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Public Spending and Transitional Dynamics of an Innovation-Based Growth Model

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Abstract

This paper extends a two-period Overlapping Generations (OLG) model of endogenous growth where the interactions between public infrastructure, human capital with R&D activities, and growth are studied. The model accounts for the externality of technical knowledge associated with human capital which promotes the innovation capacity in adopting imported technologies and developing new technologies. In doing so, we have brought to the fore a two-way interaction between human capital and innovation. 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. Based on the numerical analysis for a low-income country, we show that trade-offs in the allocation of public spending may inevitably emerge. 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 education.

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1 Introduction

Technological progress in developing countries has benefited greatly from the increase of globalization due to the adoption and adaptation of pre-existing technologies imported from more advanced countries. Developing countries are, however, impeded in promoting the growth of technological sectors due to lack of human capital. 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), Grossman and Helpman (1991), Aghion and Howitt (1992), Redding (1996), Arnold (1998), Funke and Strulik (2000), Strulik (2005), Grossmann (2007), Iacopetta (2010), Gómez (2011), Sequeira (2011), Chen and Funke (2013), and Gómez and Sequeira (2013) have suggested models in which R&D and human capital accumulation are instruments of growth and notably emphasized the complementarity between these two factors for the process of development.

So far, however, there has been little discussion about the link between public capital and human capital with R&D activities, and growth. The interplay between public capital, human capital and educational outcomes is indeed an important component and plays a key role in R&D and growth in those countries. In fact, lack of access to physical infrastructure, including electricity, transport networks, and telecommunications, continues to impede their ability to absorb foreign ideas and develop new ideas that would result in new and efficient technologies that could be disseminated nation-wide, and thereby fuelling the economy. Conversely, in many countries governments have used information and communication technologies (ICTs) to promote innovation and accumulate 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, public capital, and innovation are all determinants of long-run growth was reported by Agénor and Neanidis (2010) within the context of a two-period (adulthood and old age) Overlapping Generations (OLG) model. In their preliminary work, numerical calibrations and panel data regressions show that public capital has not only direct but also indirect effects on growth through productivity, human capital accumulation, and innovation capacity. They also accounted for these channels from the perspective of public policy.

This paper extends the model presented in Agénor and Neanidis (2010), who have studied the interactions between public infrastructure, human capital with R&D activities, and growth within the context of a two-period OLG model of endogenous growth, in several important directions. Firstly, we account for the spillover effect of the stock of ideas on learning; in doing so, we bring to the fore a two-way interaction between human capital and innovation or the so-called *implementation* innovation. Secondly, possible trade-offs in the allocation of public expenditure between infrastructure investment and other productive components of public spending, namely, education and R&D activities are illustrated numerically. Last, but by no means least, unlike Agénor and Neanidis (2010) who analyzed only the long-run balanced growth path, we study the transitional dynamics of the model, which enable us to trace the path of variables after a shock to the steady-state and to capture the interactions between public capital and human capital, and growth from the perspective of public policy.

Based on the numerical analysis using the average data for low-income countries, we have discussed potential trade-offs associated with the provision of infrastructure and other productive components. The findings of our analysis show that trade-offs in the allocation of public spending may inevitably emerge. In fact, 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 remainder of the paper has been organized in the following way. Section 2 begins by laying out the model presented in Agénor and Neanidis (2010). It then goes on to the main equation in the human capital sector where we introduce the externality of technical knowledge. Section 3 characterizes the balanced growth equilibrium. Section 4 represents the dynamics and steady-state solution of the model. Section 5 calibrates the model, whereas Section 6 focuses on several experiments to illustrate the impact of public policy, including potential trade-offs between productive components of public spending. Section 7 offers some concluding remarks.

2 The Model

Consider a two-period (adulthood and old age) OLG model of endogenous economic growth where the economy is populated by nonaltruistic individuals endowed with one unit of time in each period, 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 the 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.

