLS (FGLS) where we allow for the presence of autocorrelation within panels and heteroscedasticity and cross-sectional correlation across panels. As can be seen in column [3], the results remain consistent with the predictions of the theoretical model.

Finally, none of these estimators can handle endogeneity which may arise from omitted variables, simultaneity or reverse causality. Hence, the results on the final column are based on the two-step system GMM estimator developed by Arellano and Bover (1995) and Blundell and Bond (1998). This estimator applies a system of equations, one in levels and one in differences, and uses lagged first differences of the regressors as instruments in the first case and lagged levels of the dependent and explanatory variables as instruments in the latter case. We test the validity of the instruments using the Hansen J test. Following Roodman (2009), we collapse the instrument count in order not to overfit the endogenous variables. Needless to say, our results remain unchanged.

6 Concluding Remarks

This paper has attempted to account for the spillover effect of the existing stock of ideas on learning by extending the model developed by Agénor and Neanidis (2015). The spillover effect promotes the innovation capacity of countries in adopting imported technologies and developing new technologies. At the same time, the production of new designs depends positively on the average human capital of individuals. Thus, there is a two-way interaction between human capital and innovation or the so-called *'implementation innovation'*.

Using various empirical methods, we confirm the above theoretical ideas. In particular, we show that the stock of technical knowledge has a significant long-run effect on the accumulation of human capital and that there is a two-way causal feedback between the two in the long run.

In order to study the transitional dynamics of the model and to illustrate the impact of public policy, the model was calibrated using average data for low-income countries and sensitivity analysis was reported under different parameter configurations. Based on the numerical analysis, we illustrate potential trade-offs associated with the provision of infrastructure and other productive components, namely, the allocation of public spending to R&D and education. The findings of the numerical analysis indicate that, due to the limited amount of resources governments have, trade-offs in the allocation of public spending may inevitably emerge. More specifically, government interventions may indirectly affect the capacity of sectors to innovate through spillover effects. However, investment in infrastructure at the expense of spending on R&D is less likely to succeed in promoting growth, whereas it may be more effective to foster economic growth through an offsetting cut in another productive component of public spending, education.

The findings of the paper highlight a number of important issues. First, the development of innovative technological sectors can indirectly improve growth via its positive influence on human capital accumulation as much as human capital can as an important input into the generation and diffusion of innovative ideas. Second, infrastructure investments remain an important channel through which developing countries can galvanise their economies. Finally, given that potential trade-offs may arise in the allocation of public spending, governments in low-income countries need to use their limited budgets as part of holistic measures in order to achieve efficient outcomes.

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Appendix A
Dynamic System and Steady-State Growth

Substituting for s_t from (3) in (2) yields the lifetime budget constraint,

$$c_t^t + \frac{c_{t+1}^t}{1 + r_{t+1}} = (1 - \tau)e_t w_t. \tag{A1}$$

Each individual maximises (1) with respect to c_t^t and c_{t+1}^t, subject to the intertemporal budget constraint (A1) and $c_t^t, c_{t+1}^t > 0$. The first-order conditions give the standard Euler equation

$$\frac{c_{t+1}^t}{c_t^t} = \frac{1 + r_{t+1}}{\eta_C(1 + \rho)}. \tag{A2}$$

Substituting this result in (A1) yields

$$c_t^t = [\frac{\eta_C(1 + \rho)}{1 + \eta_C(1 + \rho)}](1 - \tau)e_t w_t, \tag{A3}$$

so that

$$s_t = \sigma(1 - \tau)e_t w_t, \tag{A4}$$

where $\sigma = 1/\left[1 + \eta_C(1 + \rho)\right] < 1$ is the marginal propensity to save.

Substituting this result in (14) yields

$$K_{t+1}^P = \sigma(1 - \tau)e_t w_t \bar{N}. \tag{A5}$$

From (11) and (13),

$$K_{t+1}^I = \upsilon_I \tau e_t w_t \bar{N}. \tag{A6}$$

Combining (A5) and (A6), this expression yields

$$k_{t+1}^I = \frac{K_{t+1}^I}{K_{t+1}^P} = \frac{\upsilon_I \tau}{\sigma(1 - \tau)} = J, \tag{A7}$$

which is constant over time.

To study the dynamics, note first that (6), together with (A7), yields

$$Y_t = J^{\varepsilon} m_t^{\gamma/\eta} z_t^{\beta} x_t^{\gamma} K_t^P, \tag{A8}$$

where, as defined in the text, $m_t = M_t/K_t^P$ and $z_t = E_t/K_t^P$.

Profit of firm i in the final sector, $\Pi_{i,t}^Y$, is given by

$$\Pi_{i,t}^Y = Y_t^i - (1 + \varphi_t)\sum_1^{M_t} p_t^s x_{s,t}^i - w_t^Y E_t N_{i,t}^Y - r_t K_t^{P,i}, \tag{A9}$$

where the price of the final good normalised to unity, p_t^s is the price of intermediate good s, w_t^Y the wage rate in the final good production sector, r_t the rental rate of private capital, and transportation costs, φ_t, distort the distribution of intermediate goods to producers of the final good and assumed to be a decreasing function of the public-private capital ratio; $\varphi_t = \varphi(k_t^I)$, where $\varphi(0) > 0$, $\varphi' < 0$, and $\lim_{k_t^I \to \infty} \varphi_t = 0$.

