International Competition, Growth, and Optimal R&D Subsidies*

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Abstract

In this paper I examine the effects of international technological competition on innovation, growth, and optimal R&D subsidies. I focus on a particular dimension of competition: the share of industries where domestic and foreign research firms compete for innovation. In a version of the fully-endogenous quality-ladder growth model I show that the effect of competition on innovation and growth depends on the specification of the research technology. Secondly, I find that increases in foreign competition trigger a business-stealing effect that reduces income and welfare and, regardless of the innovation effect, raises the optimal domestic R&D subsidy. Intuitively, the higher the threat of international competition the more instrumental innovation subsidies will be in helping domestic incumbent firms to retain their shares of the global market. Thirdly, I perform a quantitative exercise: I first build an empirical index of international technological competition and find that in the OECD countries the share of competitive sectors increased from 35 percent in 1973 to 70 percent in 1989. Then, I use this evidence to evaluate the optimality of the U.S. R&D subsidy response to observed competition in that period. I find a welfare loss of the observed policy, relative to the optimal, ranging between 0.2 and 0.5 percentage points of quality-adjusted per-capita consumption. Finally, I extend the model to account for strategic policy complementarities and show that the positive effect of competition on the optimal subsidy is robust to this set up. In addition, I find that competition increases the benefits from R&D policy cooperation.

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1 Introduction

Whether foreign competition has a positive or a negative effect on national welfare and on the long run rate of growth is an old question in economics. Schumpeter (1942), while speculating on the modus operandi of competition, points out that innovation rather than price is the main instrument of competition. In Schumpeter's view, higher competition does not mean a higher elasticity of demand for goods but a larger number of innovators working to appropriate each others rents. The entry of innovative firms, domestic and foreign, would stimulates innovation, long-run output growth and increase national welfare.[1] More recently, the strategic trade policy literature emphasized another effect of foreign competition that, though strictly related to the Schumpeterian innovation effect, affects national welfare negatively. The entry of foreign innovators increases the threat of business-stealing, which shifts profit rents from domestic to foreign firms, thus reducing domestic income and welfare.

Hence, in debating the implications of foreign competition, economists have mainly focused on two major forces: the innovation effect and the business-stealing effect. The relative strength of these two counteracting effects has also been at the root of recent policy debates on the impact of international competition. The "competitiveness debate" of the early 1990s was triggered by the reaction to the Clinton administration's target of regaining global technological leadership by means of strategic trade and industrial policies. The arguments of the opponents to strategic policies relied mainly on efficiency improvements brought by trade, and the arguments of the strategists were based on the business-stealing effect produced by foreign competition (see, for example, Krugman, 1994, and, 1996, and Tyson, 1992).

At the Lisbon European Council in March 2000, the heads of member states promised to make the E.U. "the most dynamic and competitive knowledge-based economy in the world" by 2010. This ambitious political project of pushing Europe towards a global technological supremacy, also known as the Lisbon Agenda, has fueled new debates among economists, policy makers and in the business community. The key issue here is to identify the role for strategic innovation policy in a increasingly competitive global economy (see, Sapir 2003 and Kok 2004).

Although the new trade theory and the endogenous growth literature provide many funda-

[1] In Schumpeter's own words: "[...] in capitalistic reality as distinguished from its textbook picture, it is not that type of competition [price competition] that counts but the competition from the new commodity, the new technology, the new source of supply, the new type of organization [...] -competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives". [Schumpeter (1941) p.84-86].

mental tools to study these problems, little attention has been dedicated to a specific analysis of the welfare effects of international competition in growing economies. Moreover, the exploration of the optimal policy implications of competition has been particularly neglected. In this paper I investigate the effects of changes in the scale of international technological competition on innovation, national welfare and R&D subsidies. I set up a fully-endogenous Schumpeterian growth model (Dinopoulos and Thompson, 1998, Howitt, 1999, Young, 1998), with two countries showing the same population, preferences and technology, but with different innovation subsidies and innovative set of sectors. I suppose that foreign R&D firms invest in innovation and challenge home firms, only in a subset of industries, while home firms remain unchallenged leaders in the remaining sectors. Therefore, there are some sectors where firms from both countries compete to discover the next best-quality good and appropriate monopoly rents. The measure of this set of industries, where research from both countries overlaps, will be my index of international competition. I study the effects on domestic welfare, on the rate of innovation, and on the optimal R&D subsidy, of an increase in the set of competing sectors.

I begin with a simplified economy showing constant returns to scale to R&D and no policy asymmetry between countries, and find that competition has no innovation effects, and has a business-stealing effect that reduces domestic income and welfare. I then introduce country and sector-specific decreasing returns to scale (DRS) to R&D and find that there is a positive innovation effect of competition whose strength is positively related to the concavity of the R&D technology. It follows that the welfare effect of competition is ambiguous and depends on the relative power of the business-stealing and innovation effects. The specification of parameters is key in determining the final result, especially the one that pins down the returns to R&D.[2]

The driving mechanism behind the two counteracting effects of competition are the following. On the one hand, the entry of foreign R&D workers in some sectors implies that, with a probability proportional to their research effort, monopolistic rents will shift from domestic to foreign firms. The shift of global market leadership in some sectors in favor of foreign firms will reduce aggregate domestic profits, income and national welfare. On the other hand, country-specific DRS to R&D implies higher productivity of research in competitive sectors. It follows

[2] The introduction of DRS to R&D makes the model analytically intractable. Thus, as it is often the case with endogenous growth models with asymmetric countries, I use numerical simulations to study the implications of my framework. Since the two countries have the same technologies, same preferences, and same populations my set up can be interpreted as a standard North-North trade model with endogenous technology. The countries' asymmetries are limited to the different national distribution of research accross sectors, and to country-specific R&D subsidies.

that increases in competition make the research activity more efficient, so raising aggregate innovation, growth, and, via quality improvements, national welfare.

Once I have explored the pure effects of competition on welfare I introduce strategic innovation policy by letting the domestic government choose the welfare maximizing levels of R&D subsidies in response to to changes in foreign competition - the foreign government is again assumed to be inactive. The result is that the optimal domestic subsidy is increasing in foreign competition for a wide range of parameters - even in those cases when competition is welfare improving. As foreign researchers enter the market, the threat of business-stealing raises along with the role R&D subsidies as an international rent-protecting device. In a more competitive economy government subsidies improve the ability of domestic firms to retain their shares of the global market.

I apply this result in evaluating the optimality of the U.S. policy response to the increase in international competition in the 1970s and 1980s. There is a substantial body of empirical evidence suggesting that in this period the U.S. experience increasing challenges to its technological leadership from abroad, mainly from Japan and European economies recovering from World War II. For instance, we observe a radical erosion of U.S. leadership in high-tech sectors: between 1980 and 1991 the global market share of the United States in the high-tech markets declined by 16 percent, while Japan's share increased by about 30 percent. Japan's share of high-tech export doubled from about 7 percent in 1970-73 to about 16 percent in 1988-89, while the U.S. share declined from 30 percent to about 21 percent. The loss of U.S. leadership was concentrated in four major high-tech sectors: electronics, aircraft and parts, scientific instruments, and medical equipment.[3]

Using OECD ANBERD data on R&D investment by industry I build an index of international R&D rivalry that matches my definition of technological competition and find that the U.S. unchallenged supremacy in research spending declined in the 1970s and 1980s. Specifically, I use R&D investment data at the two and three-digit industry level for manufacturing sectors, and consider a sector competitive if the U.S. share of global investment is below 50 percent. I found that the share of competitive sectors raises from 35 percent in 1973 to 70 in 1989. The result does not change very much when choosing a different threshold, weighting sectors with their value added, or focusing only on high-tech sectors. Furthermore, I also build a more

[3] See NSF (1998), appendix table 6-5., Guerrieri Milana (1991), and Tyson (1992)

standard indicator of R&D concentration, the Herfindahl index, and obtain similar qualitative trends.

A second piece of evidence that I take into account is that the erosion of the US leadership, especially in high-tech sectors, led policy makers to introduce new policy tools to deal with competitiveness threats (see Mowery, 1998, Ham and Mowery, 1997, and Cozzi and Impullitti, 2004). The scope of the new set of policies was to facilitate firms' access to public technology, to improve intellectual property rights and, more in general, to reduce the private cost of innovation. In this paper I propose a first attempt at evaluating the optimality of the U.S. policy response to increasing international competition in the 1970's and 1980s. I focus on one of the new policy tools introduced during this period: the R&D subsidy implicit in the Research and Experimentation (R&E) Tax Credit initiated in 1981. The quantitative exercise consists in computing the welfare loss of the observed U.S. policy response, with respect to the optimal policy, to changes in my indicator of international R&D competition in the period 1973-89. The results show a welfare loss of the order of 0.2 and 0.5 percentage points of the quality-adjusted per-capita consumption, and show that the loss is increasing in competition.

The final part of the paper contains an extension of the basic framework: I remove the assumption that only the domestic economy has an active innovation policy that responds to competition, so allowing the model to analyze the effects of strategic policy complementarities. First, I find that countries' best response functions are increasing in the space of R&D subsidies. This suggests the existence of strategic policy complementarities related to the business-stealing effect of subsidies. Second, I study the effects of changes in competition on the Nash subsidy: I show that the result that increases in competition raise the optimal domestic subsidy is robust to an environment with strategic policy complementarities. Moreover, I compute the gains from international cooperation in R&D policy relative to the non-cooperative solution, and show that the leader, the domestic country, loses from cooperation at low levels of competition, while gains became increasingly positive at high levels.

This paper is related to several branches of literature. In the first place, the paper relates directly to the endogenous growth literature and, more precisely, to the neo-Schumpeterian strand. Several papers in this literature have studied the impact of international trade and international competition on growth and, to a lesser extent on national welfare (e.g. Grossman and Helpman 1991 and Aghion and Howitt, 1998, Aghion and Griffith 2005, Klundert and

Smulders 1997, Peretto 1999). These works have focused primarily on the innovation and growth effects, and changes in international competition have been mainly modeled as changes in the size of the market or in the degree of product market competition. Furthermore, little attention has been dedicated to the welfare effects of international competition and to its R&D policy implications. One exception is Tang and Waelde (2001) that have investigated the welfare effects of product market competition and discussed its implications for trade policy.

My paper contributes to this this literature for the following reasons: first I adopt a pure Schumpeterian view of competition in that it is not determined by the market structure but by the number of sectors where different countries compete for innovation. Second, I study the welfare effects of competition and I also explicitly explore its implications for optimal research subsidies. Third, I focus only on R&D subsidies, and I do not consider any policies or barriers that restrict trade. In a world where other types of trade and industrial policies are now more and more regulated internationally, R&D policies still remain in the domain of national policy makers. Thus, in studing the welfare and optimal policy effects of international competition it seems important to focus on policy tools that can be implemented autonomously by governments of diffent countries.

The idea of emphasizing the business-stealing effect of international competition has its origins in the strategic trade and industrial policy literature. In a pioneering contribution, Brander and Spencer (1983) showed that, when two countries compete in a R&D race for the world industrial leadership, it will be optimal for governments to subsidize R&D. At the root of this result there is the idea that the monopoly power that characterizes many traded goods (particularly high-tech goods) provides incentives for governments' intervention: capturing larger market shares of the production of imperfectly competitive firms increases national income and welfare.[4] Most of the contributions in the strategic trade literature limit the analysis to unilateral policies and to export to a third market. These assumptions are restrictive in that they allow neither to study strategic policy complementarities and nor to account for the effect of R&D subsidies on consumers' surplus (innovation-effect). Recently, Haaland and Kind (2004) and (2005) have overcome these limits by allowing all countries to be active in innovation policy and removing the simplifying assumption that all output is exported to a third market.

Overall this literature is confined to static partial equilibruim models where the dynamic

[4] For a survey see Brander (1995).

effects of innovation are not taken into account. I introduce a strategic industrial policy game into an endogenous growth model and account for both the innovation effect and the business-stealing effect of research subsidies. Moreover, I study the interaction between international technological competition, strategic policy complementarities, and the gains from R&D policy coordination.

The rest of the paper is structured as follows. Section 2 sets up the model. In section 3 I study the pure effect of competition on innovation, growth and welfare, in the absence of policy. In section 4 I introduce innovation policy and study the effects of competition on optimal R&D subsidies in a set up where only the domestic government is active. Section 5 presents an application of my results: I compute the welfare loss associated with the U.S. R&D subsidy response to the observed increase in competition, relative to the optimal subsidy, in the period 1973-89. In section 6 I extend the model to account for the presence of strategic policy complementarities, check the robustness of my findings in this broader set up and, finally, evaluate the benefits from R&D policy cooperation. Section 7 concludes.

