Should US increase subsidies to R&D? Lessons from a Schumpeterian Growth Theory

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Abstract

In this article we build a complete endogenous growth model with R&D, physical capital and human capital and use it to evaluate quantitatively the effect on growth and welfare of implementing different deficit-neutral policies. The welfare effects of different policies are calculated by taking into account the transitional dynamics of the economy after the introduction of the policies. Our main findings carry out important policy implications; mainly, subsidies to research are the most welfare-increasing among the deficit-neutral policies, and the optimal structure of subsidies entails increasing substantially the subsidy to R&D, keeping a zero subsidy to production, and reducing the subsidy to education so as to keep the intertemporal fiscal unbalance unchanged. A detailed sensitivity analysis shows the robustness of these results.

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1. Introduction

The emergence of Schumpeterian endogenous growth theory has brought an apparently clear policy advice: with research and development activities on the center of the explanation for economic growth, R&D subsidies would be a crucial instrument to increase growth and welfare. The positive impact on welfare derives from the existence of externalities due to R&D activities. Most of this literature had evaluated the differences between the market outcomes and the social optimum considering both solutions as stationary equilibria, ignoring transitional dynamics that would arise in the path to an optimal solution and ignoring realistic fiscal systems at the market economy. Examples are in Jones and Williams (2000), Alvarez-Pelaez and Groth (2005), and Strulik (2007). We depart from this literature concentrating on the effects of certain policies in

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the market economy, considering a realistic fiscal structure as the departure point of our analysis, and taking into account the transitional dynamics that must result from the implementation of a given policy.

An important issue to be taken into account is the adherence to reality of externalities linked with R&D or other production factors, e.g. whether R&D subsidies have a microeconomic effect. Klette et al. (2000) reviews the microeconomic evidence of such externalities and cast doubts about the econometric methods used so far to evaluate the empirical impact of R&D policies. There is an increasing and recent literature that deals with Klette et al. (2000) criticisms. Lee (2011) concludes that at least for some firm types, there is evidence of a positive effect of R&D subsidies. Also, Wolff and Reinthaler (2008) showed that R&D subsidies are effective in increasing R&D private expenditures. Another important externality is the one affecting human capital, from which two types can be identified. One is linked with the effect of average human capital on income and thus on returns to education, another is linked with the peer-effects in the educational system, i.e., students within better classes and with more educated parents achieve higher results. Concerning the first type of learning externalities, Acemoglu and Angrist (2000) and Ciccone and Peri (2006) showed that empirical evidence does not support its existence. On the contrary, the peer-effects externality seems to be empirically valid, as Calvó-Armengol et al. (2009), Lefgren (2004) and Rangvid (2003) showed.

Despite the apparent clear-cut conclusion that R&D subsidies may enhance economic growth, there are few neo-Schumpeterian contributions that have been specifically concerned about the impact of different levels of R&D subsidization and other government policies in the economic growth performance and welfare of countries. We will concentrate on the effect policies have on the market economy, since we believe this is of major interest to macroeconomic policy makers. Some theoretical contributions deal with the effects of subsidies on economic growth (Zhang (1993), Davidson and Segerstrom (1998), Segerstrom (2000)). Those papers establish the conditions according to which R&D subsidies increase or not economic growth, depending on the features of the sector to which subsidies are target to. Also, Giordani and Zamparelli (2008) present a model in which it is possible to raise the long-run growth rate and the social welfare of the economy through a costless tax/subsidy scheme reallocating resources towards the relatively more promising industries. These references are all theoretical and did not include any quantitative approach to the policies implications that the models carry out.

The most recent inclusion of human capital in the neo-Schumpeterian growth theory (originally due to Arnold (1998)) reverted some of the policy implications of the first generation of Schumpeterian growth models, stated above. In this sense, models with R&D and human capital accumulation have the same implication of the previous non-scale endogenous growth model of Jones (1995), according to which R&D policies became non-effective in terms of steady-state growth effects and only human capital subsidies may increase growth.[3] However, despite stronger growth and welfare effects from human capital policies (as in Sequeira (2008)), effects on welfare from R&D subsidies are generally positive in these type of models (see e.g. Buttner (2006)), due to the fact that externalities associated with R&D are usually present and are strong.[4]

Our main distinctive features are the following. First, we implement our analysis studying not only steady-state features but also transitional dynamics, which we will conclude as essential to understand all the effects of research policy. Second, we depart from a realistically calibrated model, considering actual values for the fiscal system. Third, to study the robustness of our results we perform a detailed sensitivity analysis, which is not only constrained as usual to change some parameter values but also includes changing several important characteristics of the model. Finally, we do not compare the influence on welfare and growth of a given percentage change in each subsidy or tax rate, as usual. The reason is that the base to which this change applies may be quite different, so the same percentage change in a tax or subsidy rate may have quite different effects on the government budget depending on the tax or subsidy chosen. Hence, as a normalization procedure, for each policy instrument we compute the change in the tax or subsidy rate needed to compensate a given decrease in the government lump-sum expenditures (say, a 0.5% of GDP) so that the government budget remains balanced. Thus, we focus on deficit-equivalent changes.[5] We also provide policy advice concerning the deficit-neutral optimal subsidy scheme for the given tax structure; i.e., we compute the subsidy rates that maximize the agent's utility while keeping the intertemporal government budget balanced. As growth and deficits are in the days' agenda, we think that focusing in deficit-neutral policies gives a contribution to the discussion of the most useful policies to promote growth and welfare without compromising budget deficits. These would allow governments to implement an optimal subsidies policy without influencing deficits. All of the results are provided in such a way that they should be understood by a wide range of scientists from different fields and politicians or policy-makers.

In the second Section, we characterize the model and its market equilibrium. In the third Section, we calibrate the model with data for the main macroeconomic variables in the US. In the fourth Section, we evaluate numerically the impact of implementing several policies. In the fifth Section, we perform a detailed sensitivity analysis of the results. Finally, in the sixth Section, we present our conclusions.

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[3] For a survey on the literature of scale and non-scale endogenous growth model see Jones (1999).

[4] Sequeira (2008) found education subsidies to be more welfare-enhancing than R&D subsidies. However, his result is driven by the fact the the 'ideas' technology depends only on human capital devoted to innovation, so that the model is absent from duplication externalities and R&D spillovers.

[5] Sequeira (2008), Grossmann et al. (2010b) and Grossmann et al. (2010a) are examples in which the effects of policies are not deficit-neutral.

2. The model

We consider a closed economy inhabited by a constant population of identical representative agents. For simplicity, population is normalized to one, so that we may read all variables as *per capita* values. This model combines features studied in Gómez (2011) and Gómez and Sequeira (forthcoming), but additionally introduces a complete fiscal system.

2.1. Production

The final good, Y, which we take as numeraire, is produced with a Cobb-Douglas technology:

$$Y = D^{\beta} H_Y^{1-\beta} n^{\eta}, \qquad 0 < \beta < 1, \quad \eta > 0, \tag{1}$$

where H_Y is human capital allocated to the final good production, D is an index of intermediate capital goods, and n denotes the number of available varieties. Thus, the parameter η captures the specialization gains in the final good production, β captures the share of physical capital in the final good production and $1-\beta$ is the share of human capital in the final good production. Following Alvarez-Pelaez and Groth (2005) and Gómez and Sequeira (forthcoming), the composite index D is a CES aggregate of quantities of specialized capital goods:

$$D = n \left[\frac{1}{n} \int_0^n x_i^{\alpha} di \right]^{1/\alpha}, \tag{2}$$

where x_i is the intermediate capital good i, and α determines the elasticity of substitution between varieties. This functional form for differentiated goods is more general that the one used earlier (e.g. by Jones and Williams (2000)) as it allows to disentangle the market power from the gains from specialization. Intermediate goods are produced in a differentiated goods sector with physical capital, K_x:

$$x_i = K_{x_i}. \tag{3}$$

Moreover, in each sector i there is a competitive fringe which can produce a perfect substitute for good i (without violating patent rights) but is less productive in manufacturing the good: one unit of output require κ units of capital: $1 < \kappa < 1/\alpha$. Production of a new intermediate good requires the invention of a new blueprint. The production of new ideas is determined by human capital employed in R&D labs and by the stock of disembodied knowledge n according to the Jones and Williams (2000) technology:

$$(1+\zeta)\dot{n} = \bar{\epsilon} H_n = \epsilon \bar{H}_n^{\gamma-1} n^{\phi} H_n, \qquad \epsilon > 0, \quad 0 < \gamma \leq 1, \quad 0 \leq \phi, \quad \zeta > 0, \tag{4}$$

where H_n represents the allocation of human capital to R&D sector. The parameter ϕ measures the (positive) spillovers in R&D. The term $\bar{H}_n$ represents average human capital devoted to innovation, so this specification incorporates the potential of (negative) externalities associated to the duplication of research effort —when

$\gamma < 1$. The parameter ζ measures the creative destruction effect, e.g., the proportion of firms driven out of business when new technologies are developed.