Each producer maximises profits subject to (4) with respect to private inputs, labour and capital, and demand for all intermediate goods $x_{s,t}^i$, $\forall s$, taking factor prices, M_t, and φ_t as given:

$$r_t = \alpha \frac{Y_t^i}{K_t^{P,i}}, \quad w_t^Y = \beta \frac{Y_t^i}{E_t N_{i,t}^Y}, \tag{A10}$$

$$x_{s,t}^i = [\frac{\gamma Z_t^i}{(1+\varphi_t)p_t^s}]^{1/(1-\eta)}, \quad s = 1, ...M_t,$$

or given that each firm demands the same amount of each intermediate good, the aggregate demand for intermediate good s is

$$x_{s,t} = \int_0^1 x_{s,t}^i di = \int_0^1 [\frac{\gamma Z_t^i}{(1+\varphi_t)p_t^s}]^{1/(1-\eta)} di, \tag{A11}$$

where

$$Z_t^i = Y_t^i / \sum_1^{M_t} (x_{s,t}^i)^\eta, \tag{A12}$$

Note that all firms are idential and their number is normalised to unity, $Z_t = Z_t^i$, $\forall i$, and the total demand for intermediate goods is the same across firms, $x_t^i = x_t$, $\forall i$. Moreover, in a symmetric equilibrium, $x_{s,t}^i = x_t^i$, $\forall s$. Thus

$$\int_0^1 [\sum_1^{M_t} (x_{s,t}^i)^\eta]^{1/\eta} di = M_t^{1/\eta} x_t. \tag{A13}$$

Or equivalently, substituting (A11) into (7), together with $Z_t^i = Z_t$, $\forall i$, and then maximising with respect to p_t^s, taking Z_t and φ_t as given, yields the optimal price

$$\Pi_{s,t}^I = (p_t^s - \theta)[\frac{\gamma Z_t}{(1+\varphi_t)p_t^s}]^{1/(1-\eta)}, \tag{A14}$$

$$p_t^s = p_t = \frac{\theta}{\eta}. \ \ \forall s \tag{A15}$$

From the definition of Z_t^i in (A12), and using (A15), in equilibrium $Z_t = Y_t / M_t x_t^\eta$, equation (A10) takes the form

$$x_t = \frac{\gamma\eta}{(1+\varphi_t)\theta}(\frac{Y_t}{M_t}), \tag{A16}$$

or equivalently, equation (A16) can be rewritten, together with (A7),

$$x_t = \frac{\gamma\eta}{[1+\varphi(J)]\theta}(\frac{Y_t}{K_t^P}\frac{K_t^P}{M_t}) = \frac{\gamma\eta}{[1+\varphi(J)]\theta}(\frac{Y_t}{K_t^P})m_t^{-1}. \tag{A17}$$

Substituting this result in (A8) and rearranging yields

$$(\frac{Y_t}{K_t^P})^{1-\gamma} = [\frac{J^\varepsilon(\gamma\eta)^\gamma}{[1+\varphi(J)]^\gamma\theta^\gamma}] z_t^\beta m_t^{(\gamma/\eta-\gamma)}, \tag{A18}$$

that is,

$$\frac{Y_t}{K_t^P} = \Lambda_1 m_t^{\Psi_1} z_t^{\Omega_1}, \tag{A19}$$

where

$$\Lambda_1 = [\frac{J^\varepsilon(\gamma\eta)^\gamma}{[1+\varphi(J)]^\gamma\theta^\gamma}]^{1/(1-\gamma)},$$

$$\Psi_1 = \frac{\gamma(\eta^{-1}-1)}{1-\gamma},$$

$$\Omega_1 = \frac{\beta}{1-\gamma}.$$

Equations (A15) and (A16) can be substituted into (7):

$$\Pi_t^I = \frac{(1-\eta)\gamma}{1+\varphi_t}(\frac{Y_t}{M_t}). \tag{A20}$$

The arbitrage condition is

$$p_t^M = \Pi_t^I. \tag{A21}$$

From (A7), (A20), and (A21),

$$p_t^M = \frac{(1-\eta)\gamma}{1+\varphi(J)}(\frac{Y_t}{M_t}),$$

which can be rearranged to give

$$p_t^M = \frac{(1-\eta)\gamma}{1+\varphi(J)}(\frac{Y_t}{K_t^P})m_t^{-1}. \tag{A22}$$

From (11),

$$G_t^h = \upsilon_h \tau e_t w_t \bar{N}. \quad h = E, R \tag{A23}$$

Profit of R&D firms, Π_t^R, is given by

$$\max_{N_t^R} \Pi_t^R = p_t^M(M_{t+1} - M_t) - w_t^R E_t N_t^R, \tag{A24}$$

where $N_t^R \geq 0$, and taking wages, w_t^R, the patent price, p_t^M, and the public-private capital ratio, the initial stock of designs, as well as government spending on R&D, as given.

