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# Optimal R&D subsidies in a model with physical capital, human capital and varieties

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ABSTRACT

In this paper, we analyze the social planner solution of an endogenous growth model with physical capital, human capital and R&D. The model incorporates three sources of inefficiency: monopolistic competition in the intermediate-goods sector, duplication externalities and spillovers in R&D. A complete stability analysis for the optimal growth problem of this model is provided. We characterize the optimal policy that can decentralize the optimal solution and find that the path of the optimal R&D subsidy can be non-monotonic.


## 1. Introduction

There is a broad consensus that physical capital accumulation, knowledge formation, and R&D-based technological progress are the three main engines of growth. For the most part, they have been considered as alternative rather than complementary explanations in the theoretical literature. As a notable exception, Arnold (2000a) and Funke and Strulik (2000) (AFS henceforth) proposed an integrated endogenous growth model with physical capital, human capital and R&D, in which the economy passes through different stages of development. In the fully-industrialized phase three sectors are acting: the competitive final goods sector, the schooling sector where knowledge (human capital) is accumulated, and the intermediate-goods monopolistic sector which produces an increasing variety of goods due to R&D.

However, monopoly power is not the only plausible source of inefficiency in R&D-based growth models (see, e.g., the comprehensive review by Jones, 2005). Thus, empirical evidence reported, e.g., by Griliches (1992), Jones (1995), Engelbrecht (1997), del Barrio-Castro et al. (2002), Pessoa (2005) and Porter and Stern (2000) also supports the existence of R&D spillovers in innovation — a "standing on shoulders" or a "fishing-out" effect. Several authors have also pointed out that the R&D activity may be subject to an external effect associated to the duplication and overlap of research effort — a "stepping on toes" effect (e.g., Jones, 1995; Pessoa, 2005; Porter and Stern, 2000; Stokey, 1995). Intuitively, the larger the number of people searching for ideas is, the more likely it is that duplication of research would occur. Evidence of duplicative research has also been found, e.g., by Kortum (1993) and Lambson and Phillips (2007). Both external effects — spillovers in R&D and duplication externalities — are neglected in the AFS model, which assumes that innovation depends exclusively and linearly on human capital devoted to R&D. Additionally, Gómez (2011b) has recently examined the ability of the simplest AFS model to describe the development process and concluded that it can hardly be reconciled with data. First, Gómez (2011b) notes that previously reported simulations with the AFS model made by Funke and Strulik (2000), Gómez (2005) and Iacopetta (2010) feature three main problems, namely, instability of the steady state, too fast convergence, and unrealistic highly oscillatory dynamics which are at odds with data. Thereafter, Gómez (2011b) performs a detailed sensitivity analysis of the (two) stable roots of the fully industrialized economy which shows that numerical simulations with the AFS model could hardly yield realistic transition paths for plausible parameter values.

According with the empirical evidence, Sequeira (2011), Gómez (2011a,b) and Iacopetta (2011) have incorporated R&D spillovers and duplication externalities into the AFS model. This modification largely complicates the dynamics of the economy, which passes from being described by a third- to a fifth-order dynamical system. However, as Gómez (2011a,b) shows, this add-on to the basic AFS setup also increases significantly its ability to fit the observed data. While the previously cited works focused on analyzing the transition dynamics of the market economy and its fit to data, the incorporation of R&D spillovers and duplication externalities to the model raises the question of whether an adequate government intervention can provide the required incentives to correct these inefficiencies, so as to make the decentralized economy

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replicate the first-best solution attainable by a social planner. None of these previous contributions has analyzed this issue in this framework, so this paper seeks to fill this gap.

This paper characterizes a dynamically optimal fiscal policy capable of making the decentralized economy achieve the first-best optimum in an extended version of the AFS endogenous growth model with physical capital, human capital and R&D. The model incorporates three sources of inefficiency: monopolistic competition in the intermediate-goods sector, duplication externalities and spillovers in R&D. We first study the decentralized economy with government. Next, we characterize the social planner solution, and derive an optimal R&D subsidy policy that can decentralize the Pareto-efficient solution. The optimal growth path can be decentralized by means of a subsidy to production of intermediate goods at a constant rate combined with a time-varying subsidy (or tax) to R&D. We also perform a detailed (local) stability analysis of the first-best solution, and find that the time path of the optimal R&D subsidy can be non-monotonic. With the notable exceptions of Arnold (2000b) and Eicher and Turnovsky (1999) — in quite different setups from the one presented here — the stability analysis issue has been ignored in most of the related literature (e.g., Grossmann et al., 2010; Jones, 2005; Jones and Williams, 2000; Steger, 2005), probably because of its complexity and also because of the emphasis put on the quantitative assessment of distortions on the steady state — disregarding the transitional phase. However, the analysis of long-run effects may be misleading if the steady state is unstable because in this case the economy would not converge to it (unless, of course, it already starts on it). One then may wonder whether this is a real possibility or not. So, we show in the Appendix A that if we had assumed (more unrealistically) that there are no duplication externalities, the steady state of the socially planned economy would be instable. Thus, stability cannot be simply taken for granted.