Human capital is accumulated according to

$$\dot{H} = \xi (H_H)^{\varepsilon} (\bar{H}_H)^{1-\varepsilon} - \delta_H H, \qquad \xi > 0, \quad 0 < \varepsilon < 1 \tag{5}$$

where H_H represents the allocation of human capital to knowledge accumulation (e.g. to schools), $\bar{H}_H$ represents peer-effects externality as modelled in Gómez (2011) and ε represents the relative strengh of individual effort when compared to peer-effects in human capital accumulation.

Human capital H is supplied inelastically. Therefore, full employment requires that

$$H = H_H + H_n + H_Y = (u_H + u_n + u_Y)H, \tag{6}$$

where u_H, u_n and u_Y are the shares of human capital allocated to human capital accumulation, R&D activities and the final good production, respectively.

2.2. Individual agents

The representative agent earns wages, w, per unit of employed human capital, $H - H_H$. He also earns returns, r, per unit of aggregate wealth, A, which leads to a budget constraint

$$\dot{A} = (1-\tau_r)rA + (1-\tau_w)w(1-u_H)H + s_H w u_H H - (1+\tau_C)C + T \tag{7}$$

where τ_r is a tax on income from asset holding, τ_w is the tax on labor income, τ_C is a tax on consumption, s_H is a subsidy rate to education costs —which, in this model, are foregone earnings—, and T represents lump-sum transfers (or taxes, if it is negative) to households.

Subject to this constraint and the knowledge formation technology (5), the agent maximizes intertemporal utility

$$U = \int_0^{\infty} \frac{C^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt, \tag{8}$$

where $\rho > 0$ denotes the time preference rate, and $1/\theta > 0$ is the elasticity of intertemporal substitution. Agents take the aggregate rate of innovation as exogenous.

Let g_x denote x's growth rate, $g_x = \dot{x}/x$. The first order conditions for an interior solution yield[6]

$$g_C = \frac{1}{\theta}\left[(1-\tau_r)r - \rho\right], \tag{9}$$

$$g_w = (1-\tau_r)r - \frac{1-\tau_w}{1-\tau_w - s_H}\varepsilon\xi + \delta_H. \tag{10}$$

[6]We will consider time-invariant fiscal policies, so that $\dot{\tau}_w = \dot{\tau}_c = \dot{\tau}_r = \dot{\tau}_C = \dot{s}_K = \dot{s}_R = \dot{s}_H = 0$.

The first of these equations is the standard Ramsey rule. The second indicates that the growth rate of wages must be sufficiently low compared to the net interest rate in order to ensure investment in human capital.

2.3. Firms and Markets

The markets for the final good and its inputs are perfectly competitive. However there is a tax on corporate profits τ_c that affects the final and the intermediate goods sectors in the economy. This implies that

$$w = (1-\beta)Y/H_Y, \tag{11}$$

$$p_D = \beta Y/D, \tag{12}$$

where p_D represents the price for the index of intermediate capital goods.

The demand for each intermediate good results from the maximization of profits in the final good sector. Each firm in the intermediate goods sector owns an infinitely-lived patent for selling its variety x_i. These firms may deduct at least part of their capital costs (via depreciation allowances or an investment tax credit for instance), at rate $1+s_d$. If $s_d = 0$ capital costs are fully deductible from sales revenue; if $s_d \lesseqgtr 0$, they are less than (or more than) fully deductible. Producers act under monopolistic competition and maximize operating profits,

$$\begin{aligned}\bar{\pi}_i &= p_i x_i - Rx_i - \tau_c\left[p_i x_i - (1+s_d)Rx_i\right] \\ &= (1-\tau_c)\left[p_i - (1-s_K)R\right]x_i = (1-\tau_c)\pi,\end{aligned} \tag{13}$$

where p_i denotes the price of intermediate good i, $R = r + \delta_K$ is the unit cost of x_i and $s_K = \frac{\tau_c s_d}{1-\tau_c}$. Profit maximization in this sector implies that each firm charges a price of

$$p_i = p = \kappa(1-s_K)R. \tag{14}$$

To see this, note that a firm which owns a blueprint would choose a markup factor equal to $1/\alpha$ if it were not facing a competitive fringe. Moreover the competitive fringe would make losses at a price lower than p_i. As $\kappa < 1/\alpha$ each firm i sets the maximal price that allows it to maintain as monopolist over its own variety. With identical technologies and symmetric demand, the quantity supplied is the same for all goods, $x_i = x$. Hence, Eq. (2) can be written as

$$D = nx = K, \tag{15}$$

using the fact that intermediate goods are produced with capital goods. Therefore, combining (1) and (15), the production function can be re-written as[7]

$$Y = K^{\beta} H_Y^{1-\beta} n^{\eta}. \tag{16}$$

From $p_D D = pxn$, together with equations (12) and (14), we obtain that

$$xn = K = \frac{\beta Y}{\kappa(1 - s_K)R}. \tag{17}$$

After insertion of (14) and (17) into (13), before-tax profits can be rewritten as

$$\pi = (1 - s_K)(\kappa - 1)RK/n. \tag{18}$$

The corporate profit tax τ_c also incides over these profits.

The worth of an innovation, υ, is the present discounted (after-tax) value of the stream of monopoly profits. In equilibrium, the no-arbitrage conditions in the capital market entails that dividends paid out by an intermediate good firm, plus capital gains, must equal the after-tax interest rate and the probability that an existing innovator is driven out of business:

$$\frac{\dot{\upsilon}}{\upsilon} + (1 - \tau_c)\frac{\pi}{\upsilon} = (1 - \tau_r)r + \zeta\frac{\dot{n}}{n}, \tag{19}$$

and this condition can be rewritten as

$$\dot{\upsilon}n + (1 - \tau_c)\pi n - \zeta\dot{n}\upsilon = (1 - \tau_r)rn\upsilon. \tag{20}$$

Physical capital, K, and claims to innovative firms, $n\upsilon$, are the assets in the economy, such that $A = K + n\upsilon$. The agent owns them, and by no-arbitrage, he should be equally paid from 1 additional unit in each of both assets, so that the after-tax income would be $(1 - \tau_r)rA = (1 - \tau_r)r(K + n\upsilon)$. The agent is ultimately the owner of final-goods firms, intermediate-good firms and R&D firms. He rents its physical capital K and the fraction of human capital not devoted to education H_H and receives an after-tax income of $(1 - \tau_r)rK$ and $(1 - \tau_w)wH_H$. Furthermore, he receives the after-tax profits of firms. There are zero profits in the final-goods sector, R&D sector and in the competitive fringe, so he (only) receives dividends from the intermediate-goods firm, $(1 - \tau_c)\pi n$. Moreover, as an owner of the claims of innovative firms he receives the capital gains from those firms less the worthless innovations that were driven out of business because they were replaced by new ones (the lost is the probability of replacement of an innovation times

[7]Hence, in a way similar to that used in Alvarez-Pelaez and Groth (2005), this specification allows for disentangling the gains from specialization, η, from the markup, $1/\alpha$.

the number of innovations times its value). This is the left-hand side of the former equation. The right-hand side says that the no-arbitrage condition entails that this is equal to $(1-\tau_r)rn\upsilon$.

Finally, in an equilibrium with innovation, considering the possibility of having subsidies to R&D s_R, free-entry into R&D requires

$$(1-s_R)wH_n = \upsilon\bar{\epsilon}H_n = \upsilon\epsilon\bar{H}_n^{\gamma-1}n^{\phi}H_n. \tag{21}$$

2.4. Government

The government may subsidize (or tax) intermediate-goods production, R&D costs and foregone earnings in human capital accumulation, and provide lump-sum transfers (or impose lump-sum taxes). The fiscal policy must satisfy the requirement that the present discounted value of government expenditure equals the present discounted value of government revenue. We shall assume that government claims a fraction, s, of GDP for lump-sum transfers to households representing welfare programs. Adjustment in lump-sum transfers to households balance the government budget constraint each period, so that

$$T = sY - b,$$

and the governments budget is

$$b + \tau_r rK + \tau_w w(H - H_H) + \tau_c \pi n + \tau_C C = s_H w H_H + s_K R n x + s_R w H_n + sY. \tag{22}$$

Thus, b represents the amount of lump-sum taxes (or transfers) needed to balance the current budget and, therefore, expresses the primary budget deficit. For simplicity, we do not explicitly consider financing by debt issue since, because of Ricardian Equivalence, the lump-sum tax is equivalent to debt.