Equation (A24) can be solved for

$$w_t^R \geq \left\{(\frac{G_t^R}{E_t})^{\phi_1}(\frac{M_t}{E_t})^{\phi_2}(k_t^I)^{\phi_3}\right\} p_t^M. \tag{A25}$$

Substituting (A22) and (A23) for $h = R$ in (A25), holding with equality, and using (A7), yields, with $w_t^R = w_t$,

$$w_t = (\upsilon_R \tau w_t \bar{N})^{\phi_1} (m_t z_t^{-1})^{\phi_2} J^{\phi_3} \frac{(1-\eta)\gamma}{1+\varphi(J)} (\frac{Y_t}{K_t^P}) m_t^{-1}. \tag{A26}$$

Substituting (A19) in (A26) yields the equilibrium wage as a function of m_t and z_t.

$$w_t = \Lambda_2 m_t^{\Psi_2} z_t^{\Omega_2}, \tag{A27}$$

with

$$\Lambda_2 = \left\{ (\upsilon_R \tau)^{\phi_1} \bar{N}^{\phi_1} J^{\phi_3} \frac{(1-\eta)\gamma}{1+\varphi(J)} \Lambda_1 \right\}^{1/(1-\phi_1)},$$

$$\Psi_2 = \frac{\Psi_1 + \phi_2 - 1}{1 - \phi_1},$$

$$\Omega_2 = \frac{\Omega_1 - \phi_2}{1 - \phi_1}.$$

Now, from (10), (A7), and (A23) for $h = E$, noting that $M_t/E_t = m_t z_t^{-1}$,

$$\frac{E_{t+1}}{E_t} = (\frac{G_t^E}{\bar{N} E_t})^{\nu_1} (\frac{M_t}{E_t})^{\nu_2} (\frac{K_t^I}{K_t^P})^{\nu_3} = (\upsilon_E \tau w_t)^{\nu_1} (m_t z_t^{-1})^{\nu_2} J^{\nu_3},$$

or equivalently, using (A27) to eliminate w_t,

$$\frac{E_{t+1}}{E_t} = \Lambda_3 m_t^{\Psi_3} z_t^{\Omega_3}, \tag{A28}$$

where

$$\Lambda_3 = (\upsilon_E \tau \Lambda_2)^{\nu_1} J^{\nu_3},$$

$$\Psi_3 = \Psi_2 \nu_1 + \nu_2,$$

$$\Omega_3 = \Omega_2 \nu_1 - \nu_2.$$

Using (A5), (A27), and (A28), the dynamics of z_t are determined by

$$z_{t+1} = \Lambda_4 m_t^{\Psi_4} z_t^{\Omega_4}, \tag{A29}$$

where

$$\Lambda_4 = \frac{\Lambda_3}{\Lambda_2 \sigma (1-\tau) \bar{N}},$$

$$\Psi_4 = \Psi_3 - \Psi_2,$$

$$\Omega_4 = \Omega_3 - \Omega_2.$$

Next, we need to determine the dynamics of m_t. Dividing (9) by M_t yields

$$\frac{M_{t+1}}{M_t} = 1 + (\frac{G_t^R}{E_t})^{\phi_1} (z_t m_t^{-1})^{1-\phi_2} (k_t^I)^{\phi_3} (\frac{N_t^R}{\bar{N}}),$$

or equivalently, using (A7) and (A23) for $h = R$,

$$\frac{M_{t+1}}{M_t} = 1 + [\frac{(\upsilon_R \tau \bar{N})^{\phi_1} J^{\phi_3}}{\bar{N}}](\frac{z_t}{m_t})^{1-\phi_2} w_t^{\phi_1} N_t^R. \tag{A30}$$

To eliminate N_t^R from this expression, equation (15), together with equation (A10), yields equilibrium employment in the R&D sector:

$$N_t^R = \bar{N} - \beta(\frac{Y_t}{E_t})w_t^{-1}. \tag{A31}$$

We can substitute (A27) for w_t in (A31) to give

$$N_t^R = \bar{N} - \beta(\frac{Y_t}{K_t^P})z_t^{-1}(\Lambda_2 m_t^{\Psi_2} z_t^{\Omega_2})^{-1}. \tag{A32}$$

Substituting (A19), (A27), and (A32) in (A30) yields

$$\frac{M_{t+1}}{M_t} = 1 + \Lambda_5 m_t^{\Psi_5} z_t^{\Omega_5} \left[\bar{N} - \Lambda_6 m_t^{\Psi_6} z_t^{\Omega_6}\right], \tag{A33}$$

where

$$\Lambda_5 = (\Lambda_2 \upsilon_R \tau)^{\phi_1} J^{\phi_3} \bar{N}^{\phi_1 - 1},$$
$$\Psi_5 = \phi_2 - 1 + \Psi_2 \phi_1,$$
$$\Omega_5 = 1 - \phi_2 + \Omega_2 \phi_1,$$
$$\Lambda_6 = \beta \frac{\Lambda_1}{\Lambda_2},$$
$$\Psi_6 = \Psi_1 - \Psi_2,$$
$$\Omega_6 = \Omega_1 - \Omega_2 - 1.$$

