# Market Failure, Government Inefficiency, and Optimal R&D Policy

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January 2015

**Abstract**

This paper presents a growth model that can explain the coexistence of intellectual property rights and R&D subsidies as a response to the presence of both market and government failures. The framework can also generate the observed positive correlation between these two policy tools.

*JEL classification:* O3, O41.

*Key words:* R&D subsidies, IPR, economic growth



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# 1 Introduction

The promotion of R&D is one of the most important items in the government's policy agenda. I could not be otherwise since technological change is perceived as the main source of sustained economic growth. Two main tools of R&D policy to foster innovation are subsidies and patent protection. Both are widely used across nations, and follow clear patterns along the development process. However, standard R&D-based growth frameworks do not offer an explanation for why both tools are simultaneously used. In these models, market failures justify innovation policy, and R&D subsidies *per se* are able to achieve the first best.[1] Some of the literature on optimal intellectual property rights (IPR) suggests reasons why innovation subsidies might not be optimal, but never analyzes both tools jointly.[2] The lack of an explanation within a formal framework for the coexistence of different policy tools is an important gap in a literature that tries to shed light on the optimal design of R&D policy and its macroeconomic implications. This paper advances in that direction, and studies how this coexistence depends on financial and public sector considerations.

More specifically, we propose an R&D-based growth framework that simultaneously explains patents and government-financed R&D as a response to the existence of both market and government failures. In the model, market failures include intertemporal knowledge spillovers, diminishing returns to R&D effort, and monopoly pricing. The public sector, on the other hand, fails because the efficiency of one unit of income collected in taxes is less than one when invested in R&D. This can be due for example to public finance costs, bureaucracy corruption, and public sector inability to target R&D projects efficiently. The model also considers the existence of transaction costs in the private financial sector.

Under these circumstances, R&D subsidies must be paired with patent protection. This is the first-best outcome, unless one the following scenarios occurs: (i) the public sector is sufficiently inefficient, in which case subsidies are not implemented; (ii) the private financial activity incurs in relatively large costs, making patent protection socially undesirable.

The model can explain the observed simultaneous increase in both government R&D spending and the strength of IPR. It occurs in our framework as the public

[1] Examples include the seminal contributions of Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). For a review of the market failures considered in the R&D literature and policy analysis, see for example Acemoglu (2008).

[2] The study of optimal IPR goes back at least to Nordhaus (1968). More recent papers include O'Donoghue and Zweimuller (2004), Eicher and Garcia-Penalosa (2008), and Acemoglu and Akcigit (2012). Agnion and Tirole (1994) and Agnion and Howitt (1998) suggest that, in the absence of IPR, information problems might be behind the inability of R&D subsidies to achieve the first best.

sector becomes more efficient, because of the complementarity of private and public innovation effort. The impact on private and public R&D are, however, different depending on who becomes more efficient. While more efficient public finance increases the share of both private and public R&D in national income, a higher degree of efficiency in the financial market rises the share of private innovation effort but diminishes the public one.

# 2 Model

Consider a closed economy similar to the one in Romer (1990) populated by utility-maximizing infinitely-lived consumers. There are three types of activities: consumption-goods production, intermediate-goods manufacturing, and R&D investment. The second sector operates under monopolistic competition, and the other two obey perfect competition. R&D is intended to create new designs for new types of producer durables. In this economy, intellectual piracy can prevent the inventor from appropriating any benefit from his discoveries: when a new design is created, there is a probability $\psi$ that an intermediate-goods producer acquires the perpetual patent over the design that allows monopoly pricing. The government chooses the levels of patent protection $\psi$ and subsidies to the R&D activity.

## 2.1 Households

A continuum of identical consumers of size $L$ that grows at rate $n$ inhabit the economy.[3] Consumers are endowed with one unit of labor in each period that is supplied inelastically. Their preferences are given by the following log-utility function:

$$U = \int_t^{\infty} \exp\left[-\rho(j-t)\right] \ln c(j) \, dj \; ; \tag{1}$$

where $c(j)$ is the amount of consumption per capita in period $j$, and $\rho$ is the subjective discount rate.