2.1 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 maximize equation (1) subject to their intertemporal budget constraint with respect to c_t^t and c_{t+1}^t, taking prices as given.

2.2 Production of the Final Good

The final good is produced by using effective labor, $E_t N_{i,t}^Y$, 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 labor, 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

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

or by implication,

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

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.

2.3 Human Capital Accumulation

Individuals are assumed to devote their time to education in the first period of their lives and their human capital is produced by 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

$$e_{t+1} = (\frac{G_t^E}{\bar{N}})^{\nu_1} M_t^{\nu_2} E_t^{1-\nu_1-\nu_2}(k_t^I)^{\nu_3}, \tag{7}$$

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, unlike Agénor and Neanidis (2010), in this paper, we account for the spillover effect of the existing stock of ideas, M_t on learning, which creates a positive externality for future R&D activities although it is subject to diminishing returns.

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 reviewing the literature, the benefit of industrial diversification for human capital accumulation was first reported by McDermott (2002) within the context of an endogenous growth model.

2.4 Research and Development Sector

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

$$M_{t+1} - M_t = (\frac{G_t^R}{E_t})^{\phi_1}(\frac{M_t}{E_t})^{\phi_2}(k_t^I)^{\phi_3}\frac{E_t N_t^R}{\bar{N}}, \tag{8}$$

where G_t^R government spending on R&D, $E_t N_t^R$ effective labor 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 average human capital 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 (2010).

2.5 Government

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

$$G_t = \sum G_t^h = \tau e_t w_t \bar{N}, \qquad h = E, I, R, U \tag{9}$$

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:

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

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

Combining (9) and (10) therefore yields

$$\sum_h \upsilon_h = 1. \tag{11}$$

Assuming full depreciation for simplicity, public capital in infrastructure:

$$K_{t+1}^I = G_t^I. \tag{12}$$

2.6 Market-Clearing Conditions

The asset market clearing condition requires tomorrow's private capital stock to be equal to savings in period t by individuals born in $t-1$:

$$K_{t+1}^P = \bar{N} s_t, \tag{13}$$

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

Labor market equilibrium condition is

$$N_t^R + N_t^Y = \bar{N}, \tag{14}$$

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

3 Balanced Growth Equilibrium

As defined in Agénor and Neanidis (2010, p.13-14), a *dynamic equilibrium* for the model is a sequence of allocations $\{c_t^t, c_{t+1}^t, s_t\}_{t=0}^{\infty}$, physical capital stocks $\{K_t^P, K_t^I\}_{t=0}^{\infty}$, human capital stock $\{e_t\}_{t=0}^{\infty}$, available varieties, $\{M_t\}_{t=0}^{\infty}$, factor prices $\{w_t, r_t\}_{t=0}^{\infty}$, prices and quantities of each intermediate input $\{p_t^s, x_{s,t}\}_{t=0}^{\infty}$, $\forall s \in (1, M_t)$, a constant tax rate and public spending shares such that, given initial stocks $K_0^P, K_0^I > 0$ and $M_0 > 0$, individuals maximize utility, firms in the final-good sector, and producers of both intermediate goods and new designs in the R&D sector maximize their profits, the government budget is balanced, and all markets clear. In equilibrium, it must also be that $e_t = E_t$.

A *balanced growth equilibrium* is a dynamic equilibrium in which c_t^t, c_{t+1}^t, s_t, K_t^P, K_t^I, e_t, Y_t, M_t, grow at the constant, endogenous rate $\boldsymbol{\gamma}_Y$, the rate of return on private capital r_t, the economy-wide wage rate w_t, the price of each intermediate good p_t and the patent price p_t^M are constant. The fractions of the adult labor force engaged in the production of the final good and ideas, $n_t^h = N_t^h/\bar{N}$, with $h = R, Y$, are constant and $n_t^R + n_t^Y = 1$.