Combining (A5) and (A33) yields, noting that $M_t/E_t = m_t z_t^{-1}$,

$$m_{t+1} = \frac{1 + \Lambda_5 m_t^{\Psi_5} z_t^{\Omega_5} \left[\bar{N} - \Lambda_6 m_t^{\Psi_6} z_t^{\Omega_6}\right]}{\sigma(1-\tau) w_t \bar{N}} m_t z_t^{-1}.$$

Substituting (A27) in this expression and rearranging yields

$$m_{t+1} = \frac{1 + \Lambda_5 m_t^{\Psi_5} z_t^{\Omega_5} \left[\bar{N} - \Lambda_6 m_t^{\Psi_6} z_t^{\Omega_6}\right]}{\Lambda_7 m_t^{\Psi_7} z_t^{\Omega_7}}, \tag{A34}$$

where

$$\Lambda_7 = \Lambda_2 \sigma (1-\tau) \bar{N},$$
$$\Psi_7 = \Psi_2 - 1,$$
$$\Omega_7 = 1 + \Omega_2.$$

From (A29) and (A34), in the steady-state,

$$\tilde{z} = \left\{\Lambda_4 \tilde{m}^{\Psi_4}\right\}^{1/\Pi}, \tag{A35}$$

$$\tilde{m} = \left\{\frac{1 + \Lambda_5 \tilde{m}^{\Psi_5} \tilde{z}^{\Omega_5} \left[\bar{N} - \Lambda_6 \tilde{m}^{\Psi_6} \tilde{z}^{\Omega_6}\right]}{\Lambda_7 \tilde{z}^{\Omega_7}}\right\}^{1/\Phi}, \tag{A36}$$

where

$$\Pi = 1 - \Omega_4,$$

$$\Phi = 1 + \Psi_7.$$

From (A19), in the steady-state,

$$(\frac{\tilde{Y}}{K^P}) = \Lambda_1 \tilde{m}^{\Psi_1} \tilde{z}^{\Omega_1}, \tag{A37}$$

which implies that output grows also at the same rate as K_t^P and other aggregate variables.

From (A27), the steady-state wage rate is

$$\tilde{w} = \Lambda_2 \tilde{m}^{\Psi_2} \tilde{z}^{\Omega_2}. \tag{A38}$$

From (A28) and (A33), the steady-state growth rate of the economy can be written in two equivalent forms:

$$\boldsymbol{\gamma}_Y = \Lambda_3 m_t^{\Psi_3} z_t^{\Omega_3} - 1, \tag{A39}$$

$$\boldsymbol{\gamma}_Y = \Lambda_5 m_t^{\Psi_5} z_t^{\Omega_5} \left[\bar{N} - \Lambda_6 m_t^{\Psi_6} z_t^{\Omega_6}\right]. \tag{A40}$$

To determine the level of output and its growth rate during the transition, from (A19),

$$Y_t = \Lambda_1 m_t^{\Psi_1} z_t^{\Omega_1} K_t^P, \tag{A41}$$

which requires the path of K_t^P, and therefore equation (A5) can be divided by K_t^P:

$$\frac{K_{t+1}^P}{K_t^P} = \sigma(1-\tau) e_t w_t \bar{N},$$

which can be rewritten, together with (A27),

$$\frac{K_{t+1}^P}{K_t^P} = \Lambda_2 \sigma(1-\tau) m_t^{\Psi_2} z_t^{1+\Omega_2} \bar{N},$$

or equivalently,

$$\frac{K_t^P}{K_{t-1}^P} = \Lambda_2 \sigma(1-\tau) m_{t-1}^{\Psi_2} z_{t-1}^{1+\Omega_2} \bar{N}. \tag{A42}$$

Appendix B
Summary Statistics

Table B1: Summary Statistics – Main Results

	Obs.	Mean	Sd.	Min.	Max.
HC (ln)	1225	1.068	0.163	0.385	1.318
Stock of knowledge (ln)	1225	8.637	1.916	1.902	13.615

Table B2: Summary Statistics – Extension Results

	Obs.	Mean	Sd.	Min.	Max.
HC (ln)	1155	1.061	0.163	0.385	1.313
Stock of knowledge (ln)	1155	8.642	1.899	2.721	13.615
Initial HC (ln)	1155	0.952	0.175	0.498	1.208
Education exp. (ln)	1084	6.594	0.976	3.798	8.194
Infrastructure (ln)	1044	5.711	1.182	1.247	8.275

List of Countries: Australia; Austria; Belgium; Bulgaria; Canada; Chile; Cyprus; Denmark; Finland; France; Germany; Greece; Hungary; Iceland; Ireland; Israel; Italy; Japan; Korea; Luxembourg; Malta; Mexico; Netherlands; New Zealand; Norway; Poland; Portugal; Romania; Singapore; Spain; Sweden; Switzerland; Turkey; United Kingdom; United States.