2 The model

2.1 Households

Consider a two-country economy in which population, preferences, technologies, and institutions are identical in both countries. Households have identical intertemporally additively separable preferences with unit elasticity over an infinite set of consumption goods indexed by $\omega \in [0,1]$. Each household is endowed with a unit of labor time whose supply generates no disutility. Dropping country indexes for notational simplicity, households choose their optimal consumption bundle for each date by solving the following optimization problem:

$$\max U = \int_0^\infty N_0 e^{-(\rho-n)t} \log u(t) dt \tag{1}$$

subject to

$$\log u(t) \equiv \int_0^1 \log \left[\sum_{j=0}^{j^{\max}(\omega,t)} \lambda^{j(\omega,t)} q(j,\omega,t) \right] d\omega$$

$$c(t) \equiv \int_0^1 \left[\sum_{j=0}^{j^{\max}(\omega,t)} p(j,\omega,t) q(j,\omega,t) \right] d\omega$$

$$W(0) + Z(0) - \int_0^\infty N_0 e^{-\int_0^t (r(\tau)-n)d\tau} T dt = \int_0^\infty N_0 e^{-\int_0^t (r(\tau)-n)d\tau} c(t) dt$$

where N_0 is the initial population and n is its constant growth rate, ρ is the common rate of time preference - with $\rho > n$ - and $r(t)$ is the market interest rate on a risk-free bond available in both countries. $q(j, \omega, t)$ is the per-member flow of good ω, of quality $j \in \{0, 1, 2, ...\}$, purchased by a household at time $t \geq 0$ -ω is defined on the product line $[0, 1]$. $p(j, \omega, t)$ is the price of good ω of quality j at time t, $c(t)$ is nominal expenditure, and $W(0)$ and $Z(0)$ are human and non-human wealth levels. A new vintage of a good ω yields a quality equal to λ times the quality of the previous vintage, with $\lambda > 1$. Different versions of the same good ω are regarded by consumers as perfect substitutes after adjusting for their quality ratios, and $j^{\max}(\omega, t)$ denotes the maximum quality in which the good ω is available at time t. As is common in quality ladders models I will assume price competition at all dates, which implies that in equilibrium only the top quality product is produced and consumed in positive amounts. T is a per-capita lump-sum tax.

The instantaneous utility function has unitary elasticity of substitution between every pair of product lines. Thus, households maximize static utility by spreading their expenditures evenly across the product line and by purchasing in each line only the product with the lowest price per unit of quality, that is the product of quality $j = j^{\max}(\omega, t)$. Hence, the household's demand of each product is:

$$q(j, \omega, t) = \frac{c(t)}{p(j, \omega, t)} \quad \text{for } j = j^{\max}(\omega, t) \text{ and is zero otherwise} \tag{2}$$

The presence of a lump sum tax does not change the standard solution of the intertemporal maximization problem, which is:

$$\frac{\dot{c}}{c} = r(t) - \rho \tag{3}$$

2.2 Product market

In each country, firms can hire workers to produce any consumption good $\omega \in [0, 1]$ of the second best quality under a constant returns to scale (CRS) technology described by the simple unit cost function w^K, where $K = D, F$ is the country indicator, domestic (D) and foreign (F). However in each industry the top quality product can be manufactured only by the firm that has discovered it, whose rights are protected by a perfectly enforceable world-wide patent law. Therefore, multinational companies are free to establish subsidiaries in low wage countries to carry out the manufacturing of their products; in equilibrium, labor prices will equalize. I choose the wage as the numeraire, that is: $w^D = w^F = 1$.

As usual in Schumpeterian models with vertical innovation (see e.g. Grossman and Helpman, 1991 and Aghion and Howitt, 1998) the next best vintage of a good is invented by means of the R&D performed by challenger firms in order to earn monopoly profits that will be destroyed by the next innovator. During each temporary monopoly, the patent holder can sell the product at prices higher than the unit cost. I assume, as standard in the literature, that the patent expires when further innovation occurs in the industry. Hence the monopolist rents are destroyed not only by obsolescence but also because a competitive fringe can copy the product using the same CRS technology.

The unit elastic demand structure encourages the monopolist to set the highest possible price to maximize profits, but the existence of a competitive fringe sets a ceiling to it equal to the world's lowest unit cost of the previous quality product.[5] This allows us to conclude that the price $p\left(j^{\max}(\omega,t),\omega,t\right)$ of every top quality good is:

$$p\left(j^{\max}(\omega,t),\omega,t\right) = \lambda, \text{ for all } \omega \in [0,1] \text{ and } t \geq 0. \tag{4}$$

From the static consumer demand (2) we can immediately conclude that the demand for each product ω is:

$$\frac{(c^D(t) + c^F(t))N(t)}{\lambda} = q\left(\omega,t\right), \tag{5}$$

The above equation implies that, in equilibrium, supply and demand of every consumption good coincides. It follows that the stream of monopoly profits accruing to the monopolist which produces a state-of-the-art quality product in country $k = D, F$ will be equal to:

$$\pi^K\left(\omega,t\right) = q\left(\omega,t\right)\left(\lambda - 1\right) = (c^D(t) + c^F(t))N(t)\left(1 - \frac{1}{\lambda}\right). \tag{6}$$

Hence a firm that produces good ω in country $k = D, F$ has market value

$$v^K\left(\omega,t\right) = \frac{\pi^K\left(\omega,t\right)}{r(t) + I(\omega,t) - \frac{\dot{v}(\omega,t)}{v(\omega,t)}} = \frac{q\left(\omega,t\right)\left(\lambda - 1\right)}{r(t) + I(\omega,t) - \frac{\dot{v}^K(\omega,t)}{v^K(\omega,t)}}, \tag{7}$$

where $I(\omega,t)$ denotes the worldwide Poisson arrival rate of an innovation that will destroy the monopolist's profits in industry ω. This is an arbitrage condition which states that the expected rate of return of a stock issued by an R&D firm is equal to the riskless rate of return $r(t)$. This follows from the assumption that there are efficient financial markets channelling savings into R&D firms.

[5] Any CES utility index with elasticity of substitution not greater than one would imply this result.

2.3 R&D races

In each industry leaders are challenged by the R&D firms that employ workers and produce a probability intensity of inventing the next version of their products. The arrival rate of innovation in industry ω at time t is $I(\omega,t)$, and it is the aggregate summation of the Poisson arrival rate of innovation produced by all R&D firms targeting product ω.

Every R&D firm can produce a Poisson arrival rate of innovation in the product line it targets by use of the following technology

$$I_i^K(\omega,t) = \frac{A l_i^K(\omega,t)\left(\frac{L^K(\omega,t)}{X(\omega,t)}\right)^{-\alpha}}{X(\omega,t)}, \tag{8}$$

where $X(\omega,t) > 0$ measures the degree of complexity in the invention of the next quality product in industry ω, $L^K(\omega,t) = \sum_i l_i^K(\omega,t)$ is the total labor used by R&D firms and $I^K(\omega,t) = \sum_i I_i^K(\omega,t)$ is the total investment in R&D (total arrival rate) in country K. This technology implies that each firm's instantaneous probability of success is a decreasing function of the total domestic R&D investment in the industry. A possible interpretation of this property is that when firms do more R&D in a sector, the probability of duplicative research effort increases, thereby reducing the probability that any single firm will discover the next vintage of goods and appropriate the profit rent associated to it. Therefore, the sector-specific negative externality in research technology produces decreasing returns to scale (DRS) in R&D at the industry level.[6] Moreover, I assume the negative externality produced by duplicative research is country-specific. The country-specific nature of DRS in R&D could be motivated by the presence of some fixed costs such as lab equipment.[7]

The technological complexity index $X(\omega,t)$ was introduced into endogenous growth theory after Jones' (1995) empirical criticism of R&D based growth models generating scale effects in the steady state per-capita growth rate. It is standard to assign the index two alternative laws of motion. I will use the one introduced by Dinopoulos and Thompson [1998], that is

$$X(\omega,t) = 2\kappa N(t), \tag{PEG}$$

[6] A similar industry-specific externality with a similar interpretation can be found in Segerstrom and Lundborg (2002).

[7] A typical microfundation for this is attainable by relating the country-specific R&D externality to heterogeneous ability of workers (Eaton and Kortum 1999). As investment in research increases in a country, workers of lower ability will be used and R&D productivity will decline. In my model the presence of global labor markets do not allow for this type of intuition.

with positive k, thereby formalizing the idea that it is more difficult to introduce a new product in a more crowded market. The PEG, as well as others that are similar, rules out implausible "scale effects". More precisely, this formulation allows for sustained per-capita growth without population growth and leads to a class of models also know as fully-endogenous growth frameworks (Aghion and Howitt 2004).[8] In the present framework with quality improving consumer goods, "growth" is interpreted as the increase over time of the representative consumer utility level.

Each R&D firm chooses l_i^K in order to maximize its expected discounted profits.[9] Free entry into R&D races drives the expected profits to zero, generating the following equilibrium condition:

$$v^K(\omega,t)\frac{A\left(\frac{L^K(\omega,t)}{X(\omega,t)}\right)^{-\alpha}}{X(\omega,t)} = (1-s^K). \tag{9}$$

The usual Arrow or replacement effect [Aghion and Howitt 1992] implies that the monopolist does not find it profitable to undertake any R&D at the equilibrium wages. Putting together the free entry condition and the arbitrage condition (7) we get:

$$\frac{N(t)(c^D(t)+c^F(t))\left(\frac{\lambda-1}{\lambda}\right)}{r(t)+I(\omega,t)-\frac{\dot{v}(\omega,t)}{v(\omega,t)}}\left(\frac{L^K(\omega,t)}{X(\omega,t)}\right)^{-\alpha} = \frac{(1-s^K)X(\omega,t)}{A} \tag{10}$$

where I have substituted the profit equation (6) into the equation for the value of the firm. This condition, together with the Euler equation summarizes the utility maximizing household choice of consumption and savings, and the profit maximizing choice of manufacturing and R&D firms. Introducing the labor market clearing condition allows us to close the model and look for a general equilibrium solution.

[8] Acronym "PEG" refers to the "permanent effects on growth" of policy measures such as R&D subsidies and tariffs: they can alter the steady state pe-rcapita growth rate. A different specification of the difficulty index, proposed by Segerstrom (1998), is $\frac{\dot{X}(\omega,s)}{X(\omega,s)} = \mu I(\omega,s)$, and it formalizes the idea that early discovery fish out the easier inventions first, leaving the most difficult ones for the future. This specification is called (TEG), and it refers to the fact that it implies only "temporary effects on growth" of policy measures. That is the reason why models that use this specification are also known as semi-endogenous growth models (see also Peretto 1998, Kortum 1997 amd Jones 1995).

[9] The discounted profits equals

$$v(\omega,t)Al_i^K\left(\frac{L^K(\omega,t)}{X(\omega,t)}\right)^{-\alpha}\frac{1}{X(\omega,t)} - l_i^K(1-s^K)$$

where s^k is the R&D subsidy

2.4 Modeling international competition: the overlapping research support.

Before closing the model I need to introduce our definition of international competition. I model competition as the measure of the set of sectors where research from both countries overlaps. Let ξ_c be the set of industries where domestic and foreign researchers compete to discover the next best vintage of goods. I assume that foreign firms do not compete for innovation in the subset $1-\xi_c$, where domestic firms do not face any foreign threat to their leadership. I choose $\bar{\omega} \in (0,1)$ to be the measure of the subset of industries ξ_c. Therefore the composition of the worldwide investment in innovation will be the following:

$$
\begin{aligned}
I(\omega,t) &= I_c^D(\omega,t) + I^F(\omega,t) = I_c^D(t) + I^F(t), & \omega \in \xi_c \\
I(\omega,t) &= I_m^D(\omega,t) + 0 = I_m^D(t), & \omega \in 1-\xi_c \\
X(\omega,t) &= 2\kappa N(t) & \text{for all } \omega, ,
\end{aligned}
$$

where $\kappa > 0$, and $I_c^D(\omega,t)$ and $I_m^D(\omega,t)$ are country D's investment in R&D in the competitive and in the non-competitive sectors respectively, and $I^F(\omega,t)$ is research investment of country F. The symmetric structure of the model leads us to study only symmetric allocation of R&D investment, $I_c^D(\omega,t) = I_c^D(t)$, $I_m^D(\omega,t) = I_m^D(t)$, $I^D(\omega,t) = I^D(t)$ for all $\omega \in (0,1)$. The specified composition of R&D investment implies that the equilibrium condition (10) will be:

$$
\begin{aligned}
\frac{X(t)}{N(t)A}(1-s^K) &= \frac{\left(c^D(t)+c^F(t)\right)\left(\frac{\lambda-1}{\lambda}\right)}{r(t)+I_c^D(t)+I^F(t)-\frac{\dot{v}^K(t)}{v^K(t)}}\left(\frac{L_c^K(t)}{X(t)\overline{\omega}}\right)^{-\alpha}, & \omega \in \xi_c \text{ and } k = D, F \\
\frac{X(t)}{N(t)A}(1-s^D) &= \frac{\left(c^D(t)+c^F(t)\right)\left(\frac{\lambda-1}{\lambda}\right)}{r(t)+I_m^D(t)-\frac{\dot{v}^D(t)}{v^D(t)}}\left(\frac{L_m^D(t)}{X(t)(1-\overline{\omega})}\right)^{-\alpha}, & \omega \in 1-\xi_c,
\end{aligned}
$$

where L_c^D and L_m^D are respectively the total domestic R&D labor used in the competitive and non competitive sectors.