2.5. Equilibrium

Appendix A shows that using (4), (7), (11), (12), (13), (15), (20), (22) and after some simplification we obtain the system that governs the dynamics of the economy in terms of the variables —which are constant in the steady state—, $\varphi = Y/K$ (output to capital ratio), $\chi = C/K$ (consumption to capital ratio), u_Y (share of human capital allocated to the final good), $\psi = H^{\gamma}/n^{1-\phi}$ (adjusted human capital to technologies ratio) and g_n (the technological growth rate) as follows:

$$g_{\varphi} = \frac{1-\beta}{\beta}\left[\frac{1-\tau_w}{1-\tau_w-s_H}\varepsilon\xi - (1-\tau_r)r - \delta_H\right] + \frac{\eta}{\beta}g_n, \tag{23}$$

$$g_{\chi} = \frac{1}{\theta}\left[(1-\tau_r)r - \rho\right] - \varphi + \chi + \delta_K, \tag{24}$$

$$\begin{aligned} g_{u_Y} = \frac{1}{\beta}\Bigg\{ &- (1-\tau_r)r + \eta g_n - \beta\xi\left[1 - u_Y - (1+\zeta)^{1/\gamma}\delta^{-1/\gamma}\psi^{-1/\gamma}g_n^{1/\gamma}\right] \\ &+ \beta(\varphi - \chi - \delta_K) + \frac{1-\tau_w}{1-\tau_w-s_H}\varepsilon\xi - (1-\beta)\delta_H\Bigg\}, \end{aligned} \tag{25}$$

$$g_\psi = \gamma\xi\left[1 - u_Y - (1+\zeta)^{1/\gamma}\delta^{-1/\gamma}\psi^{-1/\gamma}g_n^{1/\gamma}\right] - \gamma\delta_H - (1-\phi)\,g_n, \tag{26}$$

$$\begin{aligned} g_{g_n} =& \frac{\gamma}{1-\gamma}\left[\frac{1-\tau_w}{1-\tau_w-s_H}\varepsilon\xi - \delta_H \right. \\ & \left. - \frac{(1-\tau_c)\beta(\kappa-1)\delta^{1/\gamma}\psi^{1/\gamma}u_Y(1+\zeta)^{1-1/\gamma}g_n^{1-1/\gamma}}{(1-s_R)(1-\beta)\kappa} + \zeta g_n - \frac{1-\phi-\gamma}{\gamma}g_n\right], \end{aligned} \tag{27}$$

where $r = \beta\varphi/[(1-s_K)\kappa] - \delta_K$.

These equations show that the dynamics of the economy is determined by the productivity and preferences parameters and also by the several fiscal instruments that have been considered in the model. There are interesting aspects that should be mentioned on the influence of different fiscal instruments on the dynamics of the economy. The first is that the subsidy to intermediate goods s_K is only influencing the economy dynamics through r, with indirect effects in the dynamics of φ, χ and u_Y. On the contrary the subsidy to R&D, s_R, has a clear positive effect in the growth rate of R&D. It can be noted also that τ_w has a negative effect on the dynamics of φ, u_Y and g_n but this happens only when the subsidy to human capital is positive ($s_H > 0$). Otherwise, if $s_H = 0$, a tax on wages has no effect on the dynamics of the economy and, as the consumption tax, acts like a lump-sum tax. Finally, the subsidy to education has a positive effect on the dynamics of φ, u_Y and g_n.

The following long-run equilibrium is found making $g_\varphi = g_\chi = g_{u_Y} = g_\psi = g_{g_n} = 0$ and solving for $(\varphi, \chi, u_Y, \psi, g_n)$:[8]

$$\hat{\varphi} = \frac{\kappa(1-s_K)}{(1-\tau_r)\beta}\left\{\frac{1}{(1+M)\theta-1}\left[(1+M)\theta\left(\frac{1-\tau_w}{1-\tau_w-s_H}\varepsilon\xi - \delta_H\right) - \rho\right] + (1-\tau_r)\delta_K\right\}, \tag{28}$$

$$\hat{g}_n = \frac{\gamma M}{(1-\phi)[(1+M)\theta-1]}\left(\frac{1-\tau_w}{1-\tau_w-s_H}\varepsilon\xi - \delta_H - \rho\right), \tag{29}$$

$$\hat{\chi} = \left[1 - \frac{(1-\tau_r)\beta}{\kappa(1-s_K)\theta}\right]\hat{\varphi} - \left(1 - \frac{1-\tau_r}{\theta}\right)\delta_K + \frac{\rho}{\theta}, \tag{30}$$

$$\hat{g}_H = (1-\phi)\hat{g}_n/\gamma, \tag{31}$$

$$\hat{u}_n = \frac{\frac{(1-\tau_c)(\kappa-1)(1+\zeta)\beta}{(1-s_R)(1-\beta)\kappa}\hat{g}_n}{\frac{1-\tau_w}{1-\tau_w-s_H}\varepsilon\xi - \delta_H - \hat{g}_H + (1+\zeta)\hat{g}_n + \frac{(1-\tau_c)(\kappa-1)(1+\zeta)\beta}{(1-s_R)(1-\beta)\kappa}\hat{g}_n}\left(1 - \frac{\hat{g}_H + \delta_H}{\xi}\right), \tag{32}$$

$$\hat{u}_Y = 1 - \hat{u}_n - \frac{\hat{g}_H + \delta_H}{\xi}, \tag{33}$$

$$\hat{\psi} = (1+\zeta)\hat{g}_n/\left(\delta\hat{u}_n^\gamma\right), \tag{34}$$

$$\hat{g}_Y = \hat{g}_C = \hat{g}_K = (1+1/M)\hat{g}_H, \tag{35}$$

[8] If $\tau_r = \tau_c = \tau_g = \tau_w = \tau_C = s_H = s_x = s_R = 0$, and $\varepsilon = 1$, we would obtain the system that describes the dynamics of the market economy in the absence of government intervention analyzed by Gómez and Sequeira (forthcoming). We proceeded in a similar manner as there to achieve the steady state equations.

where $M = (1-\beta)(1-\phi)/(\eta\gamma)$ and $\hat{r} = \beta\hat{\varphi}/[(1-s_K)\kappa] - \delta_K$. Several results can be derived from the steady-state equations (28)–(35). We will concentrate on the impact of fiscal policy, which is the aim of this paper. The subsidy to the intermediate capital goods (s_K) will decrease $\hat{\varphi}$ and $\hat{\chi}$ through the rise of physical capital in the economy. The interest income tax (τ_r) will have the opposite effect on those variables. The wage income tax (τ_w) has a positive effect on $\hat{\varphi}$ and $\hat{g}_n$ which is dependent on the subsidy to education (s_H) and the effect would not exist if $s_H = 0$. As expected the subsidy to R&D (s_R) rises the allocation of human capital to the R&D sector ($\hat{u}_n$) and the corporate income tax (τ_c) has an uncertain effect on it. Also, the subsidy to education s_H contributes to rise $\hat{\varphi}$ and $\hat{g}_n$ and thus economic growth. Naturally it decreases the allocation of human capital to the R&D sector ($\hat{u}_n$) and increases its allocation to the human capital accumulation sector.

3. Calibration of the model

For the calibration exercise we shall view the USA economy as if it were a closed economy on a balanced growth path. We mostly use values from OECD and the Penn World Table (PWT) for the USA economy. As our objective is to provide valuable policy recommendations we use the most recent data to calibrate our model. Table 1 shows the synthesis of our calibrated values. It is divided into different sets of parameters. The first two sets are the fiscal instruments in the economy, the most important sets of parameters given the novelty of our work in evaluating the impact of different fiscal measures on an endogenous growth model. For the tax system, we set values according to the OECD tax database (2010) and we picked values for USA. The corporate and individual capital income tax rates are equal, thus we set $\tau_r = \tau_c$. The value for those taxes is 0.392 for the USA.[9] Using the same source, the labor income tax, τ_w, is set equal to the total tax wedge (wage income tax rate including all social security contributions and from all levels of governments combined) which applies to average wage income. Its value is 34.4% in the USA. As the USA has not a VAT tax on consumption, we consider $\tau_C = 0$.

We may note that the value for the subsidy to physical capital costs (s_K) is difficult to calculate as there are different forms of capital costs deductions. The investment tax credit of 10% has been abolished in the USA in 1986 although similar systems remain nowadays in countries such as United Kingdom and Australia. Thus we set $s_K = 0$. The subsidy to R&D (s_R) comes from the OECD statistics on 'OECD Science, Technology and Industry: Scoreboard 2007' (the variable is the rate of tax subsidies for USD of R&D, for large firms), which is 0.066 for the USA. Finally, we need to calibrate the education subsidy rate (s_H), which

[9] We considered overall statutory tax rates on dividend income for τ_r and the basic combined central and sub-central (statutory) corporate income tax rate given by the adjusted central government rate plus the sub-central rate for τ_c. Although these values are quite stable on time, we select values from 2010.

is most difficult, in particular due to a significant part of private expenditure in education is unobservable (opportunity cost of home education, private teachers or tutors). We follow Choi (forthcoming) in obtaining a value for s_H. From (7) we see that the subsidy to education is $s_H w u_H H$, which by (11) is equal to $s_H(1-\beta)YH_H/H_Y$ which converts into $s_H(1-\beta)u_H Y/(1-u_H-u_n)$. As Choi (forthcoming) concluded, using data from 1960 to 2005, the subsidy to education is 4.7% of GDP. Thus, $s_H(1-\beta)u_H/u_Y = 0.047(1-\tau_w)$.