Table 2

Increase in Share of Government Spending on Infrastructure Investment 1/

(Absolute deviations from baseline)

Financed by a Cut in	Unproductive Spending		Education		R&D Activities	
Benchmark Values	Impact	Long run	Impact	Long run	Impact	Long run
Public-private capital stock ratio	**0.0504**	**0.0504**	**0.0504**	**0.0504**	**0.0504**	**0.0504**
Technical knowledge-human capital ratio	**-0.0141**	**-0.0626**	**0.0138**	**0.0456**	**-0.0165**	**-0.0710**
Growth rate of final output	**0.0494**	**0.0098**	**-0.0273**	**-0.0019**	**0.0569**	**-0.0026**
Experiment: $\nu_3 = 0.1$ 2/	Impact	Long run	Impact	Long run	Impact	Long run
Public-private capital stock ratio	0.0504	0.0504	0.0504	0.0504	0.0504	0.0504
Technical knowledge-human capital ratio	-0.0346	-0.1338	-0.0075	-0.0382	-0.0369	-0.1432
Growth rate of final output	0.1116	0.0192	0.0305	0.0070	0.1196	0.0061
Experiment: $\phi_3 = 0.1$ 3/	Impact	Long run	Impact	Long run	Impact	Long run
Public-private capital stock ratio	0.0504	0.0504	0.0504	0.0504	0.0504	0.0504
Technical knowledge-human capital ratio	-0.0183	-0.0852	0.0088	0.0218	-0.0188	-0.0867
Growth rate of final output	0.0430	0.0160	-0.0330	0.0053	0.0498	0.0052
Experiment: $\nu_2 = 0.4$ 4/	Impact	Long run	Impact	Long run	Impact	Long run
Public-private capital stock ratio	0.0504	0.0504	0.0504	0.0504	0.0504	0.0504
Technical knowledge-human capital ratio	-0.0157	-0.0512	0.0152	0.0360	-0.0177	-0.0560
Growth rate of final output	0.0491	0.0075	-0.0271	-0.0006	0.0563	-0.0044
Experiment: $\nu_2 = 0.6$	Impact	Long run	Impact	Long run	Impact	Long run
Public-private capital stock ratio	0.0504	0.0504	0.0504	0.0504	0.0504	0.0504
Technical knowledge-human capital ratio	-0.0173	-0.0367	0.0166	0.0249	-0.0190	-0.0387
Growth rate of final output	0.0487	0.0055	-0.0269	0.0005	0.0558	-0.0057
Experiment: $\phi_2 = 0.7$ with $\nu_2 = 0.6$ 5/	Impact	Long run	Impact	Long run	Impact	Long run
Public-private capital stock ratio	0.0504	0.0504	0.0504	0.0504	0.0504	0.0504
Technical knowledge-human capital ratio	-0.0175	-0.0355	0.0167	0.0240	-0.0190	-0.0370
Growth rate of final output	0.0464	0.0046	-0.0248	0.0011	0.0533	-0.0065

1/ Increase in υ_I from 0.061 to 0.081.

2/ ν_3 is the elasticity of human capital with respect to public-private capital ratio and set equal to 0.0 in the benchmark case.

3/ ϕ_3 is the elasticity of the flow of new ideas with respect to public-private capital ratio and set equal to 0.0 in the benchmark case.

4/ ν_2 is the elasticity of human capital with respect to externality of technical knowledge and set equal to 0.3 in the benchmark case.

5/ ϕ_2 is the elasticity of the flow of new ideas with respect to existing stock of ideas and set equal to 0.6 in the benchmark case.

Source: Authors' calculations.

Table 3: Panel unit root and cointegration results

		Panel A: Panel unit root tests					
		MW		IPS		CIPS	
		Levels	Diff	Levels	Diff	Levels	Diff
Human capital		60.61	136.02**	-0.94	-1.93**	-1.87	-1.77
Patent stock		74.54	120.30**	-1.39	-2.33**	-1.52	-2.33**
		Panel B: Panel cointegration tests					
	Panel υ	Panel ρ	Panel PP	Panel ADF	Group ρ	Group PP	Group ADF
Pedroni tests	6.72**	-2.27**	-4.74**	2.76**	-3.06**	-7.50**	1.85
			G*t*	G*a*	P*t*	P*a*	
Westerlund tests			-2.88**	-55.65**	-14.81**	-37.69**	

Notes: MW, IPS and CIPS indicate Maddala and Wu (1999), Im, Pesaran and Shin (2003), and Pesaran (2007) panel unit root tests, respectively. Three lags used in the unit root tests to account for autocorrelation and the tests include an intercept. The MW test is computed using an asymptotic Chi -square distribution; the other tests assume asymptotic normality. ** indicates rejection of the null of non-stationarity and no cointegration at the 5% level or lower. All variables are expressed in natural logarithms.