There is a capital market that supplies consumers' saving to intermediate-goods producers that issue securities. The equilibrium interest rate $r$ clears the market at each point in time. The representative consumer's feasibility constraint is then given by

$$\dot{a} = w + (r-n)a - c_t - \tau_h; \tag{2}$$

[3] When not otherwise specified, variables refer to their values at date $t$ where decisions are made.

where $w$ is the salary, $a$ represent the value of the securities owned by each consumer, and $\tau_h \geq 0$ are taxes. Consumers choose the time series of consumption that maximizes (1) subject to (2). The first order condition to this problem gives the Euler equation for consumption per capita:

$$\frac{\dot{c}}{c} = r - n - \rho. \tag{3}$$

## 2.2 Final goods

An homogeneous final output $Y$ is produced employing a variety of intermediate capital goods $x(i)$ according to

$$Y = L^{1-\alpha} \int_0^A [x(i)]^\alpha \, di \quad , \quad 0 < \alpha < 1 \ ; \tag{4}$$

Final-goods manufacturers are price takers, and earn zero profits in equilibrium. Because intermediate goods are rented rather than sold, equation (4) implies that they solve the following problem:

$$\max_{\{L, x(i)\}} \left\{ L^{1-\alpha} \int_0^A [x(i)]^\alpha \, di - \omega \, L - \int_0^A p(i) x(i) \ di \right\} ; \tag{5}$$

where $p(i)$ is the rental price of producer durable type $i$. For the interior solution to this problem, the first order conditions are

$$\omega = \alpha \, \frac{Y}{L} \tag{6}$$

$$p(i) = \alpha \, L^{1-\alpha} [x(i)]^{\alpha - 1} \quad , \quad i \in (0, A) \, . \tag{7}$$

## 2.3 Producer durables

Firms in the intermediate sector can invest capital to buy patents on new versions of intermediate goods. The patent provides a perpetual right to practice monopoly pricing on sales of the purchased variety. Firms, however, can also obtain access to the new knowledge with probability $1 - \psi$ through costless intellectual piracy. We assume that this only occurs before the patent is sold, and that when an idea is stolen from the inventor it becomes public knowledge that any firm can use. The value of $\psi$ depends on the degree of intellectual property protection chosen by the public sector.

The manufacturing process in this activity requires investing raw capital coming from saved manufacturing output as follows: a unit of capital can be converted at no cost into one unit of any variety of intermediate goods. There is no depreciation in the model.

The problem of intermediate-goods firms that buy a patent and become monopolists is

$$\max_{x(i)} [p(i) - r\tau_f] \ x(i); \tag{8}$$

where $p(i)$ is given by equation (7), and the parameter $\tau_f$ represents a transaction cost that depends on the efficiency of financial markets. In particular, for each unit that agents want to invest, they incur in a cost of $\tau_f - 1$, that is, they need to borrow $\tau_f \geq 1$ units.

The optimal solutions are standard in the literature. In particular, the price charged by the monopolist is

$$p(i) = \frac{r\tau_f}{\alpha} = p. \tag{9}$$

And the amount of profits in the symmetric equilibrium, where $x(i) = x_M$, equals:

$$\pi(i) = \left(\frac{1-\alpha}{\alpha}\right) \ r \ \tau_f \ x_M = \pi_M; \tag{10}$$

where from (7) and (9)

$$x_M = \left(\frac{\alpha^2}{r\tau_f}\right)^{1/(1-\alpha)} L. \tag{11}$$

Firms that obtain the new idea through piracy will also solve (8) but taking $p(i)$ as given because they operate under perfect competition. The solution is now

$$p(i) = r\tau_f. \tag{12}$$

As a consequence, all firms that fall into this class will produce the same amount

$$x_C = \left(\frac{\alpha}{r\tau_f}\right)^{1/(1-\alpha)} L, \tag{13}$$

and profits in equilibrium will equal zero.

Comparing expression (11) and (13), we see that

$$x_M = \alpha^{1/(1-\alpha)} \ x_C. \tag{14}$$

The amount of capital employed by monopolists is a fraction of the one rented by perfect-competition firms, and this fraction rises with the elasticity of capital in final-goods production.

## 2.4 R&D sector

A large number of firms invest in R&D to create new varieties of intermediate goods according to technology:

$$\dot{A} = \mu \ A^{\phi} \bar{R}^{\lambda-1} R, \tag{15}$$

where $R$ is the amount of output investing in R&D, and $\bar{R}$ is its average across firms. Even though the individual firm perceives constant returns, R&D investment at the aggregate displays diminishing returns ($0 < \lambda < 1$). In addition, there are intertemporal knowledge spillovers ($0 < \phi < 1$). There exist institutions that guarantee with probability $\psi$ that inventors can obtain patents on the new ideas that they generate. There is free entry in the industry.