We determine several parameter values so as to match real data for the US. The per capita output growth rate given by PWT 7.0 between 1980 and 2009 yields a per capita growth rate of $g_Y = 1.66\%$. From OECD countries database, we average the USA savings rate from 1991 and 2009, from which we obtain 15.1%, so that $sav = (g_K + \delta_K)K/Y$. We consider the growth rate of output in the education sector to be equivalent to human capital growth rate, $g_H = 0.66\%$, as calculated by Jorgenson and Fraumeni (1993, Table 8) for the USA (1979-1986). For the capital-output ratio, we take averages over the period 2003-2010 calculated from data of the US Bureau of Economic Analysis. The capital stock is taken to be total fixed assets (private and public structures, equipment and software), and imply a value for the ratio near 3. Thus, we set $K/Y = 3$. Following Grinols and Lin (2006, 2011), we set the patent life in twenty years, $F = 20$, so that $\zeta g_n = 1/F = 1/20$. This is the patent life established in the USPTO (United States Patent and Trademark Office) 'Manual of Patent Examining Procedure (MPEP), June 2010 (Latest Revision)'.[10] An important data to match when we are going to evaluate the effect of different R&D policies is time devoted to this activity. Using data from the US Bureau of Labor Statistics and from the 2008 Business R&D and Innovation Survey,[11] the share of domestic R&D employment to total employment is 1.068%, which is our target value for $u_n/(u_Y + u_n)$.

Due to the existence of scarce empirical sources for some parameters, we set values that were used in previous literature as follows. The value $\beta = 0.33$, for the capital share in income is standard in the literature. We set the gains of specification parameter as $\eta = 0.234$ following Coe and Helpman (1995), and $\delta_H = 0.035$ following Choi (forthcoming). This value is also consistent with empirical evidence analyzed by Heckman (1976). Parameter δ can be set arbitrarily, thus we set it with the usual value of $\delta = 0.1$ and we also set a typical value for $\rho = 0.02$.[12] We choose as the benchmark calibration for the duplication parameters, λ, a value of 0.5, as is usual in previous contributions (e.g., Jones and Williams (2000)). This value is in line with the estimations of Pessoa (2005) for this parameter for the most developed OECD countries (0.556 and 0.596 in regressions with fixed-effects) and in the median of the interval of Porter and Stern (2000), that

[10] It is available at http://www.uspto.gov/web/offices/pac/mpep/documents/2700_2701.htm.

[11] It is available at http://www.nsf.gov/statistics/infbrief/nsf10326/.

[12] These values are typical in calibration exercises of endogenous growth models as in Jones and Williams (2000), Iacopetta (2011), Gómez and Sequeira (forthcoming) or Grossmann et al. (2010b).

Table 1: Calibration results in the benchmark model

Fiscal policy parameters							
τ_r	τ_c	τ_w	τ_C	s_R	s_H	s_K	
0.392	0.392	0.344	0	0.066	0.0802	0	
Data to match							
$\widehat{K/Y}$	$\hat{g}_Y$	$\widehat{sav}$	F	$\hat{g}_H$	$\hat{u}_n/(\hat{u}_Y+\hat{u}_n)$		
3	0.0166	0.151	20	0.0066	0.01068		
Literature-based Parameters							
η	δ_H	λ	δ	ρ	β	ε	
0.234	0.035	0.5	0.1	0.02	0.33	0.52	
Data-based Parameters							
θ	ϕ	ξ	δ_K	ζ	κ		
1.4064	0.8847	0.1137	0.0337	1.7463	1.0473		
Results of the calibration							
$\hat{u}_Y$	$\hat{u}_H$	$\hat{u}_n$	$\hat{g}_n$	$\hat{\chi}$	$\hat{\psi}$	$\hat{r}$	s
0.6360	0.3572	0.0069	0.0286	0.283	9.490	0.0713	0.2920

presented values for λ between 0.2 and 0.85. For the parameter that governs the learning externalities, we consider $1-\varepsilon = 0.48$, as predicted by the estimations presented in Choi (forthcoming, p. 28) using data from 1963 to 2005. In a non completely comparable setup concerning human capital accumulation technology, Calvó-Armengol et al. (2009) estimate a value of 0.56 for the peer effect (in this case individual effects are not reported) in the USA. However, empirical estimates by Rangvid (2003) for learning externalities seem to attribute similar coefficients to individual effort and to peer-effects (in Denmark) and Lefgren (2004) reached small peer-effects for Chicago schools. Facing still contradictory evidence we decided to follow Choi (forthcoming) estimations for a law of motion similar to (5).

These values allowed us to calculate all the other parameters. We use the system (23)–(27) making the steady-state assumption ($g_\varphi = g_\chi = g_{u_Y} = g_\psi = g_{g_n} = 0$), and the values for the saving rate, the output growth rate, the share of the subsidy to education in GDP, the capital-output ratio, the human capital growth rate, the patent life, and the share of domestic R&D employment to total employment to determine the remaining parameters in the model (θ, δ_K, ξ, ϕ, ζ, κ and s_H).

Steady-state values resulting from this calibration, besides the calibrated variables, are also displayed in Table 1. It is interesting to note that even in non-calibrated macroeconomic variables, the model fits well the available data. In the model, given η, the growth rate of TFP is 0.0067 ($= \eta g_n$), while in the data it is

0.008 between 2007 and 2010 and about 0.005 between 1987 and 1995 (Bureau of Labor Statistics).[13] The estimated value for the markup, $\kappa = 1.047$, almost replicates the estimate of 1.049 reported by Norrbin (1993, Table 3). The (pre-tax) interest rate of 7.13% is consistent with values presented in Mehra and Prescott (1988). The value obtained for the elasticity of intertemporal substitution is also in line with the empirical estimates (e.g., Alan et al. (2009)). Our results entail that approximately one third of non-leisure time is devoted to human capital accumulation, and the other two thirds to work, which broadly accords with an average of 14 years spent on education and 35 years in work (e.g., Angelopoulos et al. (2008)). Even though we have performed a though calibration exercise forcing parameters to fulfill a high number of macroeconomic variables, we also reach quite reasonable values for the 'free' variables in the model. This evidence indicates that the model is a good benchmark to study the effects of implementing different policies, as we do below.

4. Simulation results

In this section, we will derive policy implications in this economy. Differently to most of the previous literature, we will take transitional dynamics into account, which will be computed by using the relaxation algorithm (Trimborn et al. (2008)).[14]

We shall consider reforms of the fiscal structure in which the government undertakes a permanent, unanticipated change in the (time-invariant) fiscal structure at $t = 0$. Here, fiscal structure refers to the mix of flat-rate taxes and subsidies that keeps the present discounted value of government revenues equal to the present discounted value of government expenditures; i.e., that keeps the present discounted value of the lump-sum taxes (or transfers) necessary to balance the government's budget over time equal to zero:

$$\Omega = \int_0^\infty b(t) e^{-\int_0^t (1-\tau_r) r(s) ds} dt = 0. \tag{36}$$

The quantity b is a measure of the current fiscal imbalance, whereas Ω is a measure of the intertemporal fiscal imbalance (Bruce and Turnovsky (1999)), expressed as a deficit. Hence, in this paper we focus on deficit-neutral policies. Actually, policy makers need to know the most effective instrument that would not damage the government deficit. Given that the capital income tax, τ_r, and the corporate tax, τ_c, are equal in the USA, we will consider henceforth that $\tau_c = \tau_r$.

The welfare gain of a reform is measured as the constant permanent percentage increase in consumption that leaves the household indifferent between remaining in the pre-reform equilibrium or undertaking the reform. Let $C_{\mathrm{O}}(t)$ denote the time path of consumption along the (old) balanced growth path of the market economy, and let $C_{\mathrm{N}}(t)$ the time path of consumption after the (new) fiscal policy is instituted. Hence, if

[13] From the 1987-2010 Major Sector Multifactor Productivity, http://www.bls.gov/mfp/mprdload.htm.
[14] Codes used to obtain quantitative results in this paper are available upon request from the authors.

the new fiscal structure is set at time $t = 0$, the welfare gain (or loss) of instituting this policy is measured as the value π such that

$$\int_0^\infty \frac{[(1+\pi\ )C_{\mathrm{O}}(t)]^{1-\theta}-1}{1-\theta}e^{-\rho t}dt = \int_0^\infty \frac{C_{\mathrm{N}}(t)^{1-\theta}-1}{1-\theta}e^{-\rho t}dt.$$

If U_{O} denotes the utility in the pre-reform balanced growth path, and U_{N} denotes the utility attainable after the fiscal reform, we have that $(1+\pi\ )^{1-\theta}U_{\mathrm{O}} = U_{\mathrm{N}}$, so that the welfare gain is computed as

$$\pi = \left(U_{\mathrm{N}}/U_{\mathrm{O}}\right)^{\frac{1}{1-\theta}} - 1.$$

From the government budget constraint (22), we obtain the share of GDP claimed by the government for lump-sum transfers, s. Since the economy is on its balanced growth path in its pre-tax-reform equilibrium, the requirement that the present discounted value of government revenues equals that of government expenses entails that the government budget is balanced in the pre-tax-reform equilibrium; i.e., $b = 0$. Thus, as shown in Table 1, we obtain that the share of GDP devoted to lump-sum transfers to the households is $s = 29.20\%$.