Table 4: The impact of the stock of knowledge on human capital

	SK_{it}	N	*Observations*
WD-DOLS (Kao and Chiang, 2000)	0.020 (0.010)**	35	980
MG-DOLS (Pedroni, 2001)	0.023 (0.006)**	35	980
2-step estimator (Breitung, 2005)	0.045 (0.010)**	35	980

Notes: Standard errors in parenthesis. ** indicates significance at the 5% or lower. The DOLS estimates include three leads and lags. The dependent variable is human capital. All variables are expressed in natural logarithms.

Table 5: Dynamic panel causality

Dependent variable	Source of causality (independent variable)		
	Short-run		Long-run
	ΔHC	ΔSK	ECT
ΔHC	-	-0.001 (0.001)	0.029 (0.003)**
ΔSK	-4.182 (6.648)	-	0.697 (0.388)*

Notes: ECT represents the coefficient of the error correction terms, respectively. ** and * indicate that the null hypothesis of no causal link is rejected at the 5% and 10%, respectively. All variables are expressed in natural logarithms.

Table 6: Robustness – estimation of the full theoretical model

	POLS	RE	FGLS	2-step SGMM
	[1]	[2]	[3]	[4]
Stock of knowledge	0.008	0.008	0.002	0.030
	[0.001]***	[0.003]***	[0.003]*	[0.013]**
Initial human capital	0.662	0.668	0.753	0.485
	[0.021]***	[0.074]***	[0.024]***	[0.066]***
Education expenditure	0.025	0.076	0.008	0.175
	[0.004]***	[0.004]***	[0.001]***	[0.016]***
Public infrastructure	0.012	0.002	0.001	0.025
	[0.005]**	[0.003]	[0.001]*	[0.009]*
Constant	0.128	-0.150	0.024	-0.958
	[0.035]	[0.778]	[0.029]	[0.192]
Observations	1034	1034	1034	1034
R^2	0.63			
Wooldridge test (*p-values*)		0.000		
Modified Wald test (*p-values*)		0.000		
# Countries (# instruments)				35 (22)
AR (2)				0.394
Hansen test				0.109

Notes: Standard errors in brackets, the Wooldridge test is distributed as *F* under the null of No autocorrelation. The modified Wald test is distributed as chi-squared under the null of no Heteroscedasticity across the panels. The *AR (2)* is the Arellano-Bond's 2nd autocorrelation test. The Hansen *J* statistic reports the p-values for the null of instrument validity. *, **, *** denote Significance at 10, 5 and 1% levels, respectively. All variables are expressed in natural logarithms. The dependent variable is human capital.

Figure 1a: Technical knowledge-human capital ratio
(Baseline Scenario)

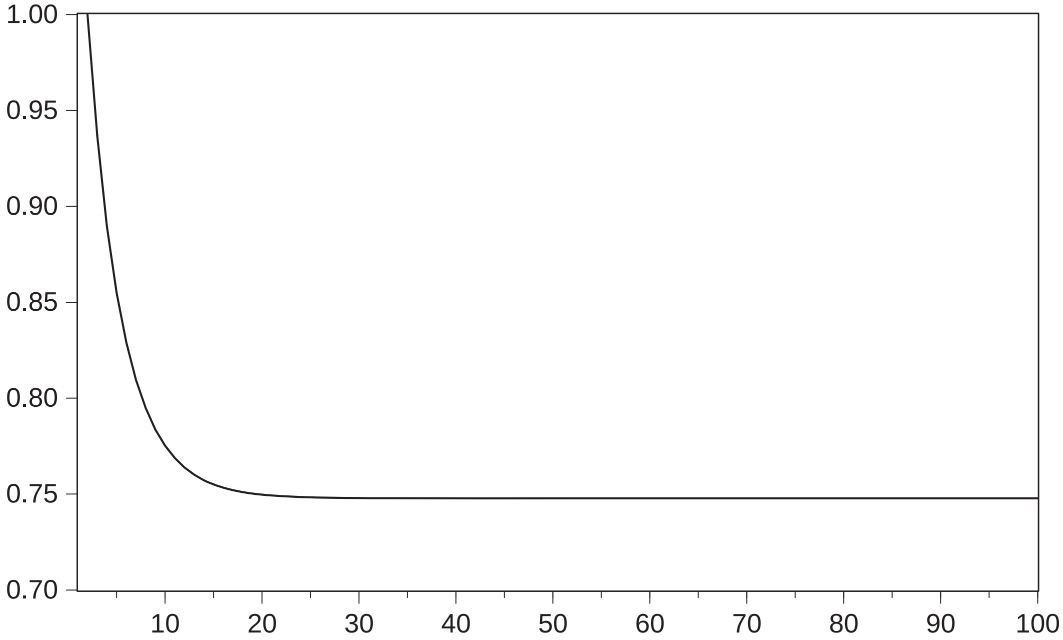


Figure 1b: Growth rate of final output
(Baseline Scenario)