4 Dynamics and Steady-State Growth

The appendix shows that the public-private capital ratio, k_t^I, is constant over time and the dynamic system can be condensed into 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. The dynamic system behaves in a complex nonlinear fashion, therefore we cannot study the stability of the model analytically; however, the stability can be verified numerically once the model is calibrated.

In the steady-state, e_t, M_t, K_t^P, and K_t^I grow at the same constant rate. The steady-state wage rate is constant thus individual consumption in both periods of life and savings in the first period grow at the same rate as e_t. The rental rate of capital is constant in the steady-state. The steady-state growth rate of output grows at the same rate as K_t^P.

5 Calibration

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 labor, β is assumed to be 0.65, as in Agénor and Dinh (2015). However, the elasticity with respect to private capital, α is slightly higher than the value used in Agénor and Neanidis (2010) and set equal to 0.2. Therefore, the elasticity with respect to intermediate inputs, $\gamma = 1 - \alpha - \beta$ is relatively lower than the value used in their study; it is set equal to 0.15.

Unlike Agénor and Neanidis (2010), 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 labor 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 (2010). The benchmark values for the parameters are summarized 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	$\varphi_0 = 0.2, \varphi_1 = 0.0$

6 Policy Experiments

To characterize 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.

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 $\phi_3 = 0.1$.

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. 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.

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.

According to Figure 5 (a,b), on impact, an offsetting cut in another productive component of public spending, v_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.

7 Concluding Remarks

This paper extended the model developed by Agénor and Neanidis (2010) who have highlighted the interactions between public infrastructure, human capital with R&D activities, and growth within the context of a two-period OLG model of endogenous growth. We accounted for the spillover effect of the existing stock of ideas on learning, which promotes the innovation capacity of developing countries in adopting imported technologies and developing new technologies. At the same time, the production of new designs positively depends on average human capital of individuals. Thus, there is a two-way interaction between human capital and innovation or the so-called *implementation* innovation. 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 also discussed 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 show that due to the limited amount of resources governments have, trade-offs in the allocation of public spending may inevitably emerge. In fact, 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.

This paper could be extended in several directions. Firstly, some of qualitative implications in this paper can be assessed with formal cross-country econometric techniques. For instance, the magnitude of the learning externality between human capital accumulation and *implementation* innovation should be higher where the existing stock of ideas is higher. Secondly, although the model is complex and behaves in a nonlinear fashion and therefore cannot be solved analytically, the welfare-maximizing allocation of public spending can be studied numerically.

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Appendix
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 maximizes (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 (13) yields

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

From (10) and (12),

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

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, $\Pi^Y_{i,t}$, is given by

$$\Pi^Y_{i,t} = Y^i_t - (1+\varphi_t)\sum_1^{M_t} p^s_t x^i_{s,t} - w^Y_t E_t N^Y_{i,t} - r_t K^{P,i}_t, \tag{A9}$$

where the price of the final good normalized to unity, p^s_t is the price of intermediate good s, w^Y_t 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; $\varphi_t = \varphi(k^I_t)$, where $\varphi(0) > 0$, $\varphi' < 0$, and $\lim_{k^I_t \to \infty}\varphi_t = 0$.

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

$$r_t = \alpha\frac{Y^i_t}{K^{P,i}_t}, \quad w^Y_t = \beta\frac{Y^i_t}{E_t N^Y_{i,t}}, \tag{A10}$$

$$x^i_{s,t} = [\frac{\gamma Z^i_t}{(1+\varphi_t)p^s_t}]^{1/(1-\eta)}, \quad s = 1, ...M_t,$$

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

$$x_{s,t} = \int_0^1 x^i_{s,t} di = \int_0^1 [\frac{\gamma Z^i_t}{(1+\varphi_t)p^s_t}]^{1/(1-\eta)} di, \tag{A11}$$

where

$$Z^i_t = Y^i_t / \sum_1^{M_t} (x^i_{s,t})^\eta, \tag{A12}$$

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

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

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

$$\Pi^I_{s,t} = (p^s_t - \theta)x_{s,t}, \tag{A14}$$

where p_t^s a fee monopolistically competitive firms in the intermediate sector must 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.