4.1. Deficit-Neutral Policies for a Given Change in Expenditures

In this section, we want to compare the effects of different fiscal instruments that can affect growth, consumption and welfare in the USA. In particular we are interested in comparing the effectiveness of the alternative policies of this economy.[15] To this end, the usual experiment consists on evaluating and comparing the effects of a given percentage points decrease in a given tax or a increase in a given subsidy. However, the base to which this change applies may be quite different, so the same percentage points change —say a 1 percent— in the tax or subsidy rate may have quite different effects on the government budget depending on the tax or subsidy chosen. Thus, as a normalization procedure, we calculate for each policy measure the equivalent to decrease the government lump-sum expenditures by a 0.5% of GDP (i.e., we make $s = 28.70\%$) and compute the value of the relevant tax or subsidy rate —one at at time, leaving the other ones unchanged— that keeps the intertemporal deficit equal to zero, $\Omega = 0$, according to (36). We will call them deficit-neutral compensating policies. For example, we calculate the reduction in the tax rate on labor income that compensates a 0.5% drop in the ratio of public spending to GDP so as to balance the government's budget over time according to (36). Then, once determined the exact measure for the fiscal instrument, we implement it at the steady-state equilibrium, and we analyse the evolution of the economy since the implementation of the policy towards the new balanced growth path. We then compare utility before and after the introduction of the fiscal policy.

[15] We compare policies that are implemented at once and last forever, i.e., a subsidy rise from 10% to 12%, for instance, means that the subsidy rate 12% will last forever.

Table 2: Effect of deficit-neutral policies compensating a $\nabla s = 0.5\%$ (in percent)

	s_R	s_H	s_K	τ_r	τ_w
Tax/subsidy rate	63.968	9.142	2.237	37.183	33.655
Income growth rate	1.660	1.827	1.660	1.660	1.647
Welfare gain	14.107	2.253	0.049	0.450	−0.178

In Table 2 we report the deficit-neutral compensating policies and their respective growth and welfare effects. For example, for a 0.5% drop in the ratio of lump-sum transfers to GDP, reducing the tax on interest income to 37.132% is deficit-neutral as well as increasing the R&D subsidy to 63.97%. The results clearly show that the subsidy to R&D is the most welfare-increasing from all the analysed deficit-neutral policies, with a welfare increase of 14.107%. The second most welfare enhancing policy is the subsidy to education, with a welfare gain of 2.253% from increasing this subsidy rate from nearly 8% to 9.142%. In this case, the greater incentives to accumulate human capital would imply a reallocation from the final good production to the human capital production and would result in an increase of the long-run growth rate of output to 1.827%. Interestingly, the subsidy to R&D is superior to the subsidy to education even though the former does not affect the long-run growth rate and the later does so. The reason is that there is a low convergence to the steady state and, therefore, the effect along the transition dominates the long-run effect. This clearly justifies our emphasis on the transitional dynamics analysis. In order to keep its budget balanced, a drop in lump-sum transfers by 5% should be compensated by instituting a subsidy to the intermediate capital goods (s_K) of 2.237%, with a negligible welfare gain of 0.05%, or lowering the tax rate on capital income (τ_r) to 37.183%, which entails a small increase in welfare of 0.45%. Interestingly, decreasing the tax on labor income (τ_w) entails a small welfare loss of 0.178% whereas the long-run growth rate of output falls slightly to 1.647%. As discussed above, a wages tax has no effect in the absence of a subsidy to education but in its presence it affects both growth and welfare. In terms of the effects on economic growth however, only those policies affecting the incentives to accumulate human capital —the ultimate source of growth— have a positive effect on long-run growth: the subsidy to education, s_H, and the wages tax, τ_w (if $s_H > 0$). In contrast, the R&D subsidy, s_R, does not affect the long-run growth rate though it may have important short-run effects.

These results clearly suggest that the R&D subsidy is the best single policy instrument to increase welfare and that its rate should be increased. Thus, we will now study the transitional dynamics that the introduction of a deficit-neutral compensating subsidy to R&D would imply. This will allow us to analyse the impact of those policies on different macroeconomic variables such as output growth rate, human capital and TFP growth rate, as in allocations of human capital and in the consumption to output ratio.

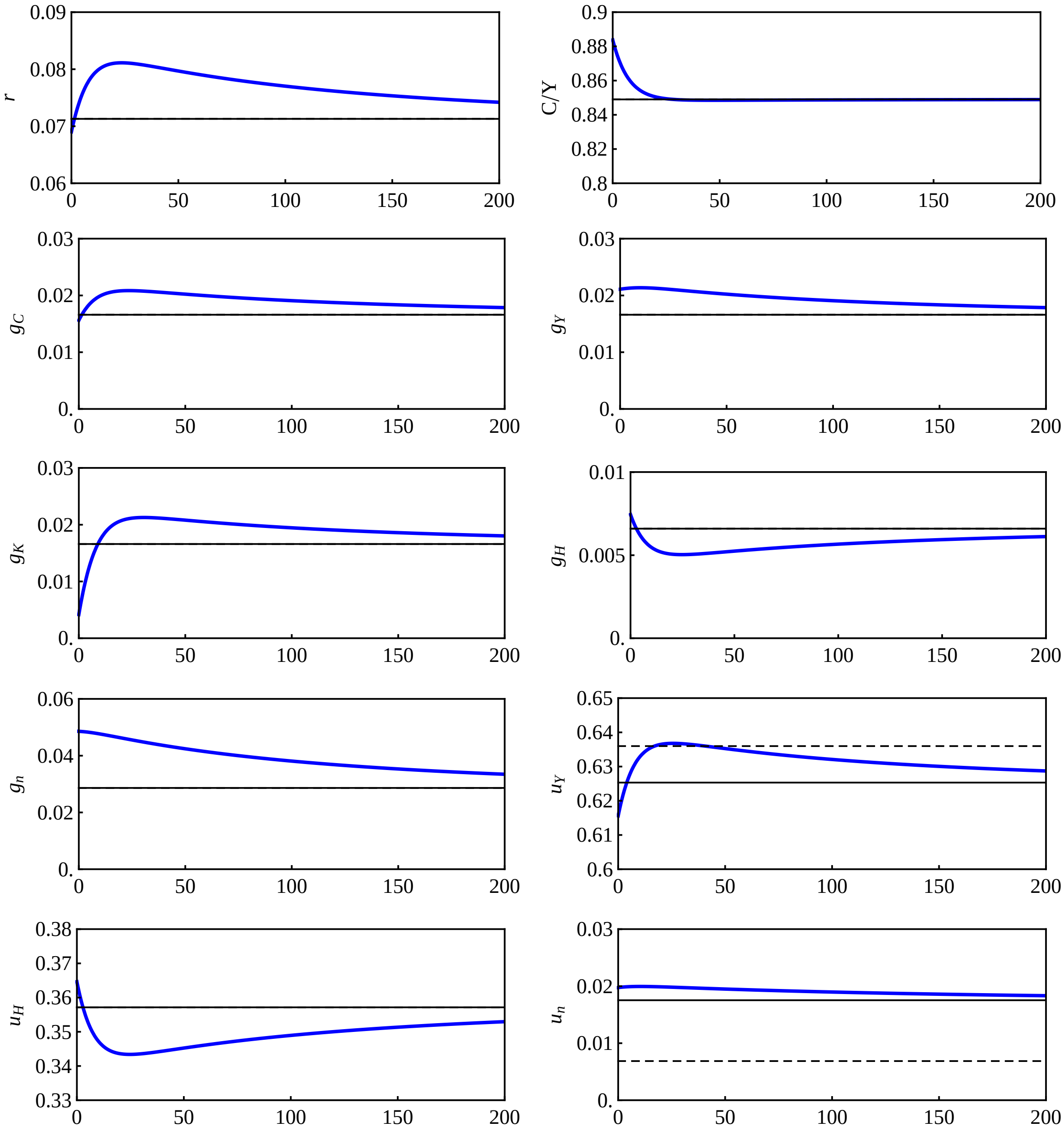

Figure 1: Adjustment paths of representative variables after increasing the subsidy to R&D.
Note: Parameter values are shown in Table 1, except for $s_R = 63.938\%$. The dashed and solid lines represent the initial and final steady-state values, respectively.