Patents not copied can be sold at a price $P_A$. In equilibrium, investment in R&D is pinned down by the *zero* profit condition

$$\frac{R}{\tau_A} = \psi M_A; \tag{16}$$

where $M_A = \dot{A} P_A$ , that is, the maximum level of revenues attainable in the market for patents, and $\tau_A \geq 1$ captures the effect of government subsidies on costs.

The fraction of government-financed R&D in total R&D investment equals $(\tau_A - 1)/\tau_A$. Hence, it is proportional to the one of the private sector. The way subsidies are introduced implies that public and private investment in innovation behave as complementary. The policy-maker chooses the value of $\tau_A$ necessary to complement each unit of private R&D so as to achieve the social optimum.[4]

Finally, the evolution of the patent price must obey the following no-arbitrage condition:

$$r = \frac{\pi + \dot{P}_A}{\tau_f P_A}.$$

It says that investors in equilibrium are indifferent between investing in the capital market and investing in the patent market.

## 2.5 Public sector

The government decide $\tau_A$ and $\psi$. We assume that patent protection enforcement is costless.[5] As a consequence, the public sector collects lump-sum taxes to finance only R&D subsidies. In particular,

$$\tau_h L \, \tau_d = \left( \frac{\tau_A - 1}{\tau_A} \right) R; \tag{17}$$

where $\tau_d \in (0, 1]$ is the efficiency level of each unit collected in taxes.

[4] We could formalize this idea, for example, assuming that public subsidies mainly finance basic R&D, whereas the private sector focuses on applied R&D. See David *et al.* (2000), among others, for evidence on the complementarity between public and private R&D.

[5] Alternatively, we could assume that maintaining the intellectual property right system requires spending equal to $\tau_\psi \psi R$; where $\tau_\psi > 0$. This would not change the main results of the paper.

The distortions captured by $\tau_d$ limit the capacity of the public sector to use taxes efficiently, and their size depends on the quality of institutions. We can think, for example, that some taxes are lost in the collection process due to corruption, or that one R&D unit financed by government is less effective than if financed by the private sector. The latter is consistent with Agnion and Howitt's (1998) suggestion that the public sector can have problems at targeting the right innovation projects due to asymmetric and incomplete information.

## 2.6 Capital market clearing and optimal R&D share

The economy's capital stock $K$ must equal the sum of all units of intermediate goods produced,

$$K = \int_0^A x(i)\ di = \psi A x_M + (1-\psi) A x_C.$$

Employing (14), we can write

$$K = A\ x_C\ \left[1 - (1 - \alpha^{1/(1-\alpha)})\psi\right]. \tag{18}$$

As expected, $K$ falls with the degree of intellectual-right protection $\psi$ because the industry moves away from perfect competition.

Expressions (7), (12) and (18) imply that

$$r = \alpha \left(\frac{AL}{K}\right)^{1-\alpha} \ \frac{\left[1 - \left(1 - \alpha^{1/(1-\alpha)}\right)\psi\right]^{1-\alpha}}{\tau_f}. \tag{19}$$

Higher transaction costs in financial markets or a stronger degree of imperfect competition lead to lower interest rates.

In the same way, combining (4) and (14), aggregate output takes the form:

$$Y = A\ L^{1-\alpha}\ x_C^{\alpha}\ \left[1 - (1 - \alpha^{\alpha/(1-\alpha)})\psi\right]. \tag{20}$$

A larger $\psi$ limits the amount of producer durables available for final-goods manufacturing, and the amount of consumption goods.

It is also simple to obtain the optimal steady-state share of R&D in national income ($s_R$). From equations (13), (16) and (20)

$$s_R = \frac{R}{Y} = \frac{\tau_A\ \psi\ g_A\ \alpha^{1/(1-\alpha)}(1-\alpha)}{\tau_f\ \left[1 - (1 - \alpha^{\alpha/(1-\alpha)})\psi\right](g_A + \rho)}; \tag{21}$$

where $g_A$ denotes the growth rate of variable $A$. The R&D share rises with intellectual property protection and R&D subsidies, but is not affected by the level of financial market development. Notice also that the expression says that R&D financed by the private sector $s_R/\tau_A$ only depends on $\psi$ (positively) and the financial cost $\tau_f$ (negatively).

