

Werner, Katharina; Prettnner, Klaus

## Conference Paper

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# Public education and R&D-based economic growth\*

Klaus Prettnner<sup>a</sup> and Katharina Werner<sup>b</sup>

a) Vienna University of Technology  
Institute of Mathematical Methods in Economics  
Argentinierstraße 8/4/105-3  
1040 Vienna, Austria  
email: klaus.prettnner@econ.tuwien.ac.at

b) University of Göttingen  
Department of Economics  
Platz der Göttinger Sieben 3  
37073 Göttingen, Germany  
email: kwerner@uni-goettingen.de

## Abstract

We analyze the short- and long-run effects of public education on economic growth and welfare. In so doing, we extend an R&D-based economic growth model by including a governmental sector that levies labor income taxes and uses the proceeds to finance teachers. An increase in the tax rate reduces consumption possibilities (and thereby individual utility), and the number of workers available for final goods production and research. At the same time, however, it increases the educational resources available per pupil. Consequently, economic growth slows down immediately after an increase in educational investments but it speeds up during the transition toward the long-run balanced growth path. Altogether, this implies a dynamic tradeoff in the sense that current cohorts lose due to educational reform, whereas future cohorts gain. We show that there exists an interior welfare-maximizing level of the provision of public education for each time horizon and show that it is higher than the levels we typically observe in industrialized countries. Since the transitional effects of an education reform on growth and welfare can be negative, our framework has the potential to explain resistance against long-run welfare improving education reforms.

**JEL classification:** I25, J24, O11, O31, O41.

**Keywords:** human capital accumulation, public education policy, quality of education, technological progress, economic growth.

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# 1 Introduction

The connection between education and economic growth has been analyzed extensively in the empirical literature. Most of the studies find a positive association between per capita GDP and measures for overall educational attainment.<sup>1</sup> Fortunately, in this context, the data show large improvements of education indicators in industrialized countries over the last decades. Table 1 displays the mean years of schooling of the population aged 15+ for the G-8 countries in 1960 and 2010 as an indicator of the *quantity* of schooling. There has been an increase over time with annualized growth rates between 0.5% and 2%. The table also contains pupil-teacher ratios in primary education, the substantial declines of which indicate rising *quality* of education. Altogether, these observations and the fact that the G-8 countries featured substantial increases in living standards over the corresponding time-frame are consistent with the results of empirical studies.

Table 1: Mean years of schooling and pupil-teacher ratios in primary education for the G-8 countries

Country	Mean years of schooling		Pupil-teacher ratios	
	1960	2010	1971	2009
Canada	8.31	11.37	23.00*	17.42*
France	4.20	10.53	22.79	18.73
Germany	5.15	11.82	17.46*	13.00
Italy	4.86	9.88	21.62	10.33*
Japan	8.02	11.59	26.39	18.05
Russia	5.16	8.84	27.95*	18.06
U.K.	7.04	9.75	24.86*	17.96
USA	9.25	12.20	14.05	13.87

Note: The data are obtained from Barro and Lee (2013) and the World Bank (2012) “Education Statistics”. The indicated year differs for the entries marked with an asterisk because of missing data. The base years for pupil-teacher ratios are 1972 for Canada, 1995 for Germany, 1981 for Russia and 1985 for the USA. The final years for the same data series are 2000 for Canada and 2007 for Italy.

Despite these empirical findings and the seminal theoretical contributions of Nelson and Phelps (1966), Lucas (1988), Galor and Weil (2000), Dalgaard and Kreiner (2001), Strulik (2005), and Bucci (2008) — showing different mechanisms by which private education exerts a positive influence on economic prosperity — the impact of *public* education policies on technological progress and economic growth has largely

<sup>1</sup>See for example Barro (1991), Sachs and Warner (1995), Bils and Klenow (2000), Krueger and Lindahl (2001), Rangazas (2002), de la Fuente and Domenéch (2006), Cohen and Soto (2007), Lutz et al. (2008), Kaboski (2009), Hanushek and Woessmann (2012) and the corresponding studies mentioned in the survey of Durlauf et al. (2005).