2.5 Labor markets clearing and national resource constraints

The unit cost of production for every good implies that the total production of goods in a country is equal to the total labor used for manufacturing in that country. The total manufacturing labor is given by the total labor supply minus the labor used in R&D. The presence of a complete set of multinationals implies that both the labor and goods market clear globally. The condition that clears both markets is the following:

$$\left(\frac{c^D(t)+c^F(t)}{\lambda}\right)N(t)=2N(t)-X(t)\left[\overline{\omega}\left(\frac{I_c^D(t)}{A}\right)^{\frac{1}{1-\alpha}}+(1-\overline{\omega})\left(\frac{I_m^D(t)}{A}\right)^{\frac{1}{1-\alpha}}+\overline{\omega}\left(\frac{I^F(t)}{A}\right)^{\frac{1}{1-\alpha}}\right]. \tag{11}$$

The LHS represents the total demand for goods (labor), and the RHS is total supply, given by total labor resources minus labor used in research.[10] To close the model I need to consider the resource constraint of the two countries. In each country total expenditures plus savings (investment in R&D) must equal the wage income plus total profits (or interest income on assets).[11]

$$\left[\overline{\omega}\left(\frac{I_c^D(t)}{A}\right)^{\frac{1}{1-\alpha}}X(t)+(1-\overline{\omega})\left(\frac{I_m^D(t)}{A}\right)^{\frac{1}{1-\alpha}}X(t)\right]+N(t)c^D(t)= \tag{12}$$

$$=N(t)+N(t)(c^D(t)+c^F(t))\left(\frac{\lambda-1}{\lambda}\right)\left[1-\overline{\omega}+\overline{\omega}\frac{I_c^D(t)}{I_c^D(t)+I^F(t)}\right]$$

$$\left[X(t)\overline{\omega}\left(\frac{I^F(t)}{A}\right)^{\frac{1}{1-\alpha}}\right]+N(t)c^F(t)=N(t)+N(t)(c^D(t)+c^F(t))\left(\frac{\lambda-1}{\lambda}\right)\left[\overline{\omega}\frac{I^F(t)}{I_c^D(t)+I^F(t)}\right] \tag{13}$$

Notice that R&D investment is simply the wage bill of R&D workers and that each country appropriates the monopoly rent in the subset of industries where that country is a world leader. It is also worth noticing that we are assuming complete "home-bias" in asset ownership, in the sense that domestic firms are completely owned by domestic population and foreign firms are completely owned by foreign population. This assumption is supported by empirical evidence on home-bias in asset ownership. French and Poterba (1991) and Tesar and Werner (1995) estimated the percentage of aggregate stock market wealth invested in domestic equities at the beginning of the 1990s to be well above 90% in the U.S. and Japan and around 80% in the UK

[10] Labor allocated to research is $L^D(t)=\overline{\omega}X(t)\left(I_c^D(t)/A\right)^{\frac{1}{1-\alpha}}+(1-\overline{\omega})X(t)\left(I_m^D(t)/A\right)^{\frac{1}{1-\alpha}}$ for the domestic country and $L^F(t)=\overline{\omega}X(t)\left(I^F(t)/A\right)^{\frac{1}{1-\alpha}}$ for the foreign country respectively.

[11] Segerstrom and Lundborg (2002) do not treat R&D expenditures as investment. They acknowledge that R&D should be treated as investment in national accounts but in reality, they claim, this is not done. We instead include R&D investment in the national budget constraint: one implication of this is that taxes levied to fund R&D subsidy cancel out in the constraint with the reduction in R&D costs due to subsidies. Considering R&D as current expenditures doesl not change our qualitative results.

and Germany. I have also worked out an alternative set up with partial "home bias" in which the qualitative results remain unaffected.[12]

Finally, I need to mention that hidden in the national resource constraints above is the assumption of balanced trade. This assumption is acceptable when focusing only on steady states equilibria, as I do in the next sections.

2.6 Balanced growth path

I focus on the steady state properties of the model, where per-capita endogenous variables are stationary. From the free entry condition (9) we get $\dot{v}^D(t)/v^D(t) = (1-\alpha)\dot{X}(t)/X(t) + \alpha \dot{L}^K(t)/L^K(t)$. Using the expressions for the R&D labor derived above we know that $\dot{L}^K(t)/L^K(t) = [1/(1-\alpha)]\, \dot{I}_c^K/I_c^K + \dot{X}(t)/X(t)$ in each competitive industry, and $\dot{L}^K(t)/L^K(t) = [1/(1-\alpha)]\, \dot{I}_m^D/I_m^D + \dot{X}(t)/X(t)$, since in steady state the allocation of R&D labor will be stationary, it follows that $\dot{L}^K(t)/L^K(t) = \dot{X}(t)/X(t)$, therefore $\dot{v}^D(t)/v^D(t) = \dot{X}(t)/X(t) = n$ (where I used (PEG). Similarly I derive $\dot{v}^F(t)/v^F(t) = \dot{X}(t)/X(t) = n$. Finally, from the Euler equation for consumption I get the steady state value of the interest rate, $r(t) = \rho$.

Taking into account the expressions for the labor used in R&D derived above, the set of no-arbitrage and free entry conditions becomes:[13]

$$\frac{2\kappa}{A}(1-s^K) = \frac{(c^D + c^F)\left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_c^D + I^F - n}\left(\frac{I_c^K}{A}\right)^{\frac{-\alpha}{1-\alpha}}, \quad \omega \in \xi_F \text{ and } K = D, F \tag{14}$$

$$\frac{2\kappa}{A}(1-s^D) = \frac{(c^A + c^B)\left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_m^D - n}\left(\frac{I_m^D}{A}\right)^{\frac{-\alpha}{1-\alpha}}, \qquad \omega \in 1-\xi_F \tag{15}$$

The remaining equations of the equilibrium system are provided by the two aggregate national resource constraints.

$$2\kappa\left[\varpi\left(\frac{I_c^D}{A}\right)^{\frac{1}{1-\alpha}} + (1-\varpi)\left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}}\right] + c^D = 1 + (c^D + c^F)\left(\frac{\lambda-1}{\lambda}\right)\left[1 - \varpi + \varpi\frac{I_c^D}{I_c^D + I^F}\right] \tag{16}$$

$$2\kappa\left[\varpi\left(\frac{I^F}{A}\right)^{\frac{1}{1-\alpha}}\right] + c^F = 1 + (c^D + c^F)\left(\frac{\lambda-1}{\lambda}\right)\left[\varpi\frac{I^F}{I_c^D + I^F}\right] \tag{17}$$

[12] In appendix B we show how to modify the basic set up to account for partial home bias.

[13] Notice that $x(t) = \frac{X(\omega,t)}{N(t)}$, that from PEG it is constant at $2k$.

The equilibrium includes also the goods market clearing condition, but as this condition turns out to be the sum of the two resource constraints (16) 17), the three equations are not linearly independent and I can omit one of them. We are left with a system of five equations that I can solve for the five unknowns $\left\{c^D, c^F, I_m^D, I_c^D, I^F\right\}$.

Before solving the equilibrium systems and deriving the main implications I complete the description of the model showing the welfare equations. Substituting the steady state instantaneous utility of the household problem (1) into the discounted utility I obtain discounted welfare indicators for both countries,

$$W^D \equiv (\rho - n)U^D = \ln \frac{c^D}{\lambda} + \frac{g}{\rho - n} \tag{18}$$

$$W^F \equiv (\rho - n)U^F = \ln \frac{c^F}{\lambda} + \frac{g}{\rho - n}, \tag{19}$$

where $g = \left[\bar{\omega}(I_c^D + I^F) + \left(1 - \bar{\omega}\right) I_m^D\right] \ln \lambda$ is the growth rate that, in our free trade economy, benefits consumers worldwide. Two-country endogenous growth models become complicated when either structural or public policy differences produce differences in endogenous variables.[14] Structural differences, in the form of different research supports and policy differences, in the form of national R&D subsidies, are crucial in my exploration of the effect of international competition on national welfare and optimal policy. In the following sections I show that an analytical solution is attainable only for the simplified set up with CRS to R&D and symmetric subsidies. For all other specifications I explore the implications of the model numerically.

3 Competition, growth and welfare

In this section I abstract from government policy and explore the "pure" impact of increases in the set of competitive sectors $\overline{\omega}$ on innovation, growth, and domestic welfare. I discuss and evaluate the role and the strength of the two forces at work: the international business-stealing and the innovation effect. Since the degree of convexity of R&D technology has both computational and conceptual implications I proceed into steps. First, I set up a simple version of the model with a constant returns technology for the research activity and I derive analytically the growth and welfare effects of competition. Later, we return to the general version of

[14] See Lundborg and Segerstrom (2002).

the model reintroducing decreasing returns to scale (DRS) to R&D and present a numerical comparative statics analysis.

3.1 Constant returns to scale in R&D

Assuming no government policy boils down to set R&D subsidies equal to zero in both countries.[15] CRS in R&D implies setting $\alpha = 0$, which gives the following R&D technology:

$$I_i^K(\omega,t) = \frac{Al_i^K(\omega,t)}{X(\omega,t)}. \tag{20}$$

The removal of different R&D subsidies and the introduction of a constant returns to scale technology imply that R&D costs and benefits are the same in both countries. It follows that innovation in competitive sectors is the same in both countries, that is $I_c^D = I^F$. Moreover, the simpler R&D technology implies that the allocation of research efforts between competitive and non-competitive sectors is pinned down only by the rates of creative destruction. As we see in eqs. (14) and (15), the optimal research allocation leads to the same economic obsolescence in competitive and non-competitive sectors:

$$I_m^D = I_c^D + I^F. \tag{21}$$

The assumption of CRS in R&D reduces substantially the nonlinearity of the steady state systems of equations and we can easily work out a closed form solution of the model, obtaining some insights on the pure effects of competition on domestic income and on the rate of innovation.

Proposition 1 *For $(\lambda - 1)\,A/\kappa \geq (\rho - n)$ a steady state equilibrium exists at all levels of competition $\overline{\omega}$. Increases in the set of competitive sectors have no effects on the growth rate and trigger a business-stealing effect that reduces domestic profits and welfare.*

Proof. See appendix A. ■

The intuition for the lack of growth effects of competition is based on the specification of the R&D technology, and on the fact that the two countries are perfectly symmetric in all features except the number of sectors in which they innovate. In this economy there are two margins

[15] The same qualitative results can be obtained with a symmetric R&D policy, both countries setting the same non-zero subsidy rate. We set it to zero for simplicity.

that pin down the decision to invest in innovation: the allocation of labor resources between production of goods and production of ideas, and the allocation of the research effort between competitive and non competitive sectors. The first margin is not affected by competition because, as we can see in eq. (9) the cost of research is fixed by the wage rate at 1. The allocation of research effort between the $\overline{\omega}$-type and the $(1-\overline{\omega})$-type of sectors, on the other hand, is not affected by competition because of constant returns in the research technology. In fact, this specification of technology implies that research is equally productive in competitive and non competitive sectors and so a change in the scale of research activity, brought by competition, does not affect research productivity. Obsolescence of innovation will adjust to accommodate foreign researchers in a way that (21) always hold. It follows that, as innovation is the same in the two types of sectors, increases in competition will only increase the share of innovation produced by $\overline{\omega}$-type sectors with no effect on the total growth rate.

The business-stealing effect reduces domestic aggregate profits because foreign firms appropriate a bigger share of the world market. Since, by assumption, the labor market is not affected by shifts in the global ownership distribution of firms, the domestic income will decrease with profits. Considering the expression for the domestic resource constraint (16) it is easy to see that this will reduce the resources available for consumption, thereby negatively affecting welfare in eq. (18).

Finally, even though competition has no effects on the global innovation intensity, by increasing the number of sectors where both countries innovate it raises the obsolescence on innovation in those sectors, thus reducing the share of global innovation performed in the domestic country. More precisely, total domestic research effort is reduced by $\partial L^D/\partial\overline{\omega} = (2\kappa/A)\left(I_c^D - I_m^D\right) < 0$. As a consequence the home country allocates more labor resources to the production of consumption goods, so increasing consumption and welfare. As showed in eq. (29) in appendix A, this effect is weaker than the negative effect of business-stealing on consumption, so the overall effect of competition on welfare is negative.

3.2 Decreasing returns to scale in R&D

Our next task is to switch back to the full model, reintroducing DRS in research and different R&D subsidies, and solve numerically for its steady state using Netwon's method. I first calibrate the parameters of the model to match some basic long-run empirical regularities of the

US economy. Then, I use the calibrated model to study the effects of competition on domestic welfare and on the optimal domestic R&D subsidy, assuming that the foreign government is not active in subsidizing innovation.

3.2.1 Calibration

We have to calibrate 6 parameters, three of them, ρ, λ, n, will be calibrated using benchmarks that are standard in the growth literature, and the others, A, α, k, will be calibrated internally in order for the model's steady state to match salient facts of the U.S. economy.

Parameters calibrated "externally"- Some parameters of the model have close counterpart in real economies so that their calibration is straightforward. I initially set ρ, which in steady state is equal to the interest rate r, to 0.05. Jones and Williams (2000) suggest that the interest rate in R&D-driven growth models is also the equilibrium rate of return to R&D, and so it cannot be simply calibrated to the risk-free rate on treasury bills - which is around 1%. They in fact calibrate their R&D-driven growth model with interest rates ranging from 0.04 to 0.14, which is closer to the average real return on the stock market for the past century of 0.07 estimated in Mehra and Prescott (1985) then to the return on risk-free assets. I set λ to 1.1 to match an average markup over the marginal cost of 0.1. Estimates of average mark-up over the marginal cost range in the interval $(0.1, 0.4)$ (Basu 1996), which in my model implies values for λ in the interval $(1.1, 1.4)$. I calibrate n to match the population growth rate of 1%, as is standard in the growth literature.