# 3 Optimal R&D Policy

The social optimal allocation is obtained solving the central planner's problem. The policy-maker takes into consideration all the failures that the economy suffers. The way some of these failures are introduced into the maximization problem is through the aggregate form of the production functions, and that is why we derive them first.

## 3.1 Aggregate production

Substituting (18) into (20), we find that

$$Y = (AL)^{1-\alpha} \left\{ \frac{\left[1-(1-\alpha^{\alpha/(1-\alpha)})\psi\right]^{1/\alpha}}{1-(1-\alpha^{1/(1-\alpha)})\psi} \; K \right\}^{\alpha} . \tag{22}$$

This aggregate production function for consumption goods implies that new ideas are a source of labor-augmenting technical change.

The quotient in expression (22) deserves further explanation. It is the result of different producer durables being manufactured in industries with different competitive structures. Because of diminishing returns to capital, it displays a U-shape with respect to $\psi$ that achieves a maximum value of 1 when all intermediate goods are produced under the same competitive structure (i.e., when either $\psi = 0$ or $\psi = 1$), and a minimum at $\bar{\psi} \in (0.5, 1)$. According to the final-goods production, a fixed $K$ should be then distributed equally among industries. However, besides this static matter, the central planner must take into account that a larger degree of imperfect competition has dynamics effects on $A$ and $K$.

Let us next focus on the R&D equation. All firms in the innovation sector invest the same amounts of inputs. This equilibrium fact and expression (15) obtain the aggregate production of ideas as

$$\dot{A} = \mu \; A^{\phi} R^{\lambda}. \tag{23}$$

A well known implication of equation (23) is that the steady-state growth rate of designs is given by exogenous parameters. In particular, in order for $\dot{A}/A$ to be a constant along the balanced growth path, the growth rate of $A^{1-\phi}$ must exactly match the one of $R^{\lambda}$. Notice next that function (22) and the feasibility constraint of the economy imply that, at steady state, output and all types of investments grow in per capita terms at the rate of the technological parameter – that is, at $g_A$. With this information, it is immediate to show that the steady-state value of $g_A$ is given by $\lambda n/(1-\phi-\lambda)$.

## 3.2 The command-optimum

R&D policy variables are chosen so as to maximize the expected flow of utility of a representative agent given the constraints of the economy. Substituting (16), (17) and (22) into the economy's feasibility constrain and the aggregate R&D technology, we can write the government's problem as:

$$\max_{\{C,\ \psi,\ \tau_A,\ K,\ A\}} \quad U = \int_0^\infty \exp(-\rho t)\ \ln\left[\frac{C(j)}{L}\right]\ dj; \tag{24}$$

subject to

$$(AL)^{1-\alpha}\left\{\frac{\left[1-(1-\alpha^{\alpha/(1-\alpha)})\psi\right]^{1/\alpha}}{1-(1-\alpha^{1/(1-\alpha)})\psi}\ K\right\}^{\alpha} = C + I + G, \tag{25}$$

$$I = \left(\dot{K} + \psi M_A\right)\tau_f, \tag{26}$$

$$G = \left(\frac{\tau_A - 1}{\tau_d}\right)\ \psi M_A, \tag{27}$$

$$\dot{A} = \mu A^{\phi}\left(\tau_A\ \psi M_A\right)^{\lambda}, \tag{28}$$

where $C$ is aggregate consumption. For simplicity, we assume that the government takes $M_A$ – the potential market for patents – as given. Equation (26) introduces the transaction cost $\tau_f$ paid on borrowing for investing in capital accumulation and patent purchase. Expression (27) gives government spending $G$, and is obtained combining (16) and (17).