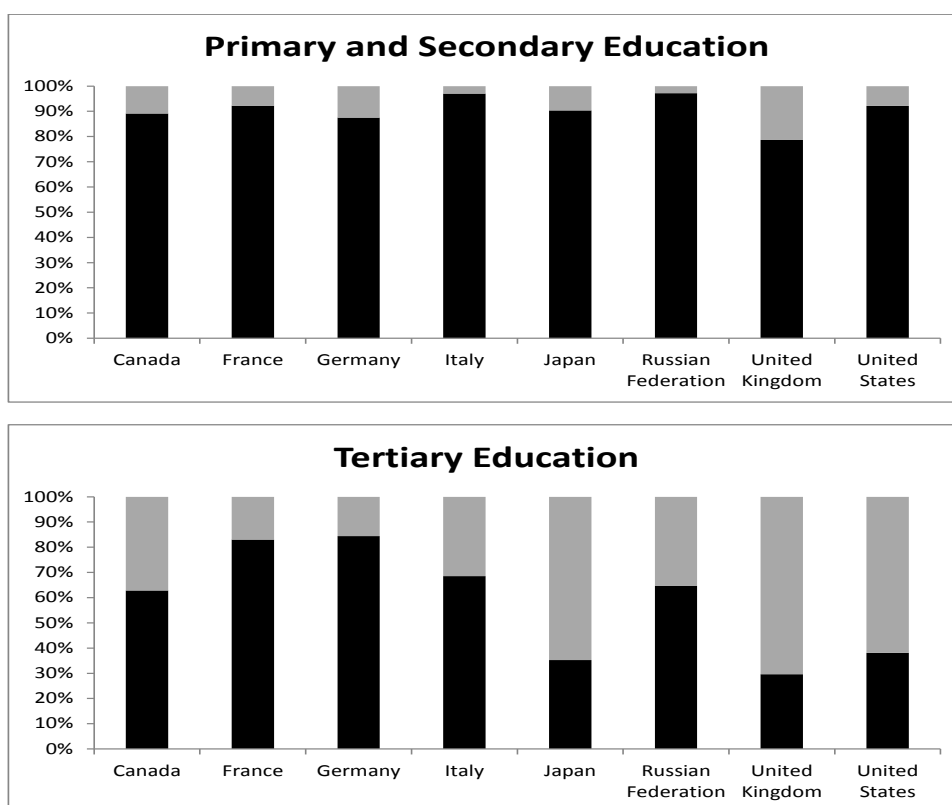
remained unexplored. A notable exception in the literature is Grossmann (2007), who analyzes the effects of public subsidies for private education in the context of R&D-based growth. He abstracts from population growth and the trade-off between labor used for education on the one hand and for goods production and R&D on the other. However, his central result — the long-run growth promoting effect of public education investments — carries over to our framework to some extent as well.<sup>2</sup> Figure 1 shows for the G-8 countries the fractions of primary and secondary education (black areas of the histograms in the upper graph) and tertiary education (black areas of the histograms in the lower graph) that are financed publicly (see also Docampo, 2007; OECD, 2012). To the extent that primary and secondary education are almost entirely financed by the state in the G-8 countries and that the majority of tertiary education expenditures in Canada, France, Germany, Italy and the Russian Federation also come from public sources, the lack of thorough theoretical analyses of the long-run growth and welfare effects of public education is rather surprising.

We attempt to introduce publicly financed schooling in a realistic way by relaxing the implicit assumption often made in the literature that the sole input in human capital accumulation is time and effort by those to be educated (or by their parents). By contrast, our model features an education sector that employs teachers to build up the human capital stock of the next generation. Consequently, an increase in education investments has two side effects: i) the additional labor required in the education sector needs to be reallocated from other productive sectors of the economy, notably the research and development (R&D) sector that develops the new blueprints and is a central driving force behind long-run economic growth; and ii) public education is financed by taxing the wage income of households, which impacts the disposable income and thereby leads to a conflict of interest between the short-run utility-maximizing households and the potential medium- to long-run gains that accrue due to education.

The basic mechanism of our model is the following. Human capital is used as an input in three sectors that compete for it on the labor market: workers produce goods in the final goods sector, scientists produce blueprints in the R&D sector, and teachers produce human capital for the next generation in the education sector. The government collects wage taxes and uses the proceeds to pay for the teachers working in the education sector. Consequently, an increase in taxes raises the number of teachers and thereby draws labor away from the other productive sectors. This harms economic growth in the *short* run. However, the increase in the number of teachers fosters human capital accumulation and thereby increases productivity of the next generations. This in turn raises medium-run economic growth. Consequently, there are important trade-offs involved in the decision of the government of how much it should invest in education

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<sup>2</sup>Outside the R&D-based economic growth literature public education has been analyzed extensively in frameworks where economic growth is driven by human capital accumulation alone. Interesting contributions include for example Docquier and Michel (1999), Blankenau and Simpson (2004), Blankenau (2005), Yew and Zhang (2013), and Abington and Blankenau (2013).



Note: The black areas of the histograms represent the fraction of governmental education expenditures and the gray areas the share of private (household and firm) education expenditures. Data source: OECD (2012) and own calculations.

Figure 1: Share of public education investments in the G-8 countries (black areas)

of the next generations.

The paper proceeds as follows: Section 2 contains the theoretical framework and the derivation of the dynamic system that fully describes the model economy. In Section 3 we derive the growth rates of endogenous variables along the balanced growth path. We then proceed to a numerical illustration of the impact of an education reform during transition and along the balanced growth path as well as on household welfare in the short- and long run. Finally, Section 4 summarizes, draws conclusions for economic policy, and highlights scope for further research.