Or equivalently, substituting (A11) into (A14), together with $Z_t^i = Z_t$, $\forall i$, and then maximizing with respect to p_t^s, taking Z_t and φ_t as given, yields the optimal price

$$\Pi_{s,t}^I = (p_t^s - \theta)[\frac{\gamma Z_t}{(1+\varphi_t)p_t^s}]^{1/(1-\eta)}, \tag{A15}$$

$$p_t^s = p_t = \frac{\theta}{\eta}. \quad \forall s \tag{A16}$$

From the definition of Z_t^i in (A12), and using (A16), in equilibrium $Z_t = Y_t/M_t x_t^\eta$, equation (A10) takes the form

$$x_t = \frac{\gamma\eta}{(1+\varphi_t)\theta}(\frac{Y_t}{M_t}), \tag{A17}$$

or equivalently, equation (A17) can be rewritten, together with (A7),

$$x_t = \frac{\gamma\eta}{[1+\varphi(J)]\theta}(\frac{Y_t}{K_t^P}\frac{K_t^P}{M_t}) = \frac{\gamma\eta}{[1+\varphi(J)]\theta}(\frac{Y_t}{K_t^P})m_t^{-1}. \tag{A18}$$

Substituting this result in (A8) and rearranging yields

$$(\frac{Y_t}{K_t^P})^{1-\gamma} = [\frac{J^\varepsilon(\gamma\eta)^\gamma}{[1+\varphi(J)]^\gamma\theta^\gamma}]z_t^\beta m_t^{(\gamma/\eta-\gamma)}, \tag{A19}$$

that is,

$$\frac{Y_t}{K_t^P} = \Lambda_1 m_t^{\Psi_1} z_t^{\Omega_1}, \tag{A20}$$

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 (A16) and (A17) can be substituted into (A14):

$$\Pi_t^I = \frac{(1-\eta)\gamma}{1+\varphi_t}(\frac{Y_t}{M_t}). \tag{A21}$$

The arbitrage condition is

$$p_t^M = \Pi_t^I. \tag{A22}$$

From (A7), (A21), and (A22),

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

which can be rearranged to give

$$p_t^M = \frac{(1-\eta)\gamma}{1+\varphi(J)}(\frac{Y_t}{K_t^P})m_t^{-1}. \tag{A23}$$

From (10),

$$G_t^h = \upsilon_h \tau e_t w_t \bar{N}. \quad h = E, R \tag{A24}$$

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

$$\max_{N_t^R} \Pi_t^R = p_t^M (M_{t+1} - M_t) - w_t^R E_t N_t^R, \tag{A25}$$

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 (A25) can be solved for

$$w_t^R \geq \left\{ (\frac{G_t^R}{E_t})^{\phi_1} (\frac{M_t}{E_t})^{\phi_2} (k_t^I)^{\phi_3} \right\} p_t^M. \tag{A26}$$

Substituting (A23) and (A24) for $h = R$ in (A26), holding with equality, and using (A7), yields, with $w_t^R = w_t$,

$$w_t = (\upsilon_R \tau w_t \bar{N})^{\phi_1} (m_t z_t^{-1})^{\phi_2} J^{\phi_3} \frac{(1-\eta)\gamma}{1+\varphi(J)}(\frac{Y_t}{K_t^P})m_t^{-1}. \tag{A27}$$

Substituting (A20) in (A27) yields the equilibrium wage as a function of m_t and z_t.