The fist order conditions for the interior solution to this dynamic programming problem are the following:

$$\frac{\dot{C}}{C} = r - \rho, \tag{29}$$

$$r = (1-\lambda)\frac{\dot{R}}{R} + \frac{\lambda(1-\alpha)g_A}{\frac{s_R}{\tau_A}\left(\tau_f + \frac{\tau_A - 1}{\tau_d}\right) - \psi f(\psi)}, \tag{30}$$

$$\frac{1}{\tau_d} - \tau_f = \psi\tau_A\ \frac{f(\psi)}{s_R}; \tag{31}$$

where

$$f(\psi) = \frac{1-\alpha^{\alpha/(1-\alpha)}}{1-\left[1-\alpha^{\alpha/(1-\alpha)}\right]\psi} - \frac{\alpha\left[1-\alpha^{1/(1-\alpha)}\right]}{1-\left[1-\alpha^{1/(1-\alpha)}\right]\psi}. \tag{32}$$

The first two conditions are the Euler equations for consumption and R&D spending, respectively. Expression (29) says that $C$ grows at the optimum at the rate implied by the interest rate, which gives the benefit of saving and renouncing to current consumption, net of the subjective discounted rate that gives the cost. If the central planner eliminates the monopoly pricing distortion then $r = \alpha Y/(\tau_f K)$. Otherwise, the interest rate is given by (19). In the same vein, Euler equation (30) requires that in the optimum agents must be indifferent between investing an additional unit in the capital market, which provides a return $r$, or allocating it to R&D, whose social return is given by the RHS of condition (30).

Expression (31) provides the trade-off between the two policy instruments $\psi$ and $\tau_A$. Their contribution to the accumulation of ideas is the same. They differ, however, in terms of the costs imposed to the economy. The LHS of (31) implies that if the government is inefficient ($\tau_d < 1$), R&D subsidies can be costly compared to private R&D. Furthermore, if $1/\tau_d$ is sufficiently larger than $\tau_f$, the optimal $\tau_A$ becomes zero and there are no subsidies to innovation. The opposite can also be true if financial markets are associate with relatively large transaction costs. In particular, when $\tau_f$ is sufficiently bigger than $1/\tau_d$, the social optimum is associated with absence of patent protection. Focusing now on the RHS, it says that patent protection distorts the industry's competitive structure. The aggregate effect of this distortion can be positive or negative. It is negative when the strictly decreasing function $f(\psi)$ takes on positive numbers, which occurs for values of $\psi$ sufficiently small ($\psi < \bar{\psi}$). In the interior solution where both patent protection and subsidies are employed, the two costs must be equalized.

Let us concentrate on balanced-growth path outcomes, and more specifically, on the ones related to the case in which both instruments are used simultaneously, because this is what we observe in reality. To guarantee the interior solution, we assume that $\tau_d \tau_f \in (\bar{\tau}, 1)$ for some $\bar{\tau}$ sufficiently large, and that $\psi < \bar{\psi}$. Combining (21) and (31) deliver the following expression that defines $\psi$ as a function of only $\tau_d$, $\tau_f$, $g_A$, $\rho$ and $\alpha$:

$$\frac{1 - \left[1 - \alpha^{\alpha/(1-\alpha)}\right] \psi}{1 - \left[1 - \alpha^{1/(1-\alpha)}\right] \psi} = \frac{1}{\alpha \left[1 - \alpha^{1/(1-\alpha)}\right]} \left[1 - \alpha^{\alpha/(1-\alpha)} - g_A \left(\frac{1}{\tau_d \tau_f} - 1\right) \frac{(1-\alpha)\, \alpha^{1/(1-\alpha)}}{g_A + \rho}\right]. \tag{33}$$

In expression (33), the LHS is strictly increasing in $\psi$ and always greater or equal than 1. As a consequence, intellectual property protection becomes stronger if $\tau_f \tau_d$ rise or $g_A$ decreases when both policy instruments coexist. We obtain that a more efficient government (higher $\tau_d$) has stronger IPR because the impact of $\psi$ on $R$ depends positively on $\tau_A$.

Equation (33) also implies that when the transaction costs increase, the government tends to stronger patent protection to incentive R&D investment. A larger transaction cost in financial markets can be as well interpreted for R&D firms as a larger risk premium. Then, the model predictions are consistent with the increase in patent protection that followed the change in financial regulations introduced in the U.S. to encourage venture capital into hi-tech firms (e.g., See Coriat and Orsi 2002).