## 2 The model

This section describes the discrete time overlapping generations version of the R&D-based economic growth framework of Jones (1995)<sup>3</sup> in which we introduce a govern-

<sup>3</sup>Due to the isomorphism between R&D-based growth models with horizontal and vertical innovations (see Segerström, 1998, for the latter), the growth effects of education investments would not be different when using a model of vertical innovation as baseline framework.

mentally funded education sector. This sector taxes wage income of households to employ teachers who educate the young. We analyze the implications of changing public education investments for long-run economic growth and welfare.

## 2.1 Basic assumptions

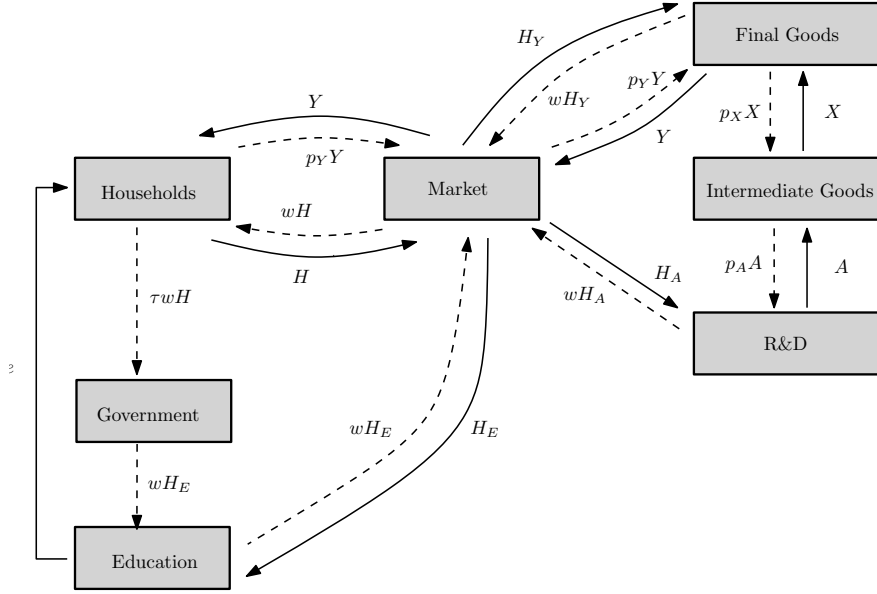
Consider an overlapping generations economy where individuals live for two periods: childhood and adulthood. Children do not face economic decisions but they receive publicly funded education, the intensity of which determines their human capital level as adults. Adults, whose cohort size at time  $t$  is given by  $N_t$ , work  $l_t \in (0, 1]$  units of their total time endowment (normalized to 1) for a wage according to their human capital level and consume all of their income. We assume that adults give birth to  $n > 0$  children such that the population grows at rate  $n - 1$ . Note that this includes the possibility of negative population growth, which is ruled out in the model setup of Jones (1995). Endogenizing population growth and private education investments along the lines of Strulik et al. (2013) would make the model more realistic but would also obscure the basic mechanisms we aim to highlight. It is therefore left for further research.

On the production side of the economy there are four sectors: final goods production, intermediate goods production, R&D, and education. Two production factors can be used in these sectors: blueprints and labor (human capital). The latter is available in three different forms: i) workers in the final goods sector, ii) scientists in the R&D sector, and iii) teachers in the education sector. The final goods sector employs workers and machines supplied by the intermediate goods sector to produce for a perfectly competitive consumption goods market. The monopolistically competitive intermediate goods sector produces the machines used in the final goods sector with the final good as the variable production factor and one machine-specific blueprint as fixed input. The blueprints are in turn supplied by the R&D sector which employs scientists to produce them. Finally, the education sector employs teachers to produce individual human capital for the next generation denoted by  $h_{t+1}$ . The expenditures for the education sector are financed by taxing the wages of adult workers. We assume that human capital and raw labor are perfect substitutes such that  $H_t = h_t L_t$  represents aggregate human capital with aggregate labor supply as given by  $L_t = l_t N_t$ . Figure 2 summarizes this model structure.

## 2.2 Consumption side

Suppose that adults choose consumption and labor supply to maximize their utility according to

$$\max_{c_t, l_t} u_t = \log c_t - \gamma \frac{l_t^{1-\mu} - 1}{1-\mu}, \quad (1)$$



Note:  $Y$  refers to the final goods consumed by households and  $p_Y$  to their price;  $X$  refers to the intermediate goods used in final goods production with  $p_X$  being the price of these intermediates;  $A$  are the blueprints used for intermediate goods production with  $p_A$  being their price;  $H$  is aggregate human capital in the production process with  $H_A$  being the human capital of scientists,  $H_E$  referring to the human capital of teachers, and  $H_Y$  denoting the human capital of workers in the final goods sector;  $w$  refers to the wage rate and  $\tau$  denotes the income tax rate that the government sets to finance education.