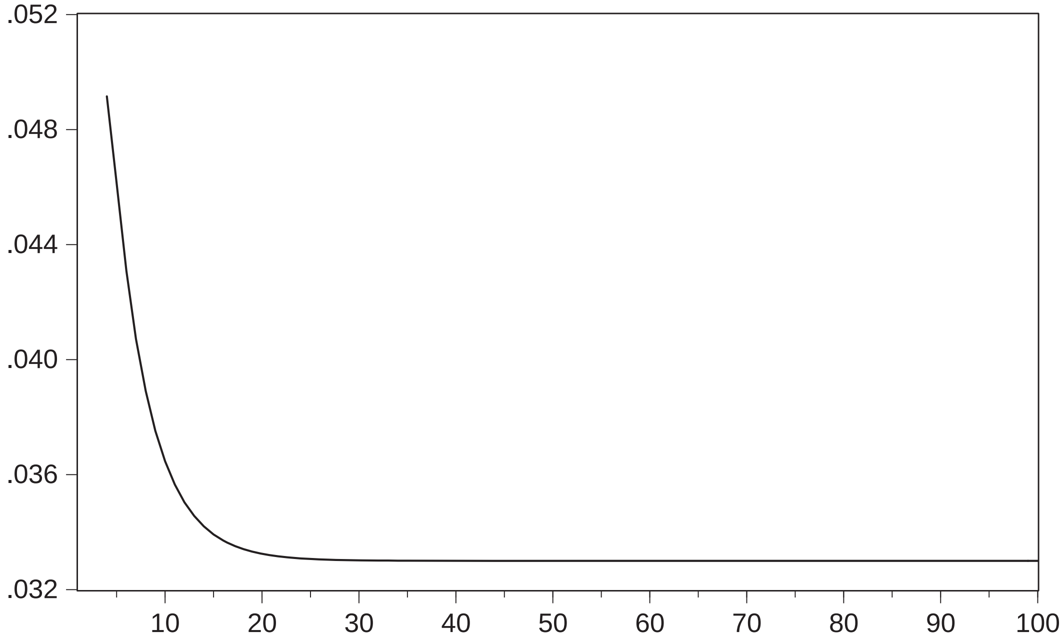
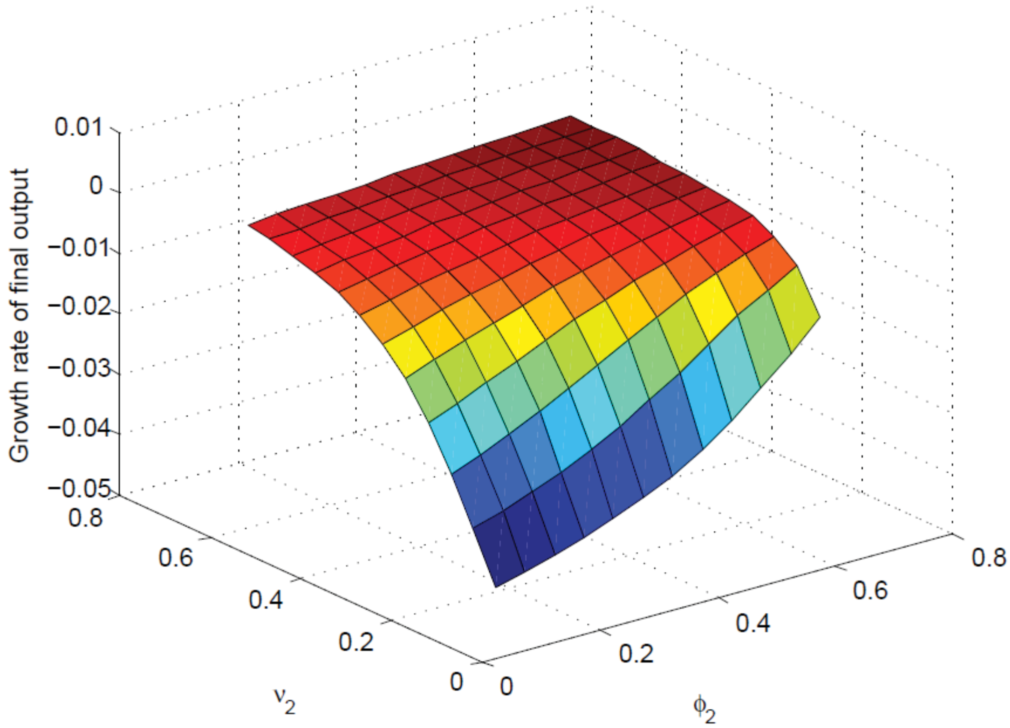


Figure 2
Increase in Infrastructure Investment
Financed by a Cut in Spending on Education
(Absolute deviations from baseline)



Notes: Increase in υ_I from 0.061 to 0.081, financed by a cut in υ_E. ν_2 is the elasticity of human capital with respect to externality of technical knowledge and ϕ_2 is the elasticity of the flow of new ideas with respect to existing stock of ideas. They are set equal to 0.3 and 0.6 respectively in the benchmark case.