$$w_t = \Lambda_2 m_t^{\Psi_2} z_t^{\Omega_2}, \tag{A28}$$

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 (9), (A7), and (A24) 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 (A28) to eliminate w_t,

$$\frac{E_{t+1}}{E_t} = \Lambda_3 m_t^{\Psi_3} z_t^{\Omega_3}, \tag{A29}$$

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), (A28), and (A29), the dynamics of z_t are determined by

$$z_{t+1} = \Lambda_4 m_t^{\Psi_4} z_t^{\Omega_4}, \tag{A30}$$

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 (8) 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 (A24) for $h = R$,

$$\frac{M_{t+1}}{M_t} = 1 + [\frac{(\upsilon_R \tau \bar{N})^{\phi_1} J^{\phi_3}}{\bar{N}}] (\frac{z_t}{m_t})^{1-\phi_2} w_t^{\phi_1} N_t^R. \tag{A31}$$

To eliminate N_t^R from this expression, equation (14), together with equation (A10), yields equilibrium employment in the R&D sector:

$$N_t^R = \bar{N} - \beta(\frac{Y_t}{E_t})w_t^{-1}. \tag{A32}$$

We can substitute (A28) for w_t in (A32) to give

$$N_t^R = \bar{N} - \beta(\frac{Y_t}{K_t^P})z_t^{-1}(\Lambda_2 m_t^{\Psi_2} z_t^{\Omega_2})^{-1}. \tag{A33}$$

Substituting (A20), (A28), and (A33) in (A31) yields

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

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 (A34) 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 (A28) in this expression and rearranging yields

$$m_{t+1} = \frac{1 + \Lambda_5 m_t^{\Psi_5} z_t^{\Omega_5} \left[\bar{N} - \Lambda_6 m_t^{\Psi_6} z_t^{\Omega_6}\right]}{\Lambda_7 m_t^{\Psi_7} z_t^{\Omega_7}}, \tag{A35}$$

where

$$\Lambda_7 = \Lambda_2 \sigma (1 - \tau) \bar{N},$$

$$\Psi_7 = \Psi_2 - 1,$$

$$\Omega_7 = 1 + \Omega_2.$$

From (A30) and (A35), in the steady-state,

$$\tilde{z} = \left\{ \Lambda_4 \tilde{m}^{\Psi_4} \right\}^{1/\Pi}, \tag{A36}$$

$$\tilde{m} = \left\{ \frac{1 + \Lambda_5 \tilde{m}^{\Psi_5} \tilde{z}^{\Omega_5} \left[\bar{N} - \Lambda_6 \tilde{m}^{\Psi_6} \tilde{z}^{\Omega_6} \right]}{\Lambda_7 \tilde{z}^{\Omega_7}} \right\}^{1/\Phi}, \tag{A37}$$

where

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

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

From (A20), in the steady-state,

$$(\frac{\tilde{Y}}{K^P}) = \Lambda_1 \tilde{m}^{\Psi_1} \tilde{z}^{\Omega_1}, \tag{A38}$$

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

From (A28), the steady-state wage rate is

$$\tilde{w} = \Lambda_2 \tilde{m}^{\Psi_2} \tilde{z}^{\Omega_2}. \tag{A39}$$

From (A29) and (A34), the steady-state growth rate of the economy can be written in two equivalent forms:

$$\boldsymbol{\gamma}_Y = \Lambda_3 m_t^{\Psi_3} z_t^{\Omega_3} - 1, \tag{A40}$$

$$\boldsymbol{\gamma}_Y = \Lambda_5 m_t^{\Psi_5} z_t^{\Omega_5} \left[\bar{N} - \Lambda_6 m_t^{\Psi_6} z_t^{\Omega_6} \right]. \tag{A41}$$

To determine the level of output and its growth rate during the transition, from (A20),

$$Y_t = \Lambda_1 m_t^{\Psi_1} z_t^{\Omega_1} K_t^P, \tag{A42}$$

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 (A28),

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

or equivalently,

$$\frac{K_t^P}{K_{t-1}^P} = \Lambda_2 \sigma (1-\tau) m_{t-1}^{\Psi_2} z_{t-1}^{1+\Omega_2} \bar{N}. \tag{A43}$$

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: Author's calculations.