Figure 2: Overview of the structure of the general equilibrium model

where  $c_t$  denotes consumption,  $l_t \in (0, 1]$  the labor supply,  $\gamma$  refers to the disutility weight of labor, and  $-1/\mu$  is the Frisch elasticity of labor supply. Note that each time period corresponds to one generation and therefore lasts for around 25 years. The budget constraint of an adult is given by

$$(1 - \tau)w_t h_t l_t = c_t, \quad (2)$$

where  $\tau$  denotes the income tax rate and  $w_t$  represents the wage per efficiency unit of labor. Consequently, the left hand side of the budget constraint refers to total lifetime income of an individual, which can be spent only on consumption. The results of the maximization problem are expressions for optimal consumption and labor supply

$$c_t = (1 - \tau)h_t w_t \left(\frac{1}{\gamma}\right)^{\frac{1}{1-\mu}}, \quad l_t = \left(\frac{1}{\gamma}\right)^{\frac{1}{1-\mu}}, \quad (3)$$

exhibiting the standard properties, that is, consumption is increasing with the wage rate per unit of effective labor and with individuals' human capital, while the labor supply is time-independent and depends negatively on the disutility weight of labor

( $\gamma$ ), and positively on the Frisch elasticity of labor supply ( $-1/\mu$ ).

## 2.3 Production side

This subsection describes the production structure in the four sectors: final goods production, intermediate goods production, R&D, and education. The treatment of the former two sectors is fairly standard (cf. Jones, 1995) such that the description can be brief. Since we augment the standard framework to account for an income tax financed public education sector that employs labor to produce human capital of the young population (and thereby increases the productivity of subsequent generations), the education sector and the R&D sector compete for talents on the labor market. To our knowledge, this trade-off has not been analyzed in the literature and we will therefore describe it in more detail.

### 2.3.1 Final goods sector

Final output  $Y_t$ , being consumed by the individuals in the economy and representing its gross domestic product (GDP), is produced according to the production function

$$Y_t = H_{t,Y}^{1-\alpha} \int_0^{A_t} x_{t,i}^\alpha di, \quad (4)$$

where  $H_{t,Y}$  is human capital employed in the final goods sector,  $A_t$  is the technological frontier, that is, it represents the most modern blueprint that has been developed in the R&D sector,  $x_{t,i}$  is the amount of the blueprint-specific machine  $i$  used in final goods production, and  $\alpha$  is the elasticity of final output with respect to machines. Due to perfect competition in the final goods market, production factors are paid their marginal products. This implies that the wage rate per unit of effective labor and prices of machines are given by, respectively,

$$w_{t,Y} = (1 - \alpha) H_{t,Y}^{-\alpha} \int_0^{A_t} x_{t,i}^\alpha di = (1 - \alpha) \frac{Y_t}{H_{t,Y}}, \quad (5)$$

$$p_{t,i} = \alpha H_{t,Y}^{1-\alpha} x_{t,i}^{\alpha-1}. \quad (6)$$

Note that the derived prices for machines rely on the property that the contribution of an intermediate goods producing firm to the output of the whole sector can be neglected.

### 2.3.2 Intermediate goods sector

We assume that a single intermediate goods producer is able to convert output one for one into machines  $x_{t,i}$  after it has purchased the corresponding blueprint from the



R&D sector. Therefore, its operating profit reads

$$\pi_{t,i} = p_{t,i}x_{t,i} - x_{t,i} \quad (7)$$

and profit maximization leads to the familiar outcome of Dixit and Stiglitz (1977) that firms charge prices for machines that are a markup  $1/\alpha$  over marginal cost. Hence, we have

$$p_{t,i} = p = \frac{1}{\alpha} \quad (8)$$

such that there is symmetry between firms and over time implying that the indices  $i$  and  $t$  can be dropped. Combining equations (6) and (8) yields the optimal output per firm

$$x_{i,t} = x_t = \alpha^{\frac{2}{1-\alpha}} H_{t,Y}. \quad (9)$$

Hence, the aggregate production function can be written as

$$Y_t = H_{t,Y}^{1-\alpha} A_t x_t^\alpha = \alpha^{\frac{2\alpha}{1-\alpha}} H_{t,Y}^{1-\alpha} A_t. \quad (10)$$

Inserting equations (8) and (9) into operating profits (7) leads to

$$\pi_{i,t} = \pi_t = H_{t,Y} \left( \alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}} \right). \quad (11)$$

### 2.3.3 R&D sector

The R&D sector employs scientists with an aggregate human capital level of  $H_{t,A}$  and with productivity  $\delta > 0$  to develop new blueprints. Following Jones (1995), the production function of a representative firm in the research sector is given by

$$A_{t+1} - A_t = \delta A_t^\phi H_{t,A}, \quad (12)$$

where  $\phi \in (0, 1)$  measures the extent of intertemporal knowledge spillovers. A constant long-run growth rate of technology requires either a constant inflow of additional scientists into R&D, or a continuous increase in education of the scientists already employed, or both.