Figure 1 shows the evolution of key macroeconomic variables when the deficit-neutral R&D subsidy policy described above ($s_R = 68.071\%$, $s = 28.70\%$) is instituted. Given the higher subsidy to R&D, time devoted to R&D and the 'ideas' growth rate increase sharply at the outset. To allow for an immediate positive effect in the R&D sector, human capital flows from the final good sector, which also entails lower savings, whereas education time remains almost unchanged. As the economy evolves, the increase in the stock of 'ideas' has a positive effect on goods production and, therefore, less time is devoted to education and more time to

Table 3: Optimal deficit-neutral subsidy structure (in percent)

s_R	s_H	s_K	$\hat{g}_Y$	Welfare gain
81.852	3.091	0	0.999	16.206

working and, accordingly, the growth rate of physical capital increases. Eventually, the economy enters in a phase of monotonic and slow convergence to the steady state. While the trade-off between time devoted to R&D and to the production of the final good is maintained in the long-run, time devoted to education recovers from the initial drop and comes back to its pre-reform steady-state value. The growth rates of income and consumption lie above their pre-reform values along the long transition involved, benefiting from the new technologies available due to the increase in the R&D activities. As a consequence, even though the long-run growth rates remain unchanged, the welfare effect of the reform is quite high.

4.2. Deficit-Neutral Optimal Subsidies Scheme

The fact that some policies allow for rises in welfare mean that we can calculate the specific value of those policies that maximize welfare for a given government's revenue, so that the deficit remain unchanged. We thus present the optimal deficit-neutral subsidies structure given (financed by) the actual tax rates values without compromising its budget constraint; i.e., so that so that the intertemporal deficit remains unchanged. The results are displayed in Table 3.

Given the current tax rates in the USA, the government should reallocate subsidies from the education sector to R&D, and keep the intermediate goods production unsubsidized. In particular, s_H should be lowered by almost 5 percentage points and s_R should be increase by more than 75 percentage points. This policy scheme would increase welfare by 16.205%, whereas the long-run rate would fall noticeably to around 1%.

Figure 2 shows the evolution of the economy after the introduction of the optimal subsidies-scheme. Due to the dominance effect of the R&D subsidy in the optimal subsidy-scheme, the qualitative behaviour in Figure 2 resembles that of Figure 1. However, as a result of the decrease in the subsidy to education, the post-reform long-run growth rates are all lower than the initial ones. However, given the higher incentives to accumulate R&D, along the earlier stages of transition the growth rate of 'ideas', income and consumption —and, eventually, the growth rate of physical capital as well— evolve above their respective pre-reform steady-state values. The drop in the subsidy to education causes a fall in the growth rate of human capital. However, the overall result of a higher technological growth rate and a lower human capital growth rate on the output growth rate is positive in the short-run. As a result of the new subsidies scheme, there is an re-allocation of time from education to innovation and working. In the long-run, however, working time returns

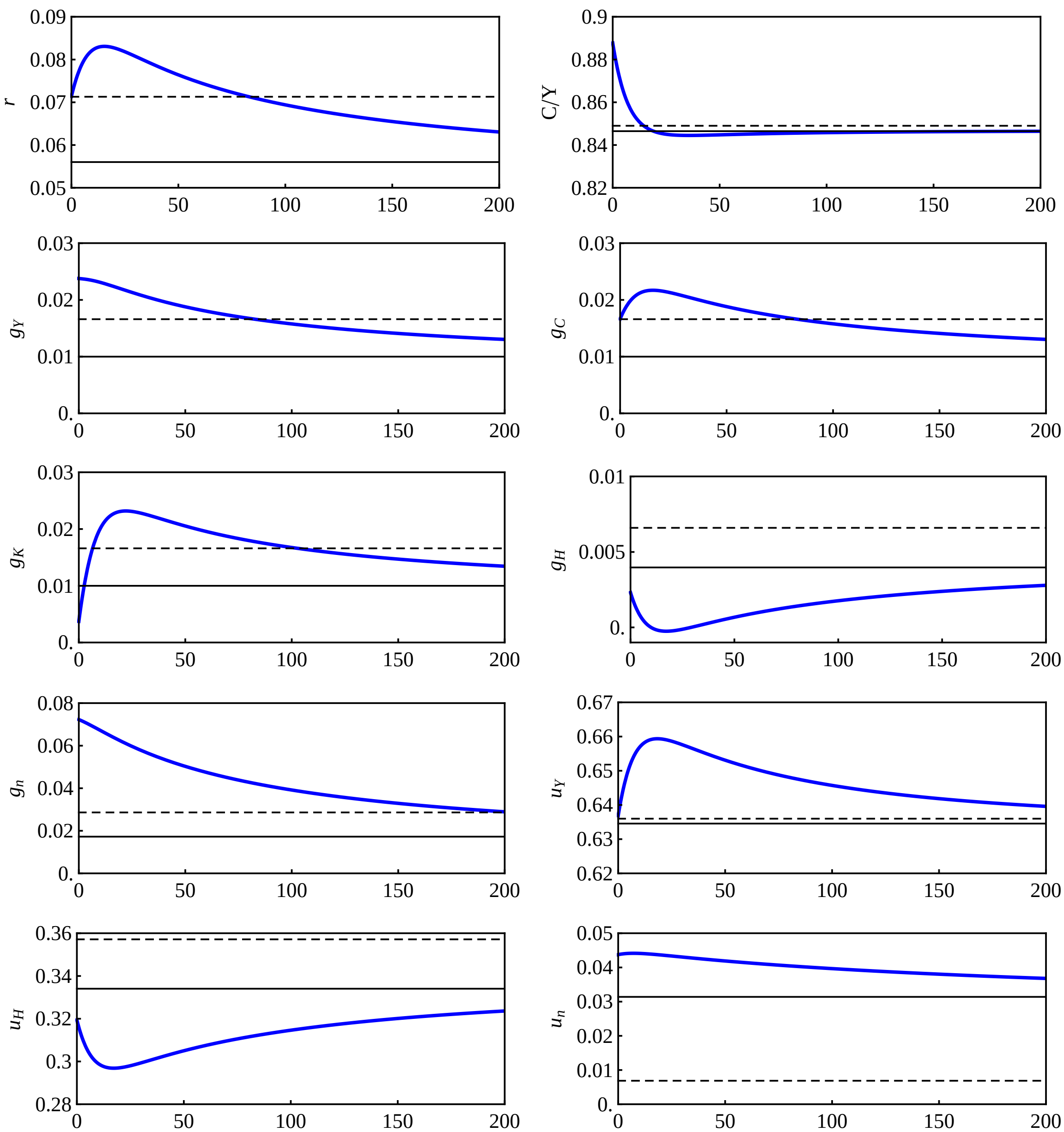

Figure 2: Adjustment paths of representative variables after introducing the optimal subsidies scheme.
Note: Parameter values are shown in Table 1, except for $s_R = 0.8185$, $s_H = 0.03091$ and $s_K = 0$. The dashed and solid lines represent the initial and final steady-state values, respectively.

to a value similar to its pre-reform value, whereas the great increase in innovation time is compensated by a similar reduction in time devoted to education. As the Figure shows, the transition is very long-lasting so that the transitional positive effects on welfare of greater transitional growth rates of consumption and income override the long-run negative effect of a lower long-run values relative to the pre-reform equilibrium.

Table 4: Calibration results in the alternative models

Higher duplication externality, $\lambda = 0.355$							
θ	ϕ	ξ	δ_K	ζ	κ	s_H	
1.4064	0.9182	0.1137	0.0337	1.7463	1.0474	0.8020	
$\hat{u}_Y$	$\hat{u}_H$	$\hat{u}_n$	$\hat{g}_n$	$\hat{\chi}$	$\hat{\psi}$	s	
0.6360	0.3571	0.00687	0.0286	0.283	4.6087	0.2920	
Learning externality associated to H							
θ	ϕ	ξ	δ_K	ζ	κ	s_H	
1.4064	0.8847	0.0693	0.0337	1.7463	1.0474	0.8020	
$\hat{u}_Y$	$\hat{u}_H$	$\hat{u}_n$	$\hat{g}_n$	$\hat{\chi}$	$\hat{\psi}$	s	
0.6360	0.3571	0.00687	0.0286	0.283	9.4899	0.2920	
Leisure in utility							
θ	ϕ	ξ	δ_K	ζ	κ	s_H	σ
1.4064	0.8847	0.3410	0.0337	1.7463	1.0474	0.8020	1.628
$\hat{u}_Y$	$\hat{u}_H$	$\hat{u}_n$	$\hat{u}_L$	$\hat{g}_n$	$\hat{\chi}$	$\hat{\psi}$	s
0.2120	0.1190	0.0023	0.6667	0.0286	0.283	16.437	0.2920

5. Sensitivity analysis: Higher duplication externalities and two alternative models

In this section we will analyze the sensitivity of the obtained results to several sensible choices. First, and given the uncertainty on the true value of the duplication externalities, we will analyze how the previous results are affected by setting a higher value for the duplication parameter. Furthermore, one may wonder whether the results presented so far concerning the relative importance of the R&D subsidy were due to the specific formulation of benchmark model used in this article. Two specific features that could eventually affect our main results were the specific functional form of the human capital law of motion and how the learning externality is modelled, and the absence of leisure in utility. In fact, the externality to human capital was the strongest candidate to bet R&D subsidies as the most welfare-enhancing policies. A change in the externality form and the possibility of leisure in the model could influence the incentives to accumulate human capital when compared to other investments, namely R&D, and thus could revert the order of importance of subsidies. Following this reasoning we have changed our benchmark model in order to test for these two alternatives. As suggested by Engen et al. (1997), the model is recalibrated so as to reflect the original long-run data reported in Table 1. The obtained results are reported in Table 4.