We now turn to the optimal R&D subsidy $\tau_A$. Combining (30), (31) and (33), we obtain

$$\tau_A = \lambda \tau_d \, \tau_f \left[ \frac{\frac{1}{\psi} - 1 + \alpha^{\alpha/(1-\alpha)}}{(1-\phi) g_A + \rho} \right] \frac{g_A + \rho}{\alpha^{1/(1-\alpha)}}. \tag{34}$$

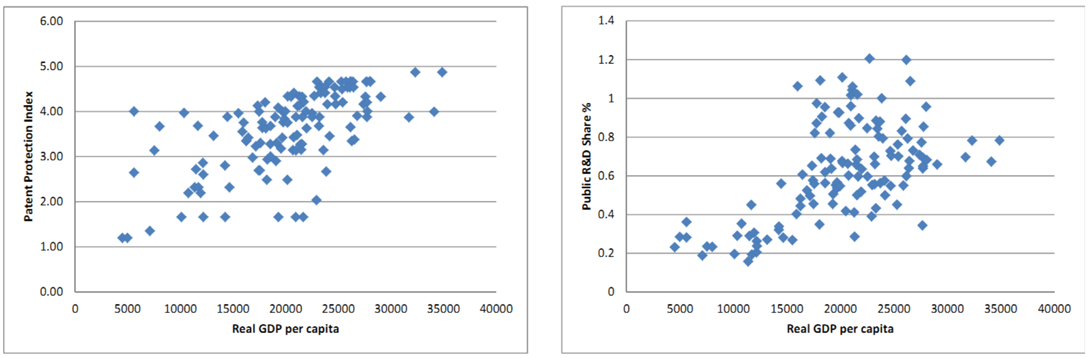
Because $\psi$ rises with $\tau_d \tau_f$, $\tau_A$ can go down or up. If the effect of $\tau_d \tau_f$ on the RHS dominates, an increase in these parameters will bring an increase in $\tau_A$. In that case, a more efficient government or a more inefficient financial sector will call for a higher innovation subsidization rate.

Finally, using expressions (21) and (34), the steady-state share of government-financed R&D equals

$$s_R \left( \frac{\tau_A - 1}{\tau_A} \right) = g_A \, (1-\alpha) \left\{ \frac{\lambda \tau_d \, \tau_f}{(1-\phi) g_A + \rho} - \frac{\psi \alpha^{1/(1-\alpha)}}{(g_A + \rho) \left[ 1 - (1 - \alpha^{\alpha/(1-\alpha)}) \psi \right]} \right\}. \tag{35}$$

Again, because both terms inside brackets go up with $\tau_d \tau_f$, the net effect on government-financed R&D is unclear.

Figure 1: Evolution of the two R&D policy tools against income per capita




Sources: Public R&D share computed using gross domestic expenditure in R&D financed by government from OECD Science and Technology Statistics 2007; Real GDP per capita from Penn World Tables; Patent protection index from Park (2008). Sample: Unbalanced panel formed by 28 OECD nations, five-year averages for the period 1981-2005.

To shed some more light on the predictions of the model, let us carry out a brief quantitative analysis using empirically-supported parameter values. In particular, pick $\alpha = 0.34$, $\lambda = 0.25$, $n = 0.01$, $g_A = 0.02$ and $\rho = 0.04$, which imply values of $r = 0.06$ and $\phi = 0.65$, and are appropriate for the US economy (e.g., see Perez-Sebastian 2007). Under this parameterization, $\bar{\psi} = 0.67$, and both $\psi$ and the share of public R&D increase with $\tau_d \tau_f$ for any $\tau_d \tau_f > 0.39$. This positive correlation between the two policy tools is what we observe in the data. For example, we can see it in Figure 1 that displays the evolution on patent protection and the public R&D share against the level of GDP per capita across nations.

# 4 Conclusion

R&D policy is one of the most important items in the public policy agenda. The lack of an efficient public R&D strategy is many times blamed for low economic growth, low wages, large unemployment rates, and even trade deficits. Two are the main types of actions that the public sector employes to promote R&D: patent protection and R&D subsidies. This paper has tried to improve our understanding of the design and evolution of these two R&D policy instruments.

Our main contribution has been building a theory that can formally explain the coexistence of IPR and R&D subsidies. In sharp contrast to more standard R&D-based growth models, R&D subsidies in our model can not achieve the first best due to the existence of government inefficiencies. The model is able to explain as well the increase in government R&D and the strength of IPR along the development path as a consequence of an improvement in government efficiency in spending relative to the private sector.

# 5 Acknowledgements

I am grateful to the Spanish Ministry of Science and Innovation (ECO2012-36719) and the Generalitat Valenciana (PROMETEO) for financial support.

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