The representative firm in the R&D sector maximizes its profits

$$\pi_{t,A} = p_{t,A} \delta A_t^\phi H_{t,A} - w_{t,A} H_{t,A}, \quad (13)$$

with  $p_{t,A}$  being the price of a blueprint and  $w_{t,A}$  being the wage rate of scientists. This leads to the optimality condition

$$w_{t,A} = p_{t,A} \delta A_t^\phi, \quad (14)$$

where wages of scientists increase in the price of blueprints. The reason is that if an

R&D firm can charge a higher price for the blueprints it develops, it would strive to increase the pace of innovation. This would require the firm to attract workers from the other two labor-using sectors of the economy: final goods production and education. To be able doing so, the R&D firm would have to pay higher wages.

Following Aghion and Howitt (2005), it is assumed that patent protection for a newly discovered blueprint lasts for one generation, that is, for around 25 years. While this assumption keeps the profit motive for R&D intact, it simplifies the simulation of transitional dynamics, and it is also more realistic than the assumption of infinitely lived patents: for example, patent protection in the United States expires after 20 years and in Germany after 25 years latest (cf. The United States Patent and Trademark Office, 2012; The German Patent and Trade Mark Office, 2012). For the model to be properly closed we assume that after a patent has expired, the proceeds of selling it are spent by the government in an unproductive way. For the balanced growth path this simplifying assumption is innocuous. Altogether, an R&D firm will then charge a price for a blueprint that is equal to the operating profit of an intermediate goods producer in period  $t$  (when patent protection is valid) because there is always a potential entrant in the intermediate goods sector willing to outbid a lower price because of free entry. To put it differently, in case that blueprints were less (more) expensive, firms would have an incentive to enter (exit) the market for intermediate goods and prices for blueprints would rise (fall). Consequently, the only stable equilibrium involves zero overall profits and the price for a blueprint has to be equal to the operating profits of the intermediate goods sector

$$p_{t,A} = \pi_t = H_{t,Y} \left( \alpha^{\frac{1+\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}} \right). \quad (15)$$

### 2.3.4 Education sector

The education sector employs teachers financed by the proceeds of income taxes in order to produce human capital (see Gersbach et al., 2009; Prettnner and Werner, 2014, who use a comparable financing scheme for basic research in an endogenous growth model). We assume a balanced governmental budget such that

$$\tau w_t h_t L_t = w_t h_t L_{t,E} \quad \Leftrightarrow \quad \tau w_t h_t l_t N_t = w_t h_t l_t N_{t,E}, \quad (16)$$

where the left-hand side represents governmental revenues, that is, the proceeds of taxing the total wage bill ( $w_t h_t L_t$ ), while the right hand side represents governmental expenditures, that is, the wages paid for teachers in the education sector ( $w_t h_t L_{t,E}$ ). This implies that the number of employed teachers is  $L_{t,E} = \tau L_t$ . The output of the education sector is schooling intensity denoted by  $e_t$

$$e_t = \Omega \frac{l_t N_{t,E}}{n N_t} = \Omega \frac{\tau l_t}{n}, \quad (17)$$

where  $\Omega$  measures the productivity of teachers and  $\tau l_t/n$  denotes the teacher-pupil ratio. This formulation implies that the intensity of schooling increases with the productivity of teachers and with public education investments per child. Recall that  $n$  is the gross population growth rate meaning that schooling intensity is also defined for a stagnating or declining population ( $n \leq 1$ ). Note that, *ceteris paribus*, faster population growth lowers the teacher-pupil ratio and thereby the schooling intensity. Building upon Mincer (1974) and following Hall and Jones (1999), Bils and Klenow (2000), Jones (2002), and Caselli (2005), schooling intensity translates into individual human capital according to  $\exp\left[\tilde{\psi}\left(\Omega\tau l_t/n\right)\right]$ , where  $\tilde{\psi}(\cdot)$  measures the extent to which it does. To put it differently,  $\tilde{\psi}(\cdot)$  represents the semi-elasticity of individual labor productivity with respect to increases in schooling intensity.<sup>4</sup> As regards the particular specification of the human capital accumulation function, Jones (2002) and Bloom and Canning (2005) use a linear relationship that can be justified upon evidence by Psacharopoulos (1994), while Hall and Jones (1999) use a piece-wise linear relationship, differentiating between primary, secondary, and tertiary education with the impact of schooling on productivity diminishing in the level of education. We allow for both a linear and a concave relationship by assuming that human capital evolves according to

$$h_{t+1} = \exp\left[\left(\Omega\frac{\tau l_t}{n}\right)^\eta\right] + \xi h_t \quad (18)$$

with  $\eta \leq 1$  specifying the extent of diminishing returns. Furthermore, we assume that children obtain a part  $\xi \leq 1$  of the human capital of their parents by observing them. Equation (18) implies that the more the government invests in education of each child the higher is the average human capital stock and therefore the productivity of the next generation. This specification is in line with the empirical findings of Card and Krueger (1992) and Rangazas (2002) suggesting that the quality dimension of schooling (education expenditures per child or the average number of pupils per teacher) is an important driver of workforce productivity. Equation (18) also implies that if the government does not invest in education at all, the human capital of the successive generation would be the same as those of their parents or would even decrease over time, depending on  $\xi$ . This can be justified by the notion that, without formal education, people are observing and learning from their parents and peers (cf. Strulik et al., 2013).