This paper is mostly related to Arnold (2000b) and Grossmann et al. (2010), who also characterize analytically the optimal dynamic fiscal policy in R&D-based endogenous growth models. However, they do not include human capital as an engine of growth. In particular, Arnold (2000b) studies the optimal combination of production and R&D subsidies in the Romer (1990) model. This model has been criticized because of the implied counterfactual scale effects and, furthermore, it does not include duplication externalities. Grossmann et al. (2010) consider instead a semi-endogenous growth model of Jones (1995), in which economic growth is driven solely by exogenous population growth and, furthermore, they do not study analytically the stability of the centrally planned economy. The different assumptions lead to significantly different results, especially regarding the behavior of the optimal R&D subsidy. In particular, we find that the optimal R&D subsidy can display a non-monotonic behavior, which is in sharp contrast with the analytical results in Arnold (2000b) and the numerical results in Grossmann et al. (2010). Other related research (e.g., Alvarez-Pelaez and Groth, 2005; Jones and Williams, 2000; Steger, 2005; Strulik, 2007) has focused instead on the quantitative assessment of distortions — mainly on the long-run, and thus disregarding the transitional phase — by resorting to numerical simulations. Hence, the optimal fiscal policy is not characterized analytically.

The remaining of this paper is organized as follows. Section 2 describes the market economy. Section 3 analyzes the centralized economy and devises an optimal policy. Section 4 concludes.

## 2. The market economy

The economy is inhabited by a constant population, normalized to one, of identical individuals who derive utility from consumption, $C$, according to

$$\int_0^\infty \frac{C^{1-\theta}-1}{1-\theta}e^{-\rho t}dt, \quad \rho>0, \quad \theta>0. \tag{1}$$

The endowment of time is normalized as a constant flow of one unit per period. A fraction $u_Y$ of time is devoted to production, a fraction $u_H$ to learning, and a fraction $u_n=1-u_Y-u_H$ to innovation. Human capital, $H$, is accumulated according to

$$\dot{H}=\xi u_H H, \quad \xi>0. \tag{2}$$

The budget constraint faced by the representative individual is

$$\dot{A}=rA+w(1-u_H)H-C-T, \tag{3}$$

where $r$ is the return per unit of aggregate wealth $A$, $w$ is the wage rate per unit of employed human capital, and $T$ are lump-sum taxes (or transfers) imposed by the government. The individual maximizes her intertemporal utility Eq. (1), subject to the budget constraint Eq. (3) and the knowledge accumulation technology Eq. (2). Let $g_\tau$ denote $\tau$'s growth rate, $g_\tau=\dot{\tau}/\tau$. The first-order conditions for an interior solution yield

$$g_C=(r-\rho)/\theta, \tag{4}$$

$$r-g_w=\xi, \tag{5}$$

as well as the standard transversality conditions, $lim_{t\to\infty}e^{-\rho t}\lambda A=lim_{t\to\infty}e^{-\rho t}\mu H=0$, where $\lambda$ and $\mu$ denote the multipliers associated to constraints Eqs. (3) and (2), respectively.

The market for final goods is perfectly competitive and the price for final goods is normalized to one. Final output, $Y$, is produced with a Cobb–Douglas technology

$$Y=K^\beta D^\eta (u_Y H)^{1-\beta-\eta}, \quad \beta>0, \quad \eta>0, \quad \beta+\eta<1, \tag{6}$$

where $K$ is the stock of physical capital and $D$ is an index of intermediate goods, $D=(\int_0^n x_i^\alpha di)^{1/\alpha}$, $0<\alpha<1$, where $x_i$ is the amount used for each one of the $n$ intermediate goods. Profit maximization delivers the factor demands

$$r=\beta Y/K, \tag{7}$$

$$w=(1-\beta-\eta)Y/(u_Y H), \tag{8}$$

$$p_i=\eta Y x_i^{\alpha-1}/D^\alpha, \tag{9}$$

where $p_i$ represents the price of intermediate $i$.

Each firm in the intermediate goods sector owns an infinitely-lived patent for selling its variety $x_i$, which costs a unit of $Y$ to be produced. The government subsidizes production so that for each unit sold of the intermediate good producers receive a unit price $p_i$ and a subsidy $s_x p_i$. Producers act under monopolistic competition and maximize operating profits, $\pi_i=[(1+s_x)p_i-1]x_i$. Profit maximization in this sector implies that each firm charges a price of $p_i=1/[(1+s_x)\alpha]$. Since both technology and demand are the same for all intermediates, the equilibrium is symmetric: $x_i=x$, $p_i=p$. Hence, the quantity of intermediates employed is $xn=(1+s_x)\alpha\eta Y$, firms profits are

$$\pi=(1+s_x)(1-\alpha)\eta Y/n, \tag{10}$$

and $D=xn^{1/\alpha}=n^{(1-\alpha)/\alpha}(1+s_x)\alpha\eta Y$. Substituting this expression into (6) yields

$$Y^{1-\eta}=[(1+s_x)\alpha\eta]^\eta K^\beta n^{(1-\alpha)\eta/\alpha}(u_Y H)^{1-\beta-\eta}. \tag{11}$$

There is free entry into the R&D sector. Invention of new intermediates is determined according to

$$\dot{n}=\bar{\delta}u_n H=\delta(\overline{u_n H})^{\gamma-1}n^\phi u_n H, \qquad \delta>0, \quad 0<\gamma<1, \quad \phi<1, \tag{12}$$