Source: Authors' calculations.

Figure 3a: Technical knowledge-human capital ratio
Permanent increase in infrastructure investment
financed by a cut in unproductive spending

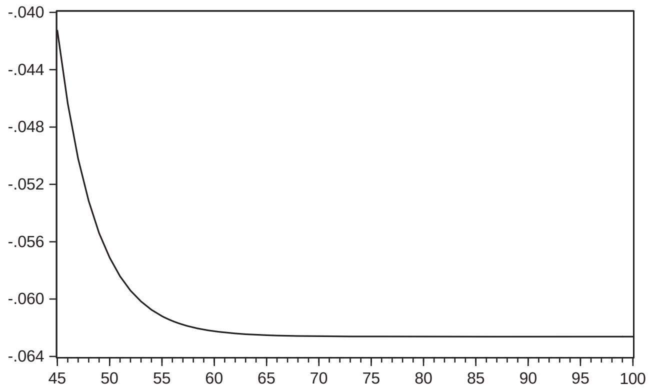


Figure 3b: Growth rate of final output
Permanent increase in infrastructure investment
financed by a cut in unproductive spending

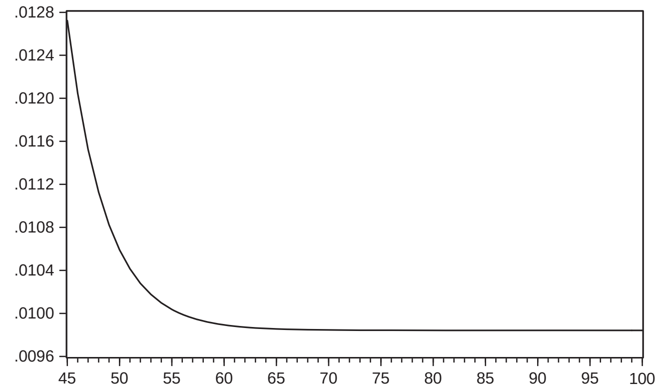


Figure 4a: Technical knowledge-human capital ratio
Permanent increase in infrastructure investment
financed by a cut in education

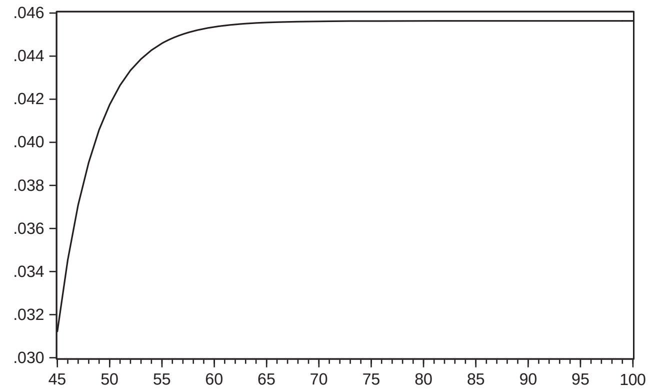


Figure 4b: Growth rate of final output
Permanent increase in infrastructure investment
financed by a cut in education

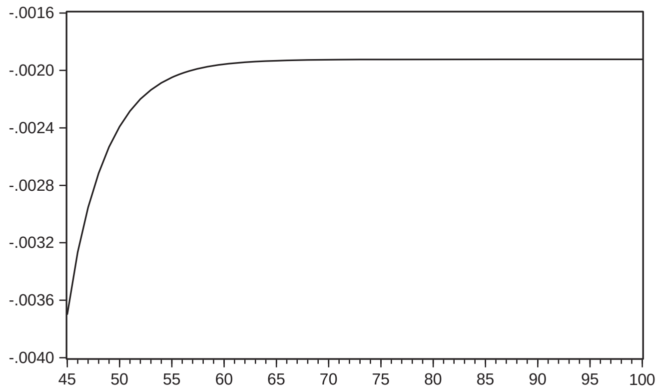


Figure 5a: Technical knowledge-human capital ratio
Permanent increase in infrastructure investment
financed by a cut in R&D activities

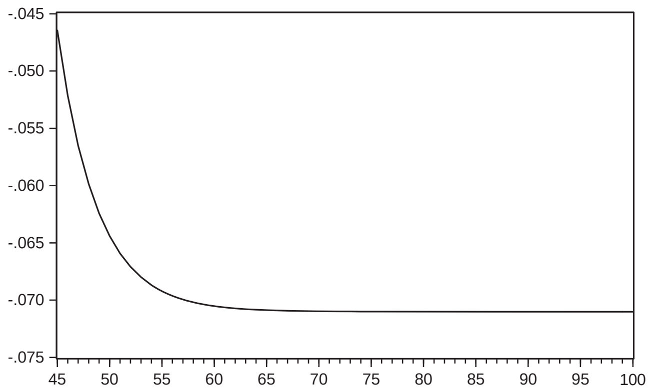


Figure 5b: Growth rate of final output
Permanent increase in infrastructure investment
financed by a cut in R&D activities