## 2.4 Market clearing and the balanced growth path of the economy

Labor market clearing implies that the total amount of available human capital is either employed in the final goods sector, in the education sector, or in the R&D sector

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<sup>4</sup>Note that this formulation assumes that schooling intensity plays a comparable role to “years of schooling” in the corresponding empirical literature. In the context of an overlapping generations model with fixed period length, an increase in years of schooling would indeed be tantamount to an increase in schooling intensity.

such that  $H_t = H_{t,E} + H_{t,A} + H_{t,Y}$ . Furthermore, we know that wages in all sectors have to equalize such that  $w_{t,E} = w_{t,A} = w_{t,Y}$ , otherwise one or more sectors would not be able to attract any workers and the economy ended up in a corner solution. Equalizing expressions (5) and (14) and noting that employment in the education sector is  $\tau L_t$ , yields demand for workers in the final goods sector and in the R&D sector as, respectively,

$$H_{t,Y} = \frac{A_t^{1-\phi}}{\alpha\delta}, \quad (19)$$

$$H_{t,A} = (1 - \tau)H_t - \frac{A_t^{1-\phi}}{\alpha\delta}. \quad (20)$$

Recalling that  $H_t = h_t l_t N_t$  and  $H_{t,E} = h_t l_t N_{t,E}$ , we see that an increase in the population size, in individual human capital or in individual labor supply immediately leads to more employment of aggregate human capital in education and in R&D. The latter fosters technological progress such that  $A_{t+1}$  rises by more than it would have otherwise. This in turn increases human capital employment in the final goods sector in generation  $t + 1$  because technological progress raises the marginal product (and therefore wages) of the workers in this sector. Altogether the development of new blueprints can then be described by

$$A_{t+1} = \delta(1 - \tau)A_t^\phi \left(\frac{1}{\gamma}\right)^{\frac{1}{1-\mu}} h_t N_t - \frac{1 - \alpha}{\alpha} A_t, \quad (21)$$

where the dynamic trade-off that public education investments imply is the following: while increasing taxes pulls labor from the R&D sector into the education sector, it also fosters human capital accumulation and therefore raises the productivity of the next generation's scientists. In the short- to medium run, the negative effect of the decrease in the number of scientists on the development of new blueprints will dominate, whereas in the long run, the positive effect of better education on the productivity of scientists will prevail.

Goods market clearing ensures that aggregate consumption of adults ( $c_t L_t$ ) is equal to total output. Putting all information together, the system fully representing the equilibrium dynamics of our model economy is therefore given by Equation (18), representing the evolution of individual human capital, Equation (21), referring to the evolution of the number of blueprints, and  $N_{t+1} = nN_t$ , denoting the population dynamics. Note that these equations hold during the transition to the balanced growth path *and* along the balanced growth path itself.

### 3 Results and discussion

Making use of the definition of a balanced growth path, that is, that the growth rate of a variable does not change over time, we can derive the long-run rate of technological progress as

$$g_A = [(g_h + 1)(g_L + 1)]^{\frac{1}{1-\phi}} - 1 = n^{\frac{1}{\phi-1}} - 1, \quad (22)$$

where  $g_j$  denotes the growth rate of variable  $j$ . Technological progress is driven by population growth as in Jones (1995). Denoting per capita GDP by  $y_t$  and putting everything together, the growth rates of aggregate GDP and per capita GDP can be written as, respectively,

$$g_Y = n^{\frac{2-\phi}{1-\phi}} - 1, \quad (23)$$

$$g_y = n^{\frac{1}{1-\phi}} - 1 = g_A. \quad (24)$$

Again, both growth rates are driven by population growth.

Now we illustrate the theoretical findings by means of a numerical example. We consider an economy whose per capita GDP grows along a balanced growth path with 2.04%. Furthermore, education expenditures are 5% of GDP, that is,  $\tau = 0.05$ , the population grows at rate 1.08%, and people work on average 1/3 of their available time<sup>5</sup>. These values correspond roughly to the experience of the United States in the second half of the Twentieth Century.