5.1. *Higher duplication externality*

Given the uncertainty on the value of the duplication externalities parameter, λ, we report the results for $\lambda = 0.355$, the minimum value estimated by Pessoa (2005) for the most developed OECD countries sample.

Table 5: Effect of deficit-neutral policies with higher duplication externality (in percent)

Deficit-neutral policies compensating a $\nabla s = 0.5\%$					
	s_R	s_H	s_K	τ_r	τ_w
Tax/subsidy rate	60.629	9.137	2.239	37.196	36.655
Income growth rate	1.660	1.826	1.660	1.660	1.647
Welfare gain	7.987	2.199	0.060	0.331	−0.175
Optimal deficit-neutral subsidy structure					
	s_R	s_H	s_K	$\hat{g}_Y$	Welfare gain
	73.682	5.358	0	1.290	6.515

The change in this parameter is important to assess the robustness of our results according to which the R&D subsidy is the most welfare-enhancing policy available. Increasing the value of duplication externalities, Table 5 shows that the results remain largely unchanged aside from the extent of the welfare effects, which are much lower now. Thus, the R&D subsidy continues to be the best policy.

5.2. New human capital externality

First, we calculate the growth and welfare effects in an environment in which the learning externality is due to the whole stock of human capital and not just to the average human capital dedicated to education. Differently to our benchmark model, this means that human capital benefits not only from peer-effects but also from home education and overall education of the community.[16] Thus, an alternative law of motion of human capital (see, e.g., Choi (forthcoming) and Lucas (2009)) is the following:

$$\dot{H} = \xi (H_H)^{\varepsilon} (\bar{H})^{1-\varepsilon} - \delta_H H, \qquad \xi > 0, 0 < \varepsilon < 1 \tag{37}$$

Using this alternative model, we calculate the deficit-neutral policies, which we present in Table 6. The results show that the importance of subsidies to R&D as a welfare-enhancing policy relative to subsidies to education is even reinforced when compared with the benchmark model. In fact, a deficit-neutral subsidy to R&D which compensates a drop in lump-sum transfers by 0.5% of GDP would increase welfare by 16.826%, which is more than in the benchmark situation. The welfare effects of alternative policies are all less than 1%. Regarding the optimal subsidy structure, this confirms the same idea. In this case , if the government aims at reallocating subsidies given the tax structures, it should increase the R&D subsidy to 87.183% and keep unsubsidized both the education sector and the intermediate goods sector. Growth effects are similar

[16]Despite we are not presenting the detailed model in this case in order to provide broader readability, it is available upon request.

Table 6: Effect of deficit-neutral policies with learning externality associated to H (in percent)

Deficit-neutral policies compensating a $\nabla s = 0.5\%$					
	s_R	s_H	s_K	τ_r	τ_w
Tax/subsidy rate	64.994	9.096	2.240	37.178	36.652
Income growth rate	1.660	1.750	1.660	1.660	1.653
Welfare gain	16.826	0.384	0.232	0.688	−0.033
Optimal deficit-neutral subsidy structure					
	s_R	s_H	s_K	$\hat{g}_Y$	Welfare gain
	87.183	0	0	1.059	36.233

to those in the benchmark case, but the implied welfare gain of switching to the optimal subsidy structure is more than duplicated.

5.3. Including leisure in the model

In this section, we consider a new utility function which reflects the fact that the agent benefits from both consumption and leisure (e.g., King and Rebelo (1993) and Turnovsky (2000)). Thus, instead of (8) in the benchmark model, we introduce leisure time, u_L as an argument of the utility function according to

$$U = \int_0^\infty \frac{C^{1-\theta} u_L^{\sigma(1-\theta)}}{1-\theta} e^{-\rho t} dt. \tag{38}$$

The additional parameter $\sigma = 1.628$ is set so as to obtain a share of time devoted to leisure of 2/3, which is the typical value considered in the literature.[17] It is interesting to note that the steady-state share of time dedicated to work $(u_Y + u_n)$ is 21.17% and the values reported by OECD for USA lie between 21.1% in 1996 and 20.2% in 2010.[18]

Using this alternative model, we calculate the deficit-neutral policies, which are presented in Table 7. In the case of the model with leisure, R&D subsidies continue to be the most welfare-increasing. Actually, reducing lump-sum transfers by a 0.5% of GDP to increase the R&D subsidy in a deficit-neutral manner yields a welfare gain of 13.524% compared with an increase of 4.695% led by human capital subsidies. Furthermore, and differently to the no-leisure model, now subsidizing R&D also has an effect on long-run growth and, in this case, the long-run income growth rate increases by around 0.09 percentage points. The increase is higher and amounts to 0.224 percentage points if the compensating instrument is the subsidy to education. Though

[17] Again, we are not presenting the detailed model in this case in order to provide broader readability. However, it is available upon request.

[18] Values were computed dividing average annual hours actually worked per worker by the total number of hours of a 365 days' year (8760). The analysed period was from 1990 to 2010. Values used by Glomm and Ravikumar (1998), p. 318-320 to estimate the share of resources dedicated to learning in a model without leisure point out for a percentage of worked hours of 20.77% of the total available time (dividing 34.9 by 168 hours of a week), consistent with our steady-state results.

Table 7: Effect of deficit-neutral policies with leisure in utility (in percent)

Deficit-neutral policies compensating a $\nabla s = 0.5\%$					
	s_R	s_H	s_K	τ_r	τ_w
Tax/subsidy rate	64.036	9.204	2.285	37.145	33.614
Income growth rate	1.749	1.884	1.682	1.677	1.704
Welfare gain	13.524	4.695	0.832	0.893	1.747
Optimal deficit-neutral subsidy structure					
	s_R	s_H	s_K	$\hat{g}_Y$	Welfare gain
	75.651	5.026	0	1.281	9.522

subsidies to human capital has a lower effect, this is the model in which its effect is more close to the effect of R&D subsidies. In this case, subsidizing the intermediate goods sector provokes a sizeable gain in welfare of 0.832% and, unlike the no-leisure case, long-run growth slightly increases to 1.677%. Decreasing the capital income tax rate has a positive welfare effect of 0.893%. One important difference with previous results is that in this model decreasing the wages tax increases welfare by 1.747%. The reason is that now a wages tax distorts the labor-leisure margin of choice which is absent in the previous models. While in previous cases the consumption tax (τ_C) acted as a lump-sum tax, here it acts on the trade-off between working and enjoying leisure. We also tested its importance, and the welfare gain obtained by a deficit-neutral change would be around 1.076% for instituting an (unrealistic) subsidy to consumption of 0.61%. On the optimal subsidies-scheme the recommendations is somewhat less strong but qualitatively similar: given the flow of government revenues, subsidies should be reallocated from education to R&D.

6. Conclusion

We build a Schumpeterian growth model with physical capital, human capital accumulation and technology in which we consider all of the most relevant fiscal policy instruments. We derive its transitional dynamics and steady-state and we show that most of the considered fiscal instruments influence both the transition and the long-run equilibrium. Then, we carefully calibrate the model based on official sources and the literature so that it can approach the behavior of the United States economy. We perform welfare analysis that takes in consideration the whole transitional dynamics caused by fiscal reforms. Noticeably, we focus on deficit-neutral fiscal reforms. Our focus on deficit-neutral policies is essential given the need of growth and welfare-promoting policies that do not damage deficits. This gain more importance in the current discussion on the paths to leave the nowadays crisis in the developed countries, which has large deficits and low growth as the two major issues.