Parameters calibrated "internally"- I simultaneously choose (A, α, κ) so that the numerical steady state solution of the model matches the following stylized facts. 1) An average growth rate for the US economy of 2.3% in the period 1951-2000 (Penn World Table). 2) An average R&D investment, as a share of GDP, of 2.5% in the period 1951-2000 (NSF S&E Indicators 2004). 3) A consumption per capita of 0.67, in the period 1951-2004 (BEA NIPA tables). 4) An average labor share of 0.67 for the period 1965-95 (Blanchard and Wolfers 2000). 5) I also use an initial value for the subsidy of 0.08, which is the weighted average of effective R&D tax credit[16] for the period 1981-90, estimated in Hall (1992). Table I below summarizes the benchmark parameters calibration.[17]

[16] The purpose of using an initial subsidy in our loss function is to set the calibrated parameters in way that, when we study the numerical effects of competition on the optimal subsidies we obtain realistic measures of the subsidies.

[17] The parameters calibrated internally have been minimizing the quadratic distance between the model steady

TABLE I
Benchmark parameters

parameter	value	moment to match	source
ρ	0.07	interest rate	Jones and Williams (2000)
λ	1.1	markup	Basu (1996)
n	0.01	population growth rate	Standard
A	0.55	internal	various
α	0.77	internal	various
κ	0.75	internal	various

It is worth noting that by calibrating the model on U.S. data I am implicitly assuming that the stylized facts listed above are similar in the two economies. Since we are studying competition for innovation among technologically advanced countries this does not appear to be an extremely restrictive assumption. If we consider OECD countries we find many similarities in the long-run fact described above.

3.2.2 Numerical simulations

Here I explore the impact of the business-stealing and of the innovation effect of competition on domestic growth and welfare. In Table III I report the results of the benchmark simulation, and below I summarize the main findings.

Result 1. *An increase in foreign competition has the following effects on the domestic country:*

i. *It triggers a business-stealing effect that, by shifting monopoly rents from domestic to foreign firms, reduces domestic aggregate profits and income, thereby worsening welfare.*

ii. *It produces an innovation effect that increases growth and welfare in both countries.*

iii. *It reduces the total amount of research labor.*

iv. *The overall effect of competition on welfare is positive in the benchmark numerical simulation, is decreasing in* α*, and becomes negative for* α *close to zero.*

The business-stealing effect works as in the simpler set up so affecting negatively home income and welfare. In order to understand the effects of competition on innovation we need to sketch a heuristic proof of the result. We begin showing that for $\alpha > 0$ R&D investment

state and the stylized facts listed above.

in equilibrium will be such that $I_m^D < I_c^D + I^F$. In section 3 we saw that in the simplified setting with CRS to R&D ($\alpha = 0$) the research arbitrage and free entry conditions (14), (15), yield $I_m^D = I_c^D + I^F$. Keeping this result in mind we consider the effects of introducing the R&D externality on the innovation arbitrage conditions. As in the simple model of the previous section, the only relevant innovation choice affected by competition is the one between competitive and non-competitive sectors. Assume $\alpha > 0$ and consider the marginal benefits of investing in research in a $\bar{\omega}$-type of sector and in a $(1-\bar{\omega})$-type of sector:

$$\frac{\left(c^D + c^F\right)\left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_m^D - n}\left(\frac{I_m^D}{A}\right)^{\dfrac{-\alpha}{1-\alpha}} = \frac{\left(c^D + c^F\right)\left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_c^D + I^F - n}\left(\frac{I_c^D}{A}\right)^{\dfrac{-\alpha}{1-\alpha}} \tag{22}$$

The arrival rate of innovation in a non-competitive sector cannot be higher than the one in a competitive sector. In equilibrium the no-arbitrage condition between investing in a R&D firm in a competitive industry and in a non-competitive industry impose that the marginal benefit of R&D (marginal productivity of R&D times the present value of the monopolistic firm) is equal in the two industries. Since the productivity of R&D is higher in the competitive industries (due to the country-specific DRS in R&D) the value of the firm in equilibrium must be lower in these industries. As the value of the firm is given by profits (which are the same in both industries) discounted by the interest rate and the creative destruction, it follows that innovation (creative destruction) in the competitive sectors must be higher than in non-competitive sectors. Hence, from (22) it follows that in equilibrium we will always have $I_m^D < I_c^D + I^F$. Since, changes in competition do not affect the cost of R&D in any sector, innovation per sector does not change, that is $\partial I_c^D / \partial \bar{\omega} = \partial I^F / \partial \bar{\omega} = \partial I_m^D / \partial \bar{\omega} = 0$. Thus, increases in competition raise the share of industries with an higher innovation arrival rate, so producing a positive effect on the aggregate growth rate of the economy - $\partial g / \partial \bar{\omega} = \left[\left(I_c^D + I^F\right) - I_m^D\right] \log \lambda > 0$ for all $\alpha > 0$.

TABLE II

NUMERICAL STEADY STATE WITH NO POLICY

Competition	0	0.2	0.4	0.6	0.8	1
Income D	1.1836	1.1651	1.1467	1.1282	1.1098	1.0915
income F	1.0000	1.0183	1.0367	1.0550	1.0732	1.0915
I_m^D	0.3305	0.3305	0.3305	0.3305	0.3305	0.3305
I_c^A	0.2848	0.2848	0.2848	0.2848	0.2848	0.2848
I^F	0.2848	0.2848	0.2848	0.2848	0.2848	0.2848
R&D Spending D	0.1638	0.1481	0.1324	0.1167	0.1011	0.0854
R&D Spending F	0	0.0171	0.0343	0.0514	0.0684	0.0854
Growth rate	0.0315	0.036	0.0406	0.0451	0.0497	0.0542
Welfare D	0.7118	0.8229	0.9339	1.0449	1.1558	1.2667
Welfare F	0.6922	0.8071	0.9221	1.0370	1.1519	1.2667

Table III below shows the sensitivity of the growth and welfare effects of competition to changes in parameter α that measure the strength of the R&D country-specific externality. As stated in result 1 for small values of α the innovation and growth effect of competition are negligible and the business-stealing effects dominates, so making competition bad for welfare. For values of α larger than 2 competition is growth and welfare enhancing.

TABLE III

DRS TO R&D, COMPETITION AND GROWTH

			$\alpha = 0.5$			
Competition	0	0.2	0.4	0.6	0.8	1
Growth rate	0.0166	0.0181	0.0196	0.0211	0.0152	0.0241
Welfare D	0.3536	0.3871	0.4206	0.4539	0.2857	0.5206
			$\alpha = 0.3$			
Competition	0	0.2	0.4	0.6	0.8	1
Growth rate	0.0097	0.0102	0.0108	0.0113	0.0119	0.0124
Welfare D	0.1975	0.2054	0.2132	0.2209	0.2286	0.2363
			$\alpha = 0.1$			
Competition	0	0.2	0.4	0.6	0.8	1
Growth rate	0.0048	0.0049	0.0050	0.0052	0.0053	0.0054
Welfare D	0.1055	0.1000	0.0945	0.0889	0.0832	0.0775

As before, increases in foreign competition reduce the total amount of resources devoted to research in the domestic country. This is a direct consequence of the fact that foreign researchers make innovation in the newly competitive sectors more obsolete. Using our expression for the total amount of domestic resources devoted to R&D, it is easy to show that $\partial L^D/\partial\overline{\omega} = 2\kappa\left[\left(I_c^D/A\right)^{\frac{1}{1-\alpha}} - \left(I_m^D/A\right)^{\frac{1}{1-\alpha}}\right]$ is negative because from (22) we know that $I_m^D > I_c^D$. As we saw in the simple model of the previous section, this implies that competition increases the domestic resources allocated to production, thus raising the quantity of goods consumed by domestic households. Again this is a second order effect in the sense that it is not strong enough to counteract the negative business-stealing effect on welfare, as was the case in the simplified model where competition has no innovation effect. In fact table III shows that domestic income declines substantially with increases in competition.

In conclusion, we have found that the welfare effect of competition is ambiguous and depends primarily on the strength of the R&D externality. It is also worth noticing that the assumption of global labor markets prevents any effect of competition on the labor market. Intuitively, international competition, by shifting monopoly rents of some sectors from domestic to foreign firms, affects domestic workers only in that they will now work for foreign companies. There are no job-displacements or wage adjustments; domestic plants are simply taken over by foreign owners. This feature of the model reduces the impact of the business-stealing effect on welfare, thus overstating the positive welfare effect of competition. Allowing for labor market that, at least in part, clears locally the business-stealing effect would reduce both profits and wages, so strenghtening the negative impact of competition on national welfare.[18]

4 International competition and optimal R&D subsidies: one government active

Now that we know the how foreign competition affects the domestic economy, we can reintroduce policy and study the impact of competition on the optimal innovation subsidy. I use the calibrated model to study the effects of competition on the optimal home subsidy under the assumption that the foreign country does not have an active R&D policy. More precisely, I perform the following numerical experiment: I find the steady state for all possible values of ω and s^D, and for a given value of s^F, map the equilibrium domestic welfare levels for all possible

[18]The presence of a global patent and of multinational is a simplifying assumption that allows us to focus on the rent-shifting effect of competition. This is a conservative assumption that reduces the negative effect of competition on domestic welfare. Removing this hypothesis would reniforce the distorsionary effect of competition and strenghten its effects on optimal subsidies.

values of the two relevant parameters, and obtain the welfare maximizing subsidy at each level of competition:

$$s^{*D}(\overline{\omega}) = \left\{\arg\max W^D(s^D, \overline{\omega})\right\}.$$

Below I only present the numerical results of the benchmark model and in appendix C I perform a sensitivity analysis to test the robustness of the results to changes in the free parameters A, α, κ, ρ, n, λ. In Table III I report the results of the numerical simulation, and result 2 summarizes the main findings.

Result 2. *Increases in international competition reduce domestic income and raise the growth rate, domestic welfare and optimal R&D subsidy.*

TABLE IV
COMPETITION & OPTIMAL SUBSIDY

Competition	0	0.2	0.4	0.6	0.8	1
Optimal subsidy D	.025	.095	.165	.230	.300	.370
Welfare Gains D %	0	.0008	.0025	.0048	.0080	.0121

To understand the movement of the optimal subsidy I show the welfare equation in a form that facilitates the intuition of the mechanism behind the result, and decompose the effects of subsidies on the marginal condition of the domestic planner in setting optimal R&D subsidies. Welfare in both countries can be expressed as

$$W^K = CS + \Pi^K + w - R^K \tag{23}$$

where the consumer surplus equals the common growth rate, $CS = CS^D = CS^F = g/(\rho - n)$, and $\Pi^K = \Pi^D$, Π^F are the logs of the per-capita aggregate real profits for the two countries[19]. The standard resource constraint effect of innovation is represented by the log of total real investment in research that reduces resources available for consumption, that is

[19] The logarithm of the per-capita consumption aggregate profits are

$$\Pi^D = \ln\left\{(c^D + c^F)\left[\left(\frac{\lambda-1}{\lambda}\right)\right]\left[1 - \overline{\omega} + \overline{\omega} I_c^D / \left(I_c^D + I^F\right)\right]/\lambda\right\}$$

and

$$\Pi^F = \ln\left\{(c^D + c^F)\left[\left(\frac{\lambda-1}{\lambda}\right)\right]\left[\overline{\omega} I^F / \left(I_c^D + I^F\right)\right]/\lambda\right\}$$

for the domestic and the foreign country respectively.

$R^K = \ln(L^K/\lambda)$.[20] Finally, labor income w is $\ln(1/\lambda)$. Eq. (24) shows the different effect of subsidies on welfare:

$$\frac{\partial W^D}{\partial s^D} = \underbrace{\frac{\partial R^D}{\partial s^D}}_{\substack{\text{Resource constr.} \\ (-)}} + \underbrace{\frac{\partial CS}{\partial s^D}}_{\substack{\text{Consumer surplus} \\ (+)}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{\text{Business-stealing} \\ (+)}} \tag{24}$$

Suppose $\overline{\varpi} = 0$, then in evaluating the optimal R&D subsidy the domestic policy maker will have to deal with the standard trade-off of one-country models. On the one hand, an increase in domestic subsidies subtracts resources to manufacturing, thus reducing production and the consumption component of welfare - this is the resource constraint effect. On the other hand, R&D subsidies stimulate domestic research that triggers innovation and raises welfare via quality improvements - this is the innovation or consumer surplus effect. The optimal subsidy will be set at a level where the two counteracting forces do not allow for any welfare-enhancing reallocation of resources between R&D and manufacturing. If we now let international competition play a role, that is we assume $\overline{\varpi} > 0$, the policy maker needs to take into account a third force: the international business-stealing effect. From eq. (16) it is easy to see that an increase in domestic R&D investment (triggered by an increase in s^D) improves national firms' capacity to appropriate global profits rents, so raising national profits and, ceteris paribus, national consumption. It follows that competition makes R&D subsidies more welfare enhancing at the margin and induces policy makers to raise their level. Using the aggregate profit equation, we can easily see that competition increases the magnitude of the business-stealing effect of subsidies, that is $\partial^2 \Pi^D / (\partial \overline{\varpi} \partial s^D) > 0$.