The effects of an increase in public education expenditures on the growth rate of per capita GDP is displayed in Figure 3. We assume that the economy initially moves along the balanced growth path. At generation five, the government decides to increase public expenditures for education as a fraction of GDP by 2 percentage points. Afterwards the reaction of the growth rate to this policy change is traced for 25 generations. The increase in public expenditures at impact draws labor out of the research sector and out of final goods production and reallocates it to the education sector. This slows down growth in the number of blueprints and of per capita GDP in the short run. However, it also increases the supply of skilled labor in the future such that growth in the medium run increases. In the long run, the economy converges to the old balanced growth path, which is solely driven by population growth as in Jones (1995). The interesting question is how the intertemporal tradeoff between the fall in short-run growth and the rise in medium-run growth affects the utility levels of different generations born at different points in time.

To answer this question, we calculate the effects of changes in public education expenditures on utility levels over different time horizons and different changes in public education expenditures ( $\Delta\tau$ ). The result is shown in Figure 4, which displays

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<sup>5</sup>For evidence see, for example, Ramey and Francis (2009).

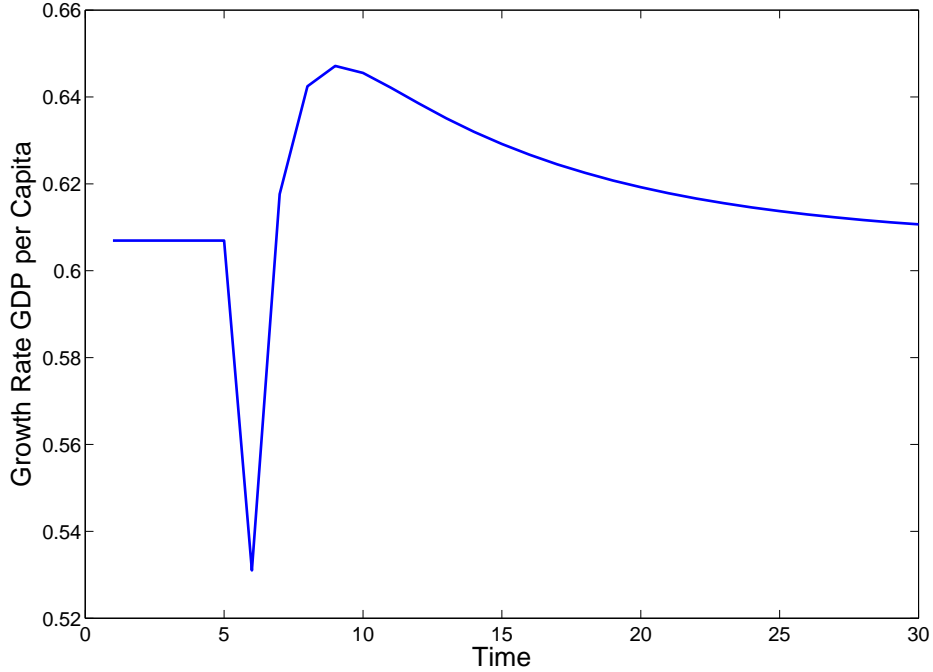


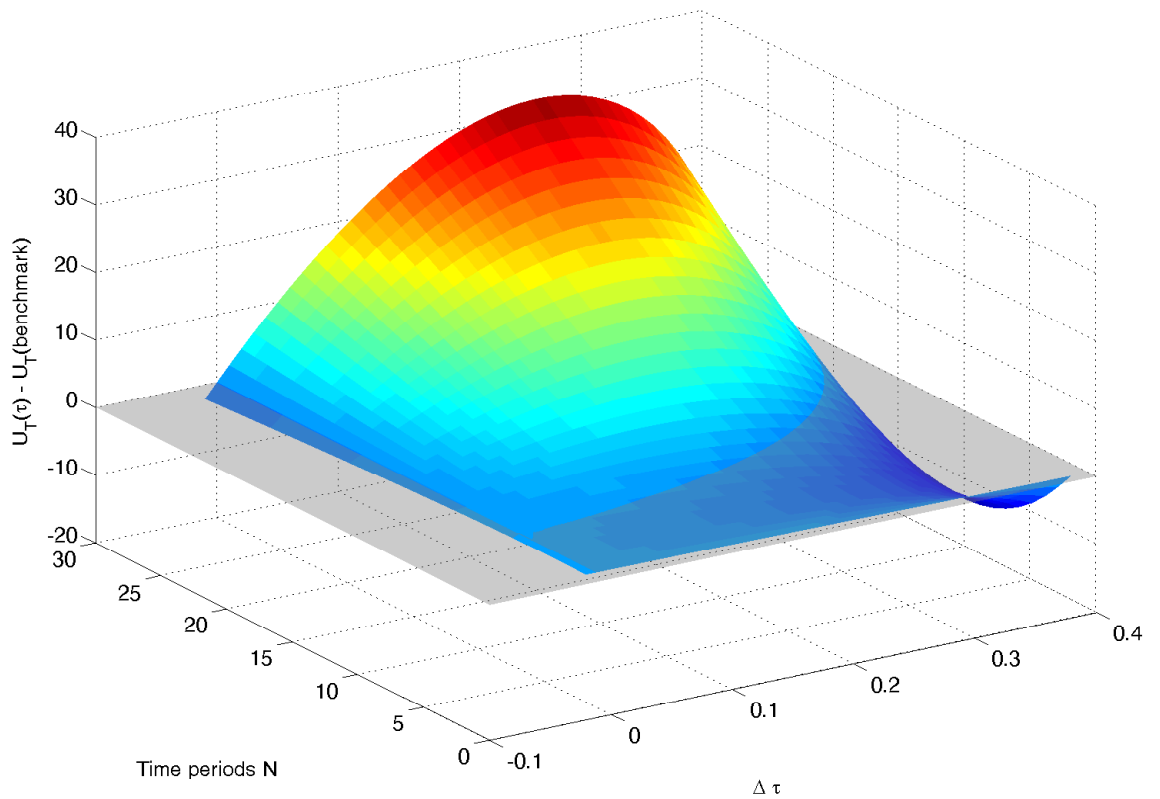
Figure 3: The effect of rising public education expenditures on growth of per capita GDP