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

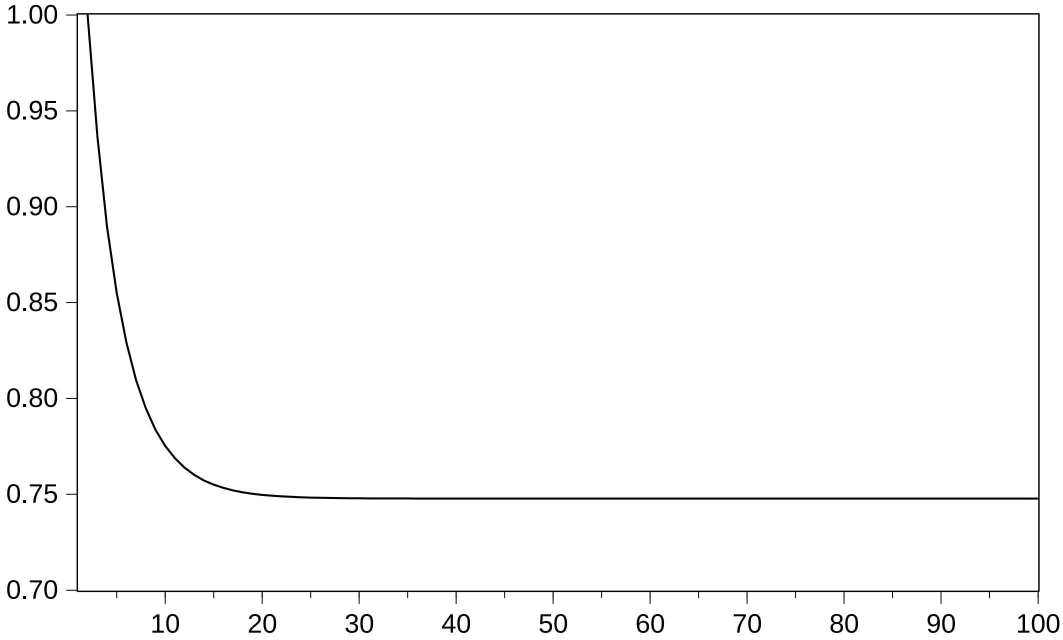


Figure 1b: Growth rate of final output
(Baseline Scenario)