Finally, even though the optimal subsidy increases primarily for the strategic reasons that I just discussed, foreign competition, by increasing the productivity of domestic R&D, improves also the balance between the resource constraint and the consumer-surplus effect. In fact, the presence of local DRS in R&D implies that reasearch efficiency is higher in competitive sectors. Hence, an increase in the number of competitive sectors raises the aggregate productivity of domestic research labor so improving the marginal effect of subsidies on innovation. Since subsidies trigger more innovation and the latter is produced more efficiently, it follows that competition increases subsidies also through its impact on the consumer surplus and resource

[20] The resource constraint effect can be also interpreted in the more standard way of innovation subtracting labor resources to the production of goods, so reducing production and consumption.

constraint effects.

In Table IV I also compute the welfare gains for the domestic country of following an optimal subsidy rule, as competition changes, with respect to a fixed subsidy rule. The simulation shows that gains from the optimal policy rule, in terms of quality-adjusted per-capita consumption, are increasing with competition from 0.04% with $\overline{\varpi} = 0.2$ it rises to 1% with $\overline{\varpi} = 1$.

5 International competition and the Research and Experimentation Tax Credit in the U.S.

In this section I use the model to perform a quantitative exercise. I first build an empirical indicator that matches my definition of international technological competition. Second, using evidence from the R&D subsidy implicit in the R&E Tax Credit introduced in the U.S. in 1981, I evaluate the optimality of this policy response to the observed increases in competition in the period 1973-89. I include the entire period along which we observe increases in competition, even though R&D subsidies are introduced only in 1981; since I perform an exercise in normative economic analysis, the extended period allows me to study the effects of the lack of government response to competition in the period 1973-80.

5.1 Features of the data

My interest is in international competition among technological leaders. Hence, I restrict the attention to the U.S., Japan, and 9 European countries: Germany, France, U.K., Italy, Sweden, Denmark, Finland, Ireland, Spain, and the Netherlands. In the period 1973-1989, R&D expenditures in these countries represented between 95 and 98 percent of the global R&D investment in manufacturing.[21] In this section I construct two indices of international R&D rivalry. I first build an indicator that embeds directly our definition of competition as the measure of the set of industries where domestic and foreign countries compete for innovation. Later, I construct a standard Herfindahl index of international R&D concentration, and show that the two indicators deliver a similar picture of the facts. In both cases I use OECD ANBERD data on R&D investment for two and three-digit manufacturing industries.

My original index is a measure of the overlapping research support that appears in the model. I take the U.S. as my domestic, leading country, and Japan and the Europe, as the

[21] See OECD ANBERD Rev.2, 2005.

foreign, follower countries. The basic criterion is the following: for each year, in the period 1973-90, we consider a sector competitive if the U.S. share of total R&D investment in that sector is smaller than 50%. My set of sectors is composed of 21 two and three-digits manufacturing sectors, and the competitive subset, $\overline{\omega}$, is the number of sectors with U.S. share of R&D below 50% divided by the total number of sectors.[22]

[FIGURE 1 ABOUT HERE]

Figure 1 shows that my measure of international competition in manufacturing has a clear increasing trend in the period considered. Competitive sectors are 35 percent of the total in 1973, rising to 70 percent in 1990. When we focus only on high-tech and medium high-tech sectors, the share of competitive sectors reaches its highest value of 70 percent in 1980. This suggests that in technology-intensive sectors, the foreign challenge to U.S. leadership has grown faster than in the rest of the economy. I also computed the index weighting the sectors with their size (value added) and the trend in competition does not change very much.[23]

It is important to emphasize that this measure of competition can be biased by the size of the country: a small country like Luxemburg, for instance, it is bound to have firms investing in R&D in fewer sectors. For this reason the index is only suitable in comparing economies of similar size and at similar state of industrial development. In fact, this paper present a North-North model where the only difference between the two countries is that, for exogenous reasons, in one of them firms innovate in all sectors an in the other they innovate in only in a subset.

Next, I check the robustness of my findings by building a more standard index of international R&D competition for the same countries and sectors. I use the Herfindahl index to compute the geographical concentration of R&D investment by sector, and for each year I consider the average across sectors. This index is simply the sum of the squares of each country's share of R&D investment. Hence, considering $\Omega = 21$ sectors and $N = 11$ countries we get the following indicator:

$$H(\omega, t) = \frac{1}{\Omega} \sum_{i=1}^{\Omega} \left[\sum_{j=1}^{N} RS_{ij}^2 \right].$$

[22] ANBERD data do not consider only four 2-digits munufacturing sectors for measurement problems.

[23] The data and the results with different specification of the index are available upon request.

Figure 2 suggests that the Herfindahl index shows a clear trend toward a less skewed international distribution of innovation activity in the period considered. Its value decreases from 0.37 in 1973 to 0.33 in 1990. Hence, both indicators suggest that there has been an increase in international R&D competition in the 1970s and 1980s.

[FIGURE 2 ABOUT HERE]

The erosion of U.S. leadership led policy makers to introduce new measures to reduce the private cost of innovation. Fiscal incentives to R&D, like the Research and Experimentation Tax Credit of 1981, were introduced. The stenghtening of intellectual protection, which began with 1982 legislation which established the Court of Appeals for the Federal Circuit, improved the protection granted to patents holders. The Bayh-Dole Patent and Trademark Amendments Act of 1980 and the Federal Technology Transfer Act of 1986, were both aimed to transform federal laboratories into sources of innovation for U.S. firms. The former allowed agencies to issue patents to small business and universities for inventions made with agency funds. The latter promoted incentives for collaboration in research between federal laboratories and firms. Another important initiative was the National Cooperative Research Act in 1984, which reduced antitrust persecutions of joint ventures for pre-commercial research. Mowery (1998) describes this set of policies as a "structural change in the US national innovation system": the post-1980 shift in technology policy direction, started during the Reagan and Bush administrations and continued as a trademark of Clinton's economic policy, was directly aimed at stimulating civilian innovation, by strenghtening the appropriability of innovations and by facilitating private firms' access to the gigantic pool of public technologies produced during the Cold War years.[24] A common characteristic of these policies is that they all aim at stimulating innovation by reducing the cost of R&D.

In our exercise we consider only one measure of this broad package of policies, the Research and Experimentation Tax Credit introduced in 1981 as a temporary measure and renewed yearly until recently when it was made permanent. The R&E tax credit is neither the most relevant nor the most effective R&D cost-reducing policy introduced in the 1980s, but it is the only one for which there are aggregate data that can be easily used in a stylized macro model.[25]

[24] See Mowery (1998), Ham and Mowery (1997), Nelson and Romer (1997), and Cozzi and Impullitti (2004) for a more detailed discussion of the technology policy shift in the 1980s.

[25] The intellectual property rigths the technology transfer policies mentioned above are relevant in terms of

The R&E tax credit was initially a 25 per cent tax credit for "incremental" research and development: incremental meant above the level of the previous year in 1981, and in the following years the increase was measured over the average R&D in the previous three years. The credit rate was reduced to 20 per cent from 1982 on. An important feature is that the tax credit is targeted to purely technological R&D -several types of research in social sciences and humanities were excluded. This technological focus meant that about 65 per cent of overall R&D spending, as reported to the Internal Revenue Service, is eligible for tax credit on average (Hall 1995).

Figure 1 shows Hall (1992) estimates of the average across firms of the effective R&D subsidy rate related to the Research and Experimentation Tax Credit.[26] As shown in the figure, the effective tax credit estimated by Hall, computing the reduction in the tax price of R&D produced by the tax credit, fluctuates around 3 and 5 percent of the cost of R&D in the period considered. Although the legislation set the official credit rate around 20 per cent, the effective credit rate has been on average around 4 per cent. This gap is due to the incremental design of the credit: by increasing the current R&D investment a firm will increase its current total tax credit but it will also raise the base level of R&D above which the credit is granted for the following three years.[27]

Even though the incremental feature of the tax credit reduced its effective rate there is extensive evidence showing that it did have an impact on private innovation. Hall (1992) working on firm-level data finds that private innovation responds to reductions in the after-tax cost of R&D -often called the tax price of R&D. In her estimates the tax price elasticity of R&D is larger than one, which means that a 5 per cent effective R&D tax credit leads to a

magnitude and impact on private innovation. For example, Link (1999) shows that in terms of government expenditures five technology transfer program, the Small Business Innovation Research Program (SBIR), the CRADAS, the Advanced Technology Program (ATP), SEMATECH, and the Dual-Use Technology Program, amounted to about 3.5 billions on average in the period 1993-96. To put this public direct funding to private research in a policy perspective, in the same period it has been estimated that the total government spending implicit in the R&E tax credit is around 1.6 billions. Hence, these five programs sum up to government outlays that are double the costs of the R&E tax credit. Notice that, other important public/private cooperation programs, like the research joint ventures under the NCRA, are not included here because of lack of data on their cost.

[26] The average is weighted with R&D spending by each firm. See Hall (1992) for details on the estimation method.

[27] We can illustrate the point with a simple example. If the official credit rate is 25 per cent, the cost to the firm of $1 of incremental R&D would be reduced by $0.25. However, the $1 increase in R&D decreases the tax credit for the next three years by $\$0.33x0.25 = \$0.083$ for each year. With a discount rate if 10 per cent the effctive tax reduction of a $1 increase of R&D spending is $\$0.25 - \left(\sum_{i=1}^{3} \$0.083/\left(1 = 0.1\right)^{i}\right) = \$0.045$. Thus, the official tax credit rate of 25 per cent becomes an effective rate of 4.5 per cent.

5 percent increase in R&D at the firm level on average. This findings are confirmed by those in Hines (1993) that uses different econometric methods, and by those in Baily and Lawrence (1992) based on macro data. Bloom, Griffith and Van Reenen (2000) find an elasticity around unity for a panel of countries including the U.S. in the period 1981-99.

Finally, it is worth noticing that the R&E tax credit is only a part of the R&D tax policy in the US, the other important parts are the general expensing rules for R&D and the foreign source income allocation rules for R&D. In brief, the first of these components is very relevant: from 1956 R&D expenditures can be expensed for tax purposes and this implies a 100 per cent write-off of expenses on a type of investment that do not generate income immediately. This is already a tax subsidy on R&D expenditures whose rate is equal to the corporate tax rate. The other component it is relative to tax treatment of expenses of multinational corporation.[28] This paper focuses only on the R&E tax credit because it represents the major change in R&D tax policy in the 1980s.[29]

A final remark of the way I model the R&E tax credit is needed. If the corporate tax rate does not change the expensing of R&D cost for tax purposes does not influence the decision to invest in research and development: the corporate tax rate is applied to total revenues net of all costs, including R&D costs. Thus, our stylized economy with no corporate tax rate is similar to one where the corporate tax rate is constant over time. As a consequence, the R&E tax credit can be modeled as a subsidy to research and development additional to the tax subsidy implicit in the expensing of R&D; and, since we do not study the effects of changes in the corporate tax credit, it is possible to model the research tax credit as a simple R&D subsidy.[30]

5.2 Welfare analysis

The scope of our quantitative experiment is to evaluate the optimality of the R&E Tax Credit in the U.S. as a response to the increase in technological competition in the 1970s and 1980s.

[28] A discussion of these the components of the US tax policy other than the R&E tax credit is beyond the scope of this paper. Exaustive discussions of these issues can be found in Hall (1992) and Hines (1993).

[29] Another important aspect of tax policy that might have played a role for innovation activity in the 1980s is the taxation on capital equipment. Much of the industrial R&D in the last 20 years has been performed in the capital equipment industries, and this means that tax subsidies to capital equipment have an impact on the demand of R&D. This aspect has been neglected in studies on the effects of the R&D tax policy but it might be important, as suggested by Hall (1995) and Mammuneas and Nadiri (1996).

[30] This actually seems to be a good way to model an R&D tax credit in a framework where only followers do research. It is as if we would have introduced a corporate tax rate on R&D firms, allow total expensing of R&D - so the corporate rate disappears from the FOC- and intruduce an additional tax credit that reduces the cost of R&D at the effective R&E credit rate.

I compute the U.S. welfare with the observed levels of competition, using the index for the measure of the overlapping research support $\overline{\omega}$, and the subsidy rate, shown in figure 1; then I compare this to the welfare under the same competition levels but using the optimal subsidy rates. I consider the following measure of the welfare loss

$$\begin{aligned}\widehat{W}^D &\equiv \int_0^\infty e^{-(\rho-n)t}\left[\int_0^1 \ln(\frac{c^D}{\lambda}\lambda^{j(\omega,t)}(1+\beta))d\omega\right]dt = \\ & \ln\frac{c^D}{\lambda} + \left[\overline{\omega}(I_c^D + I^F) + \left(1-\overline{\omega}\right) I_m^D\right]\frac{\ln\lambda}{\rho-n} + \ln(1+\beta)\end{aligned}$$

and we chose β such that $\widehat{W}^D = W^{*D}$, where W^{*D} is the present value of optimal welfare. Thus, β is the share of quality-adjusted per-capita consumption lost in the observed policy with respect to the optimal policy. Table V shows that the welfare loss of the observed policy is in the range of 0.2 and 0.5 percentage points of quality-adjusted per-capita consumption. The average loss over the period considered is about 0.4 per cent which implies a total loss of 8 per cent of per-capita quality adjusted consumption. Furthermore, the results suggests that the cost of a non-optimal policy increases in the scale of international competition.