the difference in the aggregate utility level between inhabitants of an economy that changes its education policy and inhabitants of an economy without such a change ( $\Delta\tau \equiv 0$ ). Aggregate utility is calculated as the sum of the lifetime utilities up to time horizon  $N$

$$U_N := \sum_{j=1}^N u_j(c_j, l_j). \quad (25)$$

In Figure 4 the time horizon is displayed on the  $x$ -axis. Initially (at  $N = 0$ ), the economy moves along a balanced growth path and then changes its education policy ( $\Delta\tau$ ). The extent of this change is displayed on the  $y$ -axis. The associated change of aggregate utility in comparison to the benchmark case of an unchanged policy is displayed on the  $z$ -axis. The figure reveals that an increase in  $\tau$  reduces welfare for the cohorts that are already alive and for the cohorts born immediately after the policy change that suffer because of the short-run slowdown but do not yet gain enough from the rise in medium run growth. However, the policy change raises welfare over longer time horizons because the medium-run increase in economic growth yields higher income levels for cohorts born sufficiently long after the change in education policy. These cohorts experience income gains to the extent that they are even over-compensated for the higher level of taxes. The larger the increase in  $\tau$ , the more pronounced is

the initial decrease of welfare and the longer it takes until welfare gains materialize. The reaction of long-run welfare levels (summed over 30 generations) is positive for small increases in education expenditures, but turns negative after a certain level of education expenditures has been surpassed. Consequently, there exists an interior welfare-maximizing public education expenditure  $\tau$  for each time horizon. After 30 generations, the maximum level of welfare would be reached by increasing  $\tau$  to around 0.31, which corresponds to 31% of GDP, a level that exceeds the observed education expenditures in OECD countries by a factor of 5.



Note: The figure displays the difference in aggregate utility levels between inhabitants of an economy that changes its public education policies and inhabitants of an economy without such a change. The time horizon is displayed on the  $x$ -axis, while the change in  $\tau$  is displayed on the  $y$ -axis. In case that the difference is positive, the inhabitants of the economy with the corresponding change in the research policy are better off in the relevant time period. The shaded plane corresponds to case where inhabitants of both economies are equally well off, that is, the difference equals zero.

Figure 4: Changes in lifetime utility for changes in public education expenditures  $\tau$  for different time horizons ( $x$ -axis) and different changes in  $\tau$  ( $y$ -axis)

## 4 Conclusions

We developed an R&D-based growth model with endogenous labor supply and a public education sector that is financed by wage taxes. We find that increasing public expenditures for education leads to a shift of employment from R&D and final goods production into education and thereby leads to a reduction of growth in the short run. In the medium run, however, the rise in education expenditures increases the human capital level and thereby the productivity of workers and scientists to the extent that technological progress and economic growth speed up. Naturally, these effects imply an intertemporal tradeoff between the short run costs of education and its long-run benefits. We show, by means of a numerical illustration, that cohorts alive or born immediately after an increase in education expenditures stand to lose from such a policy, whereas future cohorts stand to benefit. Furthermore, we show that there is an interior expenditure level on education that maximizes the welfare of different cohorts. This level exceeds the level that we observe in industrial countries by a substantial amount.

Altogether our analysis shows that educational investments are crucial for long-run economic prosperity and explains the cross-sectional positive association between education and per capita GDP that empirical studies find. In addition, our analysis has the potential to explain why governments are often reluctant to raise education expenditure levels: they are mainly concerned with the voters who are currently alive than with the welfare levels of future cohorts. Promising avenues for further research are to endogenize population growth and private education investments along the lines of Strulik et al. (2013). Furthermore, an interaction between public education and basic research as supplied by universities and public research facilities along the lines of Prettner and Werner (2014) could prove useful to better understand the feedback effects between education and R&D.

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