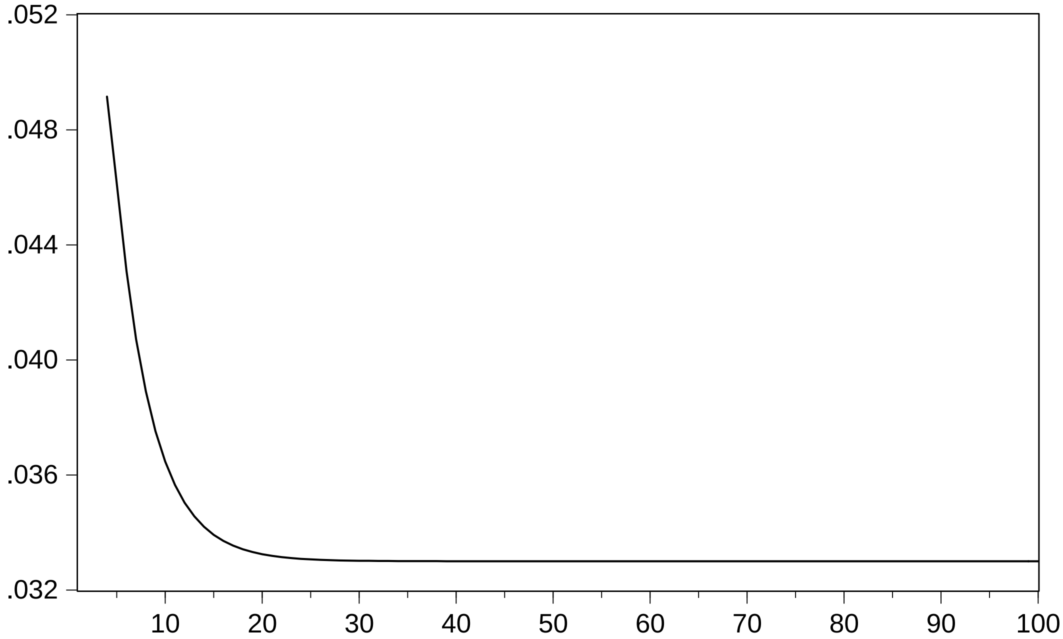
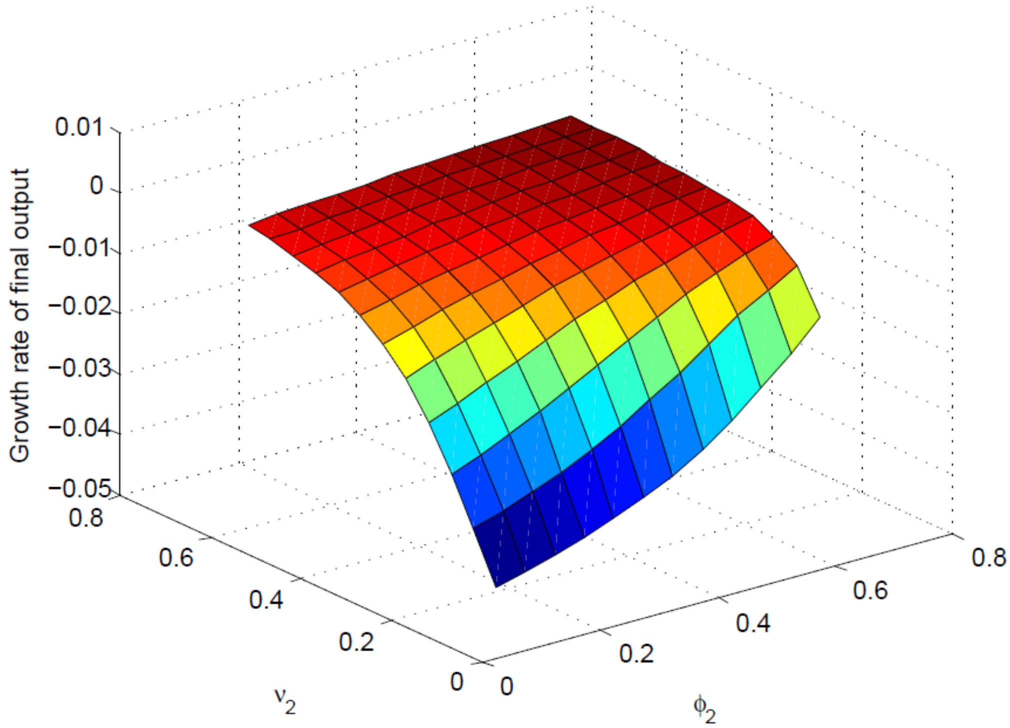


Figure 2
Increase in Infrastructure Investment
Financed by a Cut in Spending on Education
(Absolute deviations from baseline)



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: Author's calculations.

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

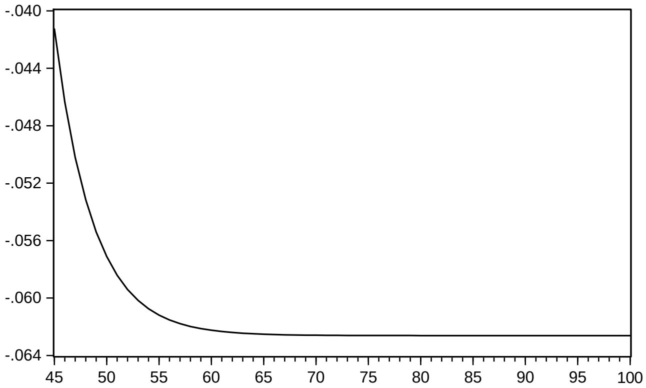


Figure 3b: Growth rate of final output
Permanent increase in infrastructure investment
financed by a cut in unproductive spending