When comparing the deficit-neutral effects of changing the taxes or subsidies that are present on our economy, we discovered that the most welfare-increasing deficit-neutral policy is the research policy based on the subsidy to R&D costs. The nearest best policies, in terms of welfare, although with a significantly lower welfare effect, are the subsidy to education (rises) and the capital income tax rate (decreases). This result has a strong policy implication: governments aiming at increasing growth, consumption and welfare, and simultaneously maintain deficits constant, should use the research policy. Both subsidies to R&D and education would have long-lasting positive effects on economic growth although only the subsidy to human capital has a permanent effect on growth. This means that the strong effect of R&D subsidies on its long transition path compensates the lower or null effect they have on the long-run equilibrium. This plenty justifies our transitional dynamics analysis.

As we want to provide significant policy advise according the bundle of optimal policies that can be implemented, we computed the set of subsidies that are optimal to face the current tax values in US. This exercise lead to the second important conclusion of the paper: current tax structure in the US allow to a slightly decrease in the subsidy to education and a huge increase in the R&D subsidy. This implies that this fiscal movement yields significant welfare effects, that oscillated, depending on the models and calibration values between 6% to more than 36%. This policy-reform would imply a reallocation of resources from the human capital sector to the R&D and the industrial sector. The results presented on the paper were tested against important alternative assumptions both on the calibration side and on the functional side, and they were proved to be robust to these changes.

We showed that using a state-of-the-art endogenous growth model with Schumpeterian features that incorporates a realistic fiscal system would imply interesting policy implications that could be shown very clearly, in a language accessible to a broad scope of researchers, politicians and practitioners. To sum up we advise for implementation of higher subsidies to R&D if countries aim to attain higher welfare in the long-run eventhough they do not wish to increase deficits. Alternatively, countries may choose to change the composition of the subsidy-scheme, decreasing subsidies to education and increases subsidies to R&D in order to attain higher welfare, consumption and economic growth in the long-run. This analysis of transitional dynamics after deficit-neutral policy-reforms may be a benchmark for future research.

AppendixA. Derivation of Transitional Dynamics Equations

We shall take into account that $\overline{u_n H} = u_n H$ in equilibrium. Differentiating $A = K + nv$, we get $\dot{A} = \dot{K} + \dot{n}v + n\dot{v}$. Using (7) and (22) we arrive at

$$\dot{A} = (1-\tau_r)rA + (1-u_H)wH - (1+\tau_C)C - (s_K Rnx + s_R wu_n H) + \tau_c \pi n + \tau_r rK + \tau_C C. \tag{A.1}$$

Now, using that $\dot{A} = \dot{K} + \dot{n}\upsilon + n\dot{\upsilon}$, and eliminating $\tau_r rA = \tau_r rK + \tau_r n\upsilon$, we get:

$$rA + w(1-u_H)H - C - (s_K Rnx + s_R wu_n H) + \tau_c \pi n = \dot{K} + \dot{n}\upsilon + n\dot{\upsilon} + \tau_r n\upsilon \tag{A.2}$$

Now we use (20) to substitute for $\dot{\upsilon}n$, use that $(1-u_H)H = H_Y + H_n$ in the expression above which yields

$$\begin{aligned} rA + wH_Y + (1-s_R)wH_n - C - s_K Rnx + \tau_c \pi n& \\ = \dot{K} + \dot{n}\upsilon - (1-\tau_c)\pi n + \zeta\dot{n}\upsilon + (1-\tau_r)rn\upsilon + \tau_r rn\upsilon& \\ = \dot{K} + (1+\zeta)\dot{n}\upsilon + rn\upsilon - (1-\tau_c)\pi n& \end{aligned} \tag{A.3}$$

Some simplification, using (4), (13) and $r = R - \delta_K$ yields

$$\dot{K} = RK + wH_Y - C - s_K Rnx + \pi n - \delta_K K \tag{A.4}$$

Now, use (11), (17) and (13) to obtain $\dot{K} = Y - C - \delta_K K$. Now, using that $\varphi \equiv Y/K$ and $\chi \equiv C/K$, so that $r = \beta\varphi/((1-s_K)\kappa) - \delta_K$, we have that

$$g_K = \varphi - \chi - \delta_K. \tag{A.5}$$

Some equations that will be needed for solving the model are presented below. Log-differentiating (16) and (11), respectively, we get

$$g_Y = \beta g_K + (1-\beta)(g_{u_Y} + g_H) + \eta g_n, \tag{A.6}$$

$$g_w = g_Y - g_{u_Y} - g_H. \tag{A.7}$$

Log-differentiating (4) yields

$$g_{g_n} = \gamma(g_{u_n} + g_H) - (1-\phi)g_n. \tag{A.8}$$

Log-differentiating (21), substituting g_υ from (19), π from (13), w from (11), and υ from (21), we get

$$g_w = (1-\tau_r)r + \zeta g_n + (\gamma-1)(g_{u_n} + g_H) - \frac{(1-\tau_c)\beta(\kappa-1)u_Y}{(1-s_R)(1-\beta)\kappa u_n} g_n + \phi g_n. \tag{A.9}$$

The equilibrium dynamics of the market economy in terms of the variables φ, χ, u_Y, ψ and g_n expressed in the system (23)–(27) is determined as follows. We have used that $u_H = 1 - u_Y - u_n$ and $u_n = (1+\zeta)^{1/\gamma}\delta^{-1/\gamma}\psi^{-1/\gamma}g_n^{1/\gamma}$. Eq. (23) results from (A.6) and (10). Eq. (23) is obtained from (9) and (A.5). From Eqs. (A.7) and (10), using (A.5) and (5), we get (25). From $g_\psi = \gamma g_H + (\phi-1)g_n$, using (5), we obtain (26). Eq. (27) results from (A.8), (A.9) and (10), using (5).

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Supplementary material (not intended for publication)

Computation of adjustment paths and the welfare gain

Let $C_{\rm O}(t)$ denote the time path of consumption along the (old) balanced growth path of the market economy, and let $C_{\rm N}(t)$ the time path of consumption after the new fiscal policy is instituted. If the new fiscal structure is set at time $t = 0$, the welfare gain (or loss) of instituting this policy is the value π such that

$$\int_0^\infty \frac{[(1+\pi\ )C_{\rm O}(t)]^{1-\theta}-1}{1-\theta}e^{-\rho t}dt = \int_0^\infty \frac{C_{\rm N}(t)^{1-\theta}-1}{1-\theta}e^{-\rho t}dt.$$

Assuming, without loss of generality, that the initial value of the capital stock is normalized to unity, $K(0) = 1$, consumption in the pre-reform balanced growth path would be given by $C_{\rm DE}(t) = \hat{\chi}\mathrm{e}^{-\hat{g}t}$. It remains to show how to compute the adjustment path of post-reform consumption, $C_{\rm SP}(t)$.

It can be shown that saddle-path stability of the market economy requires two stable roots, so that the stable manifold is two-dimensional. The initial point in the stable manifold to start the simulation is determined by the initial value of the predetermined variables. However, the dynamic system (23)–(27) features only one *true* predetermined variable, $\psi = H^\gamma n^{\phi-1}$. Now we show how the dynamics of the economy can be rewritten in terms of two *true* state variables —and three *jump* variables.

Note first that the output-capital ratio φ can be expressed as

$$\varphi = (u_Y H/K)^{1-\beta}n^\eta = u_Y^{1-\beta}\psi^{-\frac{\eta}{(1-\phi)}}q, \tag{A.10}$$

where the state variable q is defined as

$$q = H^{1-\beta+\eta\gamma/(1-\phi)}K^{-(1-\beta)}.$$

Hence, the dynamics of the market economy in terms of the variables χ, u_Y, ψ, g_n and q is determined by the system (24)–(27), together with

$$g_q = \Big(1-\beta+\frac{\eta\gamma}{1-\phi}\Big)g_H - (1-\beta)\,g_K, \tag{A.11}$$

where g_K and g_H should be substituted with (A.5) and (5), respectively, and r should be replaced with $r = \beta q u_Y^{1-\beta}\psi^{-\eta/(1-\phi)}/[\kappa(1-s_K)] - \delta_K$. The steady state value of q at the decentralized economy can be simply computed from (A.10) as $\hat{q} = \hat{u}_Y^{(1-\beta)}\hat{\psi}^{\eta/(1-\phi)}\hat{\varphi}$.

At time $t = 0$, when the new fiscal policy is instituted, the system jumps to the two-dimensional stable manifold of the market economy which include the policy change. The initial point in this stable manifold is determined by the initial values of the predetermined variables, $\psi(0) = \hat{\psi}$ and $q(0) = \hat{q}$. Thereafter, the economy moves towards the new steady state of the decentralized economy along this stable manifold.

Once the time paths of the variables χ, g_n, u_Y, ψ and q are known, we can solve for the time path of physical capital by solving the differential equation (A.5) with initial condition $K(0) = 1$. Finally, we compute the adjustment path of consumption as $C_{\mathrm{N}}(t) = \chi_{\mathrm{N}}(t)K_{\mathrm{N}}(t)$, where "N" means the equilibrium of the decentralized economy after the policy change.