TABLE V

WELFARE LOSS RELATED TO OBSERVED US R&D SUBSIDY

years	1973	1975	1977	1979	1981	1983	1985	1987	1989
competition	0.35	0.4	0.45	0.5	0.55	0.65	0.65	0.7	0.7
optimal subsidy	.1450	.1630	.1800	.1970	.2150	.2490	.2490	.2670	.2670
observed subsidy	0	0	0	0	.034	.05	.053	.036	.033
welfare Loss in %	.0020	.0024	.0030	.0035	.0031	.0038	.0037	.0050	.0051

The U.S. R&E Tax Credit estimated in Hall (1992) does not seem to be responding optimally to changes in competition. Even though the scope of this exercise is not to explain the actual U.S. policy response to competition I will make a few remarks on how future research could tackle a positive analysis of the facts.

First, the non-optimality of the US response might be due to the fact that the government did not target social welfare in choosing the R&E tax credit. It might be that in setting its innovation policy the U.S. government has privileged specific rather than general interests. In this case, then, a political economy approach could help explaining the conduct of policy makers.

Second, as I mentioned above, we do not have an appropriate measure of the supply-side policy response to competition implemented in the U.S. in that period. Here there are several issues to discuss. In the first place, the effective size of the R&E tax credit has been greatly reduced by its incremental feature, and so has been the scale of its impact. In the second place, the government might have used tax instruments that have an indirect impact on R&D, such as tax credit on investments in capital equipment, that our model cannot account for. This could be an interesting theme for future research. In the third place, non-tax policies might have been considered more effective than direct R&D subsidies in response to international competition. For lack of date it is very hard to measure for the impact on private innovation of the technology transfer and intellectual property rights policies introduced in the 1980s. Further work is needed for a better measurement of these policy tools. In conclusion, for a more complete evaluation of the US innovation policy response to international competition we would primarily need better data; once in possession of better measures of policy, the model should be extended introducing a more complete set of supply-side innovation policy instruments, such as, patent policy and some mechanism of technology transfer from public labs and agencies to private firms.

6 Strategic policy complementarity

Next, I remove the assumption that the foreign country is not active in subsidizing R&D and explore the effects of strategic policy complementarity. I first search for the existence of a strategic policy interaction between the two policy makers, and then test the robustness of Result 1 studying the effects of competition on the optimal domestic competitive subsidy. Finally, I explore the role of competition in shaping the incentives for cooperation in R&D policy.

6.1 International R&D rivalry and policy competition

A two-stage policy game between the two countries is set up: at stage 1, countries set their subsidies, and at stage two R&D and manufacturing firms choose their profit maximizing level of activity, and households choose their utility maximizing consumption bundles. Policy makers simultaneously repeat the game setting different subsidies in order to solve $\partial W^K/\partial s^K = 0$.

The first step is to verify the presence of strategic interaction, that is, to study the effect of the R&D subsidy of a country on the optimal subsidy of the other. Second, I show that the

R&D policy competition that results from strategic interactions allows for a Nash equilibrium solution, and study the ways competition affects it.

As before, we proceed with the numerical solution using the benchmark calibrated parameters. The algorithm to compute the best response functions is straightforward: I fix the competition level, and for each point in the grid of a country's subsidy I compute the optimal subsidy of the other country; the same exercise is then repeated at different levels of competition. In figures 3 to 5 we plot the best response functions for the two countries at different levels of competition.

[FIGURES 3-5 ABOUT HERE]

Result 3. *The strategic policy complementarity induced by the business-stealing effect of R&D subsidy competition leads to upward sloping best response functions.*

In order to clarify the intuition behind this result we need to understand how changes in the subsidy of a country affect the marginal conditions used by policy makers in the other country to set its optimal R&D subsidy. I focus on the impact on the optimal home subsidy of increases in the foreign subsidy. I again refer to the effects of home subsidies on home welfare shown in (24). First, since I assumed DRS in R&D at the industry level, increases in the intensity of foreign research do not affect directly the productivity of domestic R&D, so it does not affect the marginal effect of domestic subsidies on innovation. Second, raising foreign research increases the obsolescence of innovation in competitive sectors, thus reducing domestic research in those sectors. It follows that the marginal productivity of domestic R&D increases, and thus at the margin, the innovation effect of domestic subsidy is stronger while the resource constraint is weaker. Finally, the business-stealing effect of domestic subsidies becomes stronger because now domestic firms are aggressively challenged by foreign innovators in competitive sectors, thus the rent-shifting effect of subsidies is more relevant than before. Intuitively, higher foreign subsidies imply higher *intensity* of foreign business-stealing, therefore the role of domestic subsidies as a rent-shifting devise increases. From (16) it is easy to see that the effect of home subsidies on home profits is increasing in the level of the foreign subsidy, that is to say that the cross-partial $\partial^2\Pi^D/(\partial s^F \partial s^D)$ is positive. In conclusion, an increase in the foreign subsidy improves the marginal effects of the domestic subsidy on welfare, thus producing a positive effect on the optimal domestic subsidy. The explanation for the best-response of the foreign country is analogous and we can omit it.

It is worth noticing that when research supports are asymmetric ($\overline{\varpi} < 1$) the Nash equilibrium strategy shows high subsidy in the foreign and low subsidy in the domestic country. This implies that the smaller is the set of sectors where national firms innovate the higher the optimal subsidy is. Intuitively, in a model with country and sector specific DRS in R&D, both the creative and the destructive effects of innovation occur locally and at the industry level. It follows that with few innovative sectors a lot of research effort will be concentrated in those sectors, innovation will have high obsolescence rate and research will be less productive. As a consequence, the market solution will show more underinvestment in R&D than in those economies with a bigger set of innovative sectors.[31]

Result 4. *An increase in the level of international competition raises the optimal competitive subsidy of the domestic country. This subsidy is higher than the one without strategic policy complementarity at each level of competition.*

This result shows that the positive effect of competition on the optimal domestic subsidy is robust to the introduction of strategic policy complementarities. In figures 3-4 we see that increases in competition shift the domestic best response function upwards, and also make it steeper. The driving force of these changes is again the business-stealing effect. As R&D rivalry increases, the threat of international rent-stealing becomes more relevant and triggers a higher competitive (Nash) subsidy. More precisely, higher foreign competition implies a higher *scale* of foreign business-stealing because the number of industries where domestic firms are challenged by foreigners is larger. Moreover, the same factor makes the domestic best response steeper, which implies that the sensitivity of domestic optimal subsidy to changes in s^F raises. Here the idea is that as competition increases the scale of business-stealing foreign subsidies represent a wider threat for the domestic market leadership.

[31] It is possible to prove this result analytically. In Appendix D, available upon request, I develop a single-country version of the model where firms innovate only in a subset of sectors. I show that, if parameters values satisfy $A \ln \lambda > k(\rho - n)$, the optimal subsidy is always decreasing in the set of innovative sectors. It is easy to check that our calibrated parameters satisfy this restriction ($0.55 \ln 1.1 = 0.0524 > 0.75(0.05 - 0.01) = 0.03$).

TABLE VI
Competition & optimal Nash subsidy

Competition	0.2	0.4	0.6	0.8	1
optimal subsidy	.095	.165	.230	.300	.370
optimal Nash subsidy	0.1	0.18	0.26	0.34	0.42

In this paper we are mainly interested in studying the domestic country, the former leader that experiences increasing competition from the foreign follower. Thus, we comment only briefly on the latter. The smaller change in foreign Nash subsidies is the result of a general equilibrium effect. On the one hand, an increase in $\overline{\omega}$ raises both foreign innovation and its national aggregate profits, so for each s^D the level of s^F that maximizes W^F should be lower – in fact, foreign best response shifts left. On the other hand, the fact that the domestic best response shifts upward, as $\overline{\omega}$ increases, triggers strategic interaction, and the foreign policy maker reacts by raising its subsidy - a movement along foreign's best response. The small effect of competition on foreign subsidies is the general equilibrium result of these two counteracting forces: the movement along foreign's best response, triggered by domestic aggressive policy, more than compensates the shift of foreign's best response.

Finally, as we can see in table IV, the presence of strategic policy competition produces an increase of the optimal domestic Nash subsidy with respect to the case with no strategic policy complementarities. As we discussed above, introducing foreign R&D subsidies implies a higher intensity of the international business-stealing threat, thus leading the domestic policy maker to set larger subsidies at each level of competition.

6.2 The gains from cooperation in innovation policy

International policy competition yields national subsidies that are not optimal from a global point of view for the following reasons: first, governments do not take into account the positive innovation effect of R&D subsidies on foreign consumer surplus; second, the negative business-stealing effect of national subsidies on foreign aggregate profits is not considered by governments that maximize their own welfare. Hence, the need for policy coordination emerges.

In this section I introduce policy coordination that internalizes the business-stealing effect and takes into account the consumer surplus (innovation) effect in both countries. We consider a form of cooperation where subsidies are set separately by governments in order to maximize global welfare; that is,

$$\left\{s_c^D, s_c^F\right\} = \arg\max\left\{W^W\right\}$$

where

$$W^W = 2CS + \Pi^D + \Pi^F + 2w - R^D - R^F. \tag{25}$$

is the global welfare equation. Using our benchmark calibrated parameters, we compute numerically the optimal subsidies under cooperation, s_c^D and s_c^F, and compare the welfare outcome of cooperative and non-cooperative policy (s_n^D,s_n^F).

Result 5. *International competition induces R&D policy cooperation. For the country that experiences increases in foreign competition, the home country in our model, the incentives to cooperate are negative at low levels of competition but raise with competition and, after the threshold* $\bar{\omega} = 0.5$, *become increasingly positive .*

TABLE VII
GAINS FROM COOPERATIVE R&D POLICY

	Coop		Non-Coop		Gains D	Gains F
competition	s_c^D	s_c^F	s_n^D	s_n^F	$W^D(s_c^D, s_c^F) - W^D(s_n^D, s_n^F)$	$W^F(s_c^D, s_c^F) - W^F(s_n^D, s_n^F)$
0.2	0.59	0.76	0.1	0.41	-0.0352	0.1486
0.4	0.64	0.76	0.18	0.41	-0.0018	0.1191
0.5	0.67	0.77	0.22	0.41	0.0125	0.1066
0.6	0.69	0.77	0.26	0.41	0.0265	0.0944
0.8	0.73	0.77	0.34	0.41	0.0489	0.0755
1	0.78	0.78	0.42	0.42	0.0627	0.0627

A first result shown in Table VII is that, as it was the case with no cooperation, foreign competition increases domestic optimal subsidies. Moreover, it turns out that the level of optimal domestic subsidy is higher with cooperation than without it. To grasp the intuition of the mechanisms at work here we need to examine the effects of domestic subsidies on the global welfare function. Eq. (26) below shows the effects of domestic subsidies on the world welfare.

$$\frac{\partial W^W}{\partial s^D} = \underbrace{\frac{\partial R^D}{\partial s^D}}_{\substack{\text{Resource constr.} \\ (-)}} + 2\underbrace{\frac{\partial CS}{\partial s^D}}_{\substack{\text{consumer surplus} \\ (+)}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{\text{Business-stealing} \\ (+)}} + \underbrace{\frac{\partial \Pi^F}{\partial s^D}}_{\substack{\text{Business-stealing} \\ (-)}} . \tag{26}$$

Comparing (26) with (24) we can observe that two additional effects appears in the case with cooperation. First, there is the internalization of the negative business-stealing effect of domestic subsidies on foreign profits. Second, domestic subsidies have a double consumer surplus effect, because policy cooperation takes into account the positive quality-improving effect of R&D subsidies in both countries. Therefore in the cooperative solution we have two additional and counteracting effects of domestic subsidy: the negative business-stealing effect on foreign income that is internalized when domestic government maximizes aggregate welfare, and which reduces the optimal subsidy, and the positive innovation effect on foreign welfare which increases the optimal domestic subsidy. In our numerical simulation this second effect is stronger than the first effect, which explains the result that optimal domestic subsidies are higher in the cooperative equilibrium.

The intuition for the relationship between the optimal domestic subsidy and competition is as follows: the business-stealing effect is out of the game with cooperation, so we focus on the two remaining effects shown in (26). We have a standard resource constraint effect and a double innovation effect. The fact that the optimal domestic subsidy increases with competition is related to the specification of R&D technology: DRS to R&D imply that when competition is low research is performed mainly by domestic workers, so their productivity is low. With increases in competition, a larger share of research is conducted by foreigners. Thus, research effort is more evenly spread among countries and, as a consequence, domestic R&D labor is more productive and the innovation effect of subsidies is higher. It follows that the optimal domestic subsidy will be higher the higher is the level of competition.

Finally, table VII presents the main result of this section: the home country gains from cooperation only at high levels of competition, and incentives to cooperate increase with competition. Symmetrically, foreign gains from cooperation decrease with the level of international competition. Intuitively, the domestic government has little incentive to cooperate when competition is low because foreign innovation and business-stealing are not sufficiently relevant. Hence, when the competitive threat is low the domestic country has few incentives to internalize foreign business-stealing while the opposite happens in the foreign country.

I want to conclude this section suggesting a possible application of this last result. My findings in this section may be of particular relevance for innovation policy in the European Union. In fact, the E.U., to a larger extent than for instance NAFTA and ASEAN, has an institutional framework that could potentially promote R&D policy coordination. The E.U. has common policy in many areas, such as trade, regulation, and competition, but seems to leave innovation policy to national governments. As clearly stated in the Sapir Report: "Many policies are decided and implemented autonomously 'within' Member States . . . .this can be regarded as a regime of policy competition. Examples include, education, innovation [...] There is very little legislative EU activity in the fields of innovation, education and research, all of which are meant to represent common priorities for the Lisbon Strategy" (Sapir 2003 p.76 and p.78).[32] Moreover, in Europe we observe some national economies like Germany, Sweden, and France innovating in a broad variety of sectors, while in some others, especially the newer members from eastern Europe, innovation is scanty and concentrated in fewer sectors. For instance, excluding R&D investment form Italy, Ireland, Denmark, Spain, Finland, and the Netherlands, in the computation of the Herfindahl index for each single industry, does not substantially change the index.[33] In these cases, where research asymmetries among countries are strong, our analysis could provide a basic framework for evaluating the welfare gains of cooperative R&D policies. Our results suggest that leading-edge countries would experience a welfare loss when forced to cooperate with backward countries, and would gain when they coordinate their R&D policy with other leading countries. As a consequence, the E.U. Commission's laissez-faire attitude might be motivated by the reluctance of the leading countries - those with higher investment in innovation and higher decision power - to coordinate their policy with the laggards. The enlargement of the EU to include Eastern European countries has increased geographic asymmetries in the area and, in doing so, it might have decreased the leaders' willingness to cooperate in innovation. A possible policy implication is that only by reducing regional disparities, that is by increasing technological competitiveness of lagging members in many sectors, will it be possible to design a credible common innovation policy in Europe. Further research could explore the implications and the empirical relevance of this of this interpretation.

[32] Recently some works in the strategic industrial policy literature have begun tackling the issue of R&D policy coordination in economic unions. See, for example, Haaland and Kind (2004).

[33] See also the evidence in Archibugi and Coco (2005).

7 Conclusion

In this paper I have analyzed the effects of international competition on optimal innovation subsidies. I have used a quality-ladders non-scale growth model where domestic and foreign firms compete to invent the next top-quality good in order to appropriate the global monopoly rents associated with it. The scale of international competition is modeled as the measure of the set of industries where foreign and domestic R&D workers compete for innovation. Trade is free but innovation policy is active by means of subsidies to R&D.

First, I have investigated the pure effects of competition on innovation, growth, and welfare. For this purpose I set up a simplified version of the model where government policy has been removed, or equivalently I set R&D subsidies at a common level in both countries, and found that the innovation effect of competition strongly depends on the specification of the R&D technology. I showed that with CRS in R&D competition has no innovation effects and has a negative business-stealing effect that reduces domestic income and welfare. Introducing DRS to R&D I find that a high concavity of the research technology implies a strong innovation effect of competition. For sufficiently high decreasing returns to research the innovation effect more than compensates the business-stealing effect and competition proves to be welfare enhancing.

Second, I allowed the domestic government to subsidize R&D, while still keeping the foreign government inactive, and studied the optimal response of the domestic subsidies to increases in foreign competition. I found that in the benchmark numerical simulation the optimal domestic subsidies are increasing in the scale of competition. This result is robust to the sensitivity analysis performed on a wide range of parameters' deviation from the benchmark. The result is driven by the international business-stealing effect produced by the arrival of foreign innovators in sectors where domestic firms were previously unchallenged. Intuitively, the higher the threat of international competition the more instrumental innovation subsidies will be in helping domestic incumbent firms retain their shares of the global market.

Third, I have applied this last result to the evaluation of the optimality of the U.S. R&D subsidies response to increasing international competition in the 1970s and 1980s. I built an indicator of international R&D rivalry that matches our idea of competition and found that the set of competitive sectors increased form 30 percent 1973 to 70 percent in 1989. Using this indicator I found that the observed policy response to competition implies a welfare loss in the range of 0.2 to 0.5 percentage points of quality-adjusted per-capita consumption, and the loss is increasing in the level of competition.

Finally I removed the assumption that only domestic subsidies respond to competition and extended the model to account for international policy complementarities. I showed that my basic result is confirmed in this more complex and realistic exercise: foreign competition increases the optimal domestic Nash subsidy. Moreover, the presence of strategic policy complementarities suggests the importance of evaluating the gains from cooperation in R&D policy. I found that for the foreign (laggard) country, gains are always positive and increasing in competition. The domestic (leading) country loses from cooperation at low level of competition, and the losses are decreasing with competition; above the threshold of 50 percent of competitive industries the losses become gains. This result might provide a first insight on the problem of coordinating innovation policy in the E.U.: leading countries might have been benefiting from the lack of a common innovation policy and this could explain the institutional inertia on the issue.

There is not an extensive literature on the specific issues addressed in the paper. Competition in growth models is generally introduced as a change in the degree of market power or a change in the intensity of entry of new firms in the product market (see e.g. Aghion and Griffith 2005, and Tang and Waelde 2001). Morover, little research has been dedicated to the study of the welfare effects on competition and of its optimal policy implications. The contribution of this paper is to focus on a dimension of competition, different from changes in entry and market structure, and directly study its optimal policy implications. Trade or entry liberalization in the product market might not necessarily imply that foreign innovators will challenge previous world leaders. Liberalizing the world market for aircrafts may not create another Airbus immediately: it might take another historical policy measure, as a group of European countries did in the 1980s, to create a competitive aircraft industry from scratch. For some social and/or institutional reasons, countries may concentrate their innovation efforts in some sectors and not in others, even if entry and trade are free in all industries[34].

In the section on strategic complementarities the paper touched on some issues that are proper of the strategic trade and industrial policy literatures. Here the basic contribution is the introduction of strategic policy considerations in an endogenous growth model. This allows

[34] Cozzi (2005) shows that in a tariff free world social norms might have a role in shaping the international distribution of innovation efforts. In an neo-Shumpeterian framework with sunsopt equilibria he shows that industrial policies might have a role as coordination devises.

to study the impact of competition on the optimal strategic subsidy in a set up that adds to the standard business-stealing effect the innovation and growth effect of competition on welfare.

This paper is amenable to many extensions. First, removing the assumption of the presence of a full set of multinationals in every industry could allow us to account for the effects of competition on the labor market. With a labor market clearing locally, at least in part, the effect of competition on optimal policy should be stronger: an international wage-stealing effect would be added to the business-stealing. Moreover, introducing frictions in the labor market could allow us to study the unemployment effects of competition: the international business-stealing effect will destroy jobs, the innovation effect of competition will create jobs, and the net effect of the two forces will determine the final impact on unemployment.

As a second extension, future research could improve our preliminary attempt at a quantitative evaluation of the optimality of the U.S. policy response to increasing international competition in the last decades. Improving the measurement of the innovation cost-reducing policies introduced in the 1980s is needed for a more detailed and complete quantitative exercise. Extending to model to include a broader set of policy instruments is another step in the direction of improving the breadth and quality of our quantitative exercise. Furthermore, these extensions and better data can also allow the use of this model for a positive analysis of the U.S. policy response to competition.

Thirdly, in this set up, the scale of international competition is exogenous. Introducing a mechanism of imitation, or letting the set of competitive sectors depend on institutional changes, can provide a link between the competition and economic decisions, thus endogenizing the degree of technological competition.

Finally, in the baseline model, as it is standard in quality-ladder models, only followers do R&D. Entry of foreign research firms increases the economic obsolescence of innovation and produces a congestion effect at the industry-level that reduces the productivity of researchers. As a consequence domestic followers can only respond to competition by adjusting their research effort to the new obsolescence level of innovation, and competition ends up discouraging domestic innovation. Introducing innovation by incumbent firms, as for instance in Aghion et al. 2003 and 2004, Segerstrom (2005), Etro (2004) could account for positive effects of foreign competition on domestic incumbents' innovation. Domestic incumbents incentives to innovate in order to escape entry of foreign firms and keep their leadership may be stronger than the disincentive related to the standard "Arrow effect". Hence, with innovation by incumbents, changes in the scale of competition could produce a mechanism of “defensive innovation” different from that in Thoenig and Verdier (2003). Moreover, my framework could be used to evaluate the optimality of the market response to competition and study the role for corrective policies.

Appendix A: steady state equilibrium with no policy and CRS in R&D

Here I derive the equilibrium conditions for the simplified set up with no subsidies and CRS to R&D ($\alpha = 0$) and provide a proof of proposition 1. A first implication of these simplifying assumptions is that foreign and domestic research in competitive sectors are equal, that is $I_c^D = I^F = I_c$, and we have only two free entry and arbitrage conditions:

$$\frac{2k}{A} = \frac{\left(c^D + c^F\right)\left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_c - n}, \qquad \omega \in \xi_F \tag{27}$$

$$\frac{2k}{A} = \frac{\left(c^A + c^B\right)\left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_m^D - n}, \qquad \omega \in 1 - \xi_F \tag{28}$$

From which we obtain that innovation obsolescence is the same in competitive and non competitive sectors,

$$I_m^D = I_c^D + I^F = 2I_c$$

Substituting into the labor market clearing and the resource constraint conditions (11) (16) and (17) and keeping one of the two free entry and arbitrage conditions, precisely (28), we obtain a system of three equations and three unknowns (I_m^D, c^D, c^F). It is easy to prove that that only two of eqs. (11), (16) and (17) are linearly independent, so we can solve the system. After some simple algebra we obtain

$$\begin{aligned} I_m^D &= \frac{1}{\lambda}\left[(\lambda-1)\frac{A}{k} - (\rho - n)\right] \\ c^D &= 1 + \frac{k}{A}\left(2 - \overline{\omega}\right)(\rho - n) \\ c^F &= 1 + \frac{k}{A}\overline{\omega}\,(\rho - n), \end{aligned} \tag{29}$$

For $(\lambda - 1) A/k \geq (\rho - n)$ we have an equilibrium with positive investment in innovation. These equilibrium conditions show that increases in foreign competition do not affect innovation, reduce domestic and increase foreign consumption, thus proving proposition 1.

Appendix B: partial home bias in asset ownership

The alternative setup modifies the national resource constraints in order to account for the partial home bias in the following way. The domestic resource constraint, eq. (16), becomes:

$$2k\left[\overline{\omega}\left(\frac{I_c^D}{A}\right)^{\frac{1}{1-\alpha}}+(1-\overline{\omega})\left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}}\right]+c^D=1+\rho\phi\left[(1-\overline{\omega})v_m^A+\overline{\omega}\frac{I_c^D}{I_c^D+I^F}v_c^A\right]+\rho\gamma\overline{\omega}\frac{I^F}{I_c^D+I^F}v^F$$

where ϕ is the share of domestic assets owned by domestic consumers, γ is the share of foreign asset owned by domestic consumers, and v_m^A, v_c^A, v^F, are the values of domestic and foreign firms. Thus, national income, the RHS of the resource constraint, is given by wages plus returns on assets owned by domestic consumers. Symmetrically for the foreign country we get the alternative version of (17):

$$2k\left[\overline{\omega}\left(\frac{I^F}{A}\right)^{\frac{1}{1-\alpha}}\right]+c^F=1+\rho(1-\phi)\left[(1-\overline{\omega})v_m^A+\overline{\omega}\frac{I_c^D}{I_c^D+I^F}v_c^A\right]+\rho(1-\gamma)\overline{\omega}\frac{I^F}{I_c^D+I^F}v^F$$

Appendix C: sensitivity analysis

In this section I test the robustness of our basic results to changes in the calibrated parameters. I report only the effects of parameters changes on the findings in result 2, that is on the impact of competition on optimal R&D subsidy.[35] More precisely, for each parameter A, α, k, ρ, n, λ I take values representing about one half and twice the benchmark, and I simulate the effect of competition on the optimal R&D subsidy.[36] I am mainly interested in showing the robustness of our mechanism to changes in the parameters' choice, so I will not provide a detailed analysis of the effect of each parameter on the optimal subsidy and on the relationship between competition and R&D subsidies. For a rigorous account of these effects, a full welfare analysis should be performed, but the complexity of the model makes this exercise, as much as the derivation of the steady state equilibrium, analytically intractable. Hence, I will only briefly discuss the cases where the results are weaker, providing some intuition of the forces at work in those cases.

I report the results of the sensitivity analysis in figure A. The first thing that we observe looking at the figure is that we do not find cases that contradiction the basic finding reported

[35] We also performed the robustness check for the model with strategic interaction, and we found that parameters change affect the two frameworks similarly.

[36] At the lower bound of some parameters value there is no real numerical solution. In these cases we take the lower value for which a solution exists. This happens with α, for which we take a lower bound at 0.5, and with A, for which we set a lower bound at 0.4. Moreover we set the lower bound for ρ at the minimum compatible with the standard condition of bounded intertemporal utility, that is $\rho > n$. Finally, the value of the quality jump λ is already set at a low level in the bechmark, so we choose a quality jump of 1 percent to be the lower bound.

in result 2. In fact, even though we do have situations where competition has a negligible effect on the optimal subsidy, in no cases there is a negative effect. Digging deeper into the various cases I discuss here those two special situations: one where competition has no effect on the optimal subsidy: strong DRS to R&D, $\alpha = 0.99$, and another when the optimal subsidy is always positive, $\rho = 0.1$.

[FIGURE A ABOUT HERE]

As I have widely discussed above, higher values of α imply a high innovation effect of competition, so leading to large improvements in domestic welfare. Intuitively, a stronger concavity of the R&D technology makes innovation by two countries much more productive than innovation with only one country. Hence, the sensitivity analysis shows numerically the effects of changes in α discussed intuitively in result 1. A consequence of this large innovation effect of competition is that, as shown in figure A.2b., it nullifies the impact of the business-stealing effect on the optimal subsidy. Notice that the optimal subsidy is stuck at an extremely negative value, this is due to the fact that R&D activity is not productive enough to compensate for the resources it uses from social point of view. Hence, it is optimal to tax R&D at each level of competition.

When the population discounts the future heavily -high ρ that in steady state implies high rate of interest r- it is intuitive to expect that the consumer surplus (or innovation) effect of R&D subsidy is low, as we see in eq. (18). It follows that, as showed in figure A 4b., the resource constraint effect dominates the business-stealing and consumer surplus effects, and the optimal subsidy is always negative. Even though the resource constraint effect dominates, the strength of the business-stealing effect of subsidies is strongly increasing in competition and, in line with result 2, we obtain that the R&D tax is decreasing with competition.[37]

Finally, when competition is low we find a negative optimal subsidy rate at low total factor productivity of R&D, low A, low quality jumps λ, and high R&D difficulty index k. In all these cases though, the the business-stealing effect of subsidy is strong enough to increase optimal subsidies, so confirming the robustness of our findings in result 2.

[37] We do not report the sensitivity analysis for changes in n because it is symmetrical to changes in ρ. They act in an opposite direction on the discount factor.

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Figure 1. International competition and US R&D Tax Credit: 1973-89

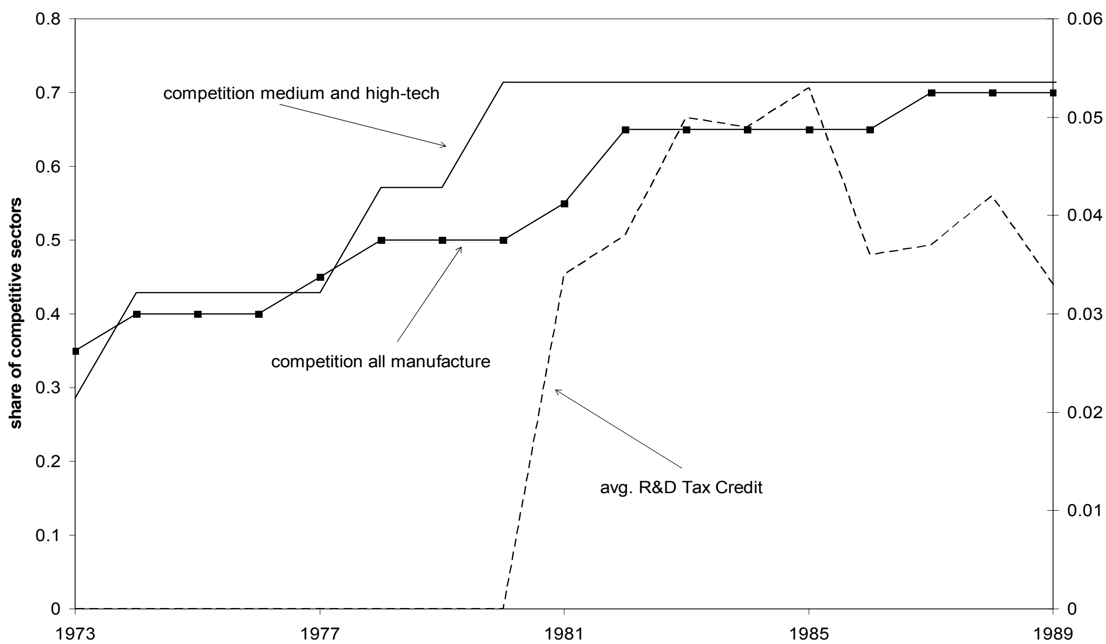

Figure 2. Average sectoral Hirfindahl index of international R&D concentration.

Figure 3. Nash subsidies with 30 percent of competitive sectors

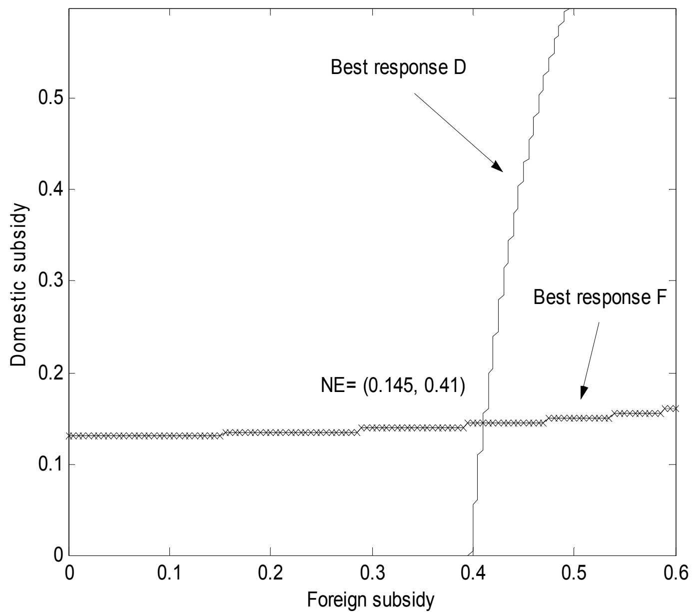

Figure 4. Nash subsidies with 60 percent of competitive sectors

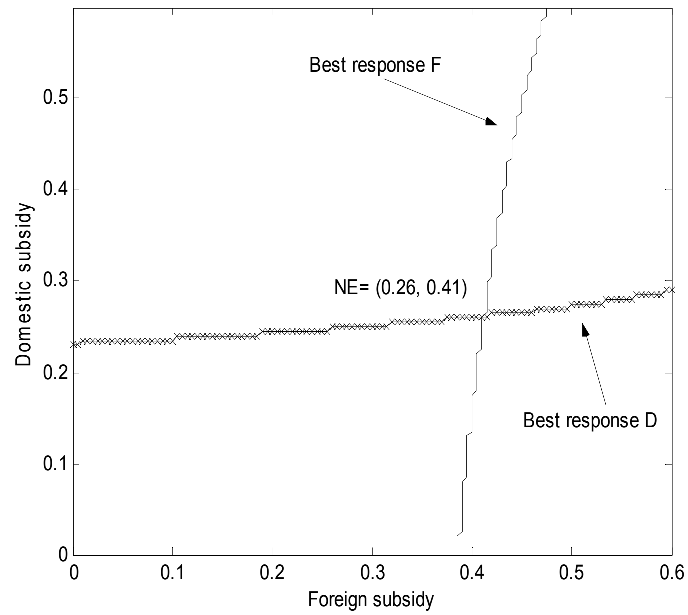

Figure 5. Nash subsidies with 100 percent of competitive sectors

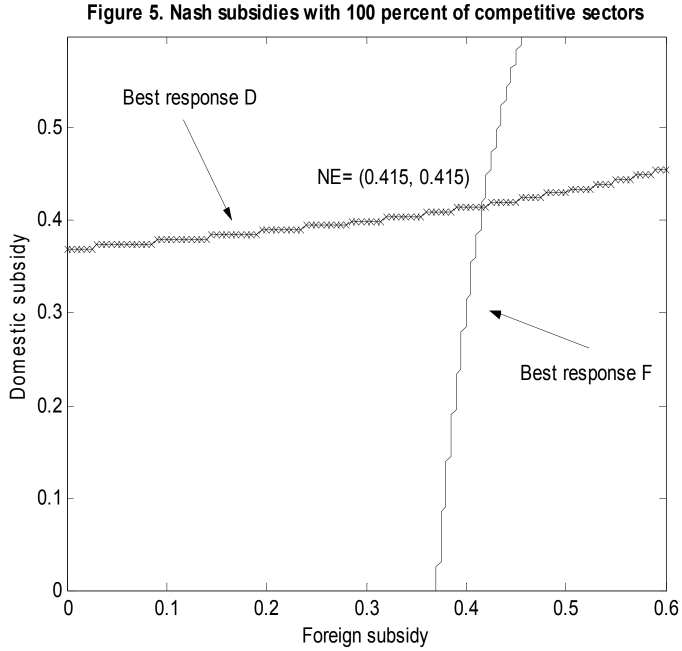

Figure A. Sensitivity analysis

Figure A.1 Benchmark simulation

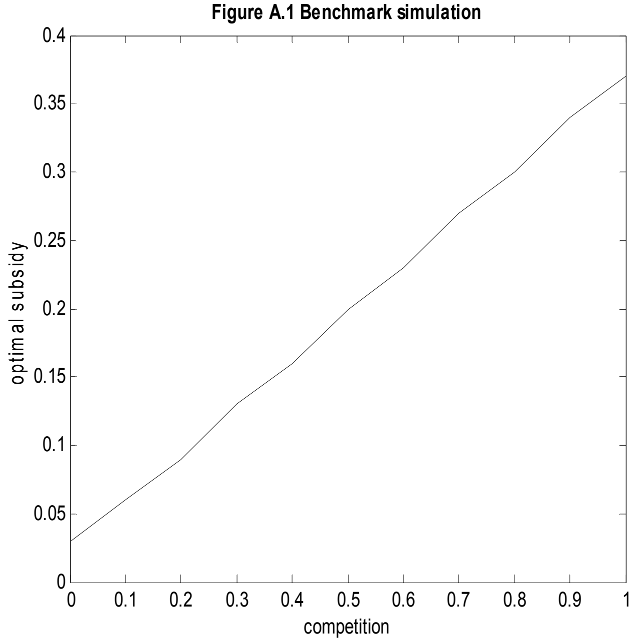

Figure A.2a. Alpha=0.5

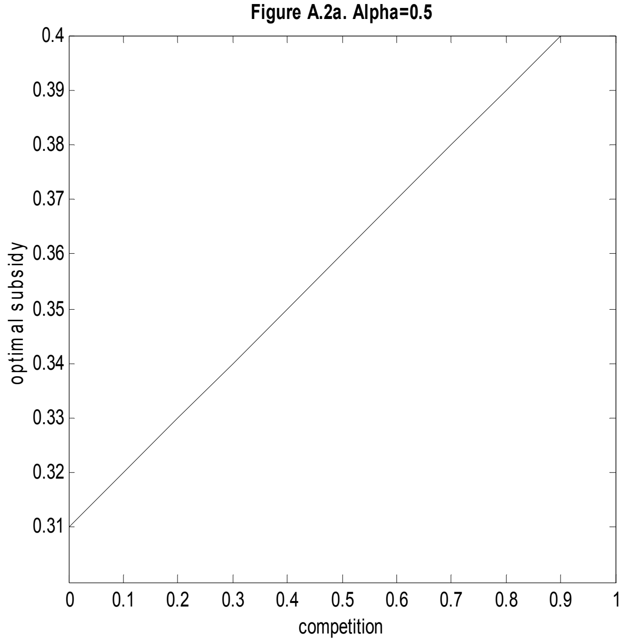

Figure A.2b. Aplha=0.99

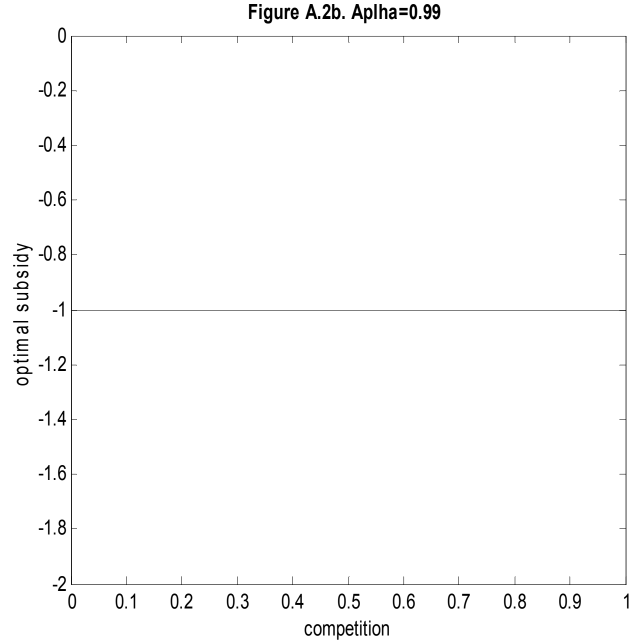

Figure A.3a. Lambda=1.05

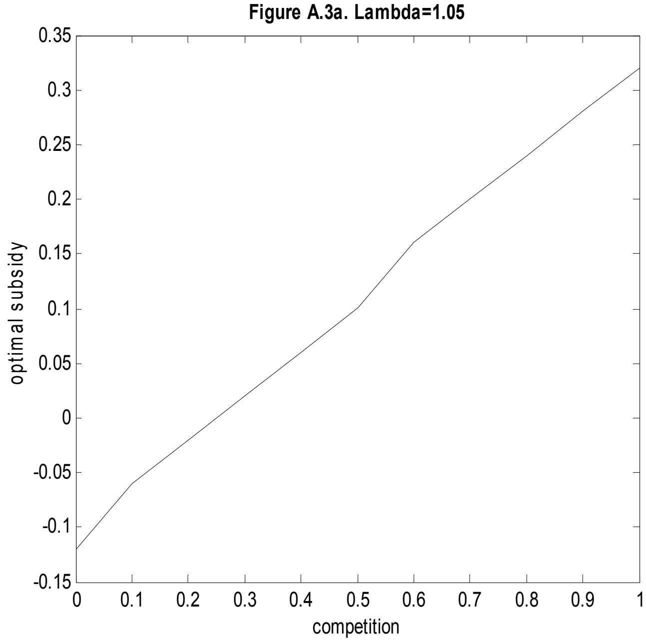

Figure A.3b. Lambda=2