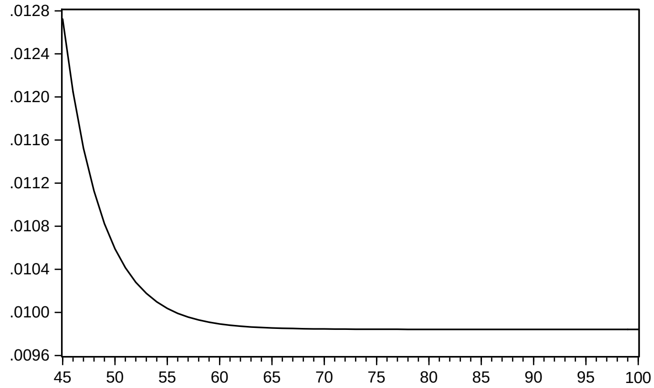


Figure 4a: Technical knowledge-human capital ratio
Permanent increase in infrastructure investment
financed by a cut in education

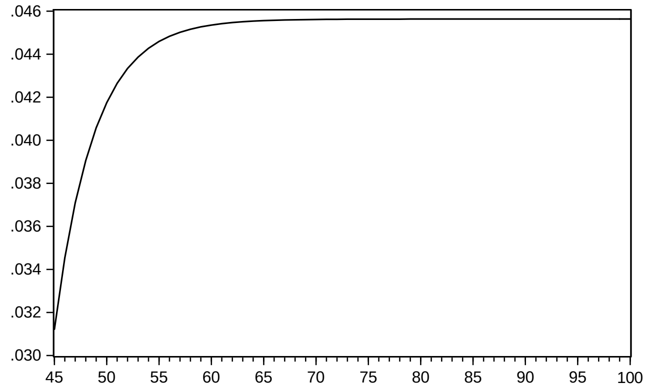


Figure 4b: Growth rate of final output
Permanent increase in infrastructure investment
financed by a cut in education

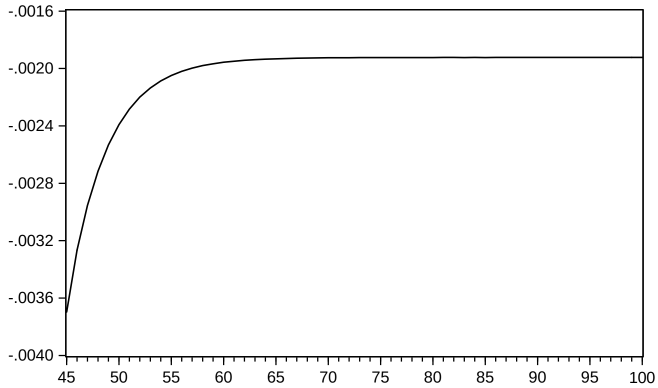


Figure 5a: Technical knowledge-human capital ratio
Permanent increase in infrastructure investment
financed by a cut in R&D activities

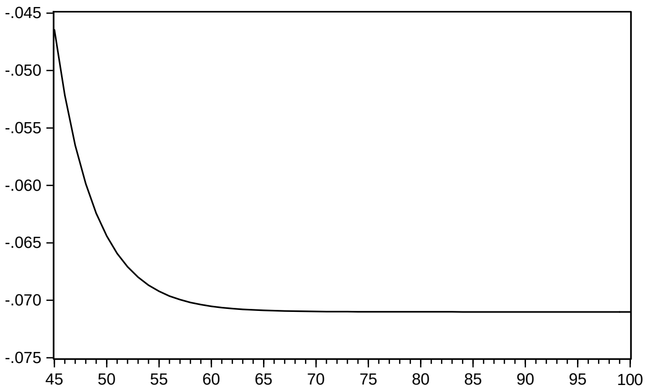


Figure 5b: Growth rate of final output
Permanent increase in infrastructure investment
financed by a cut in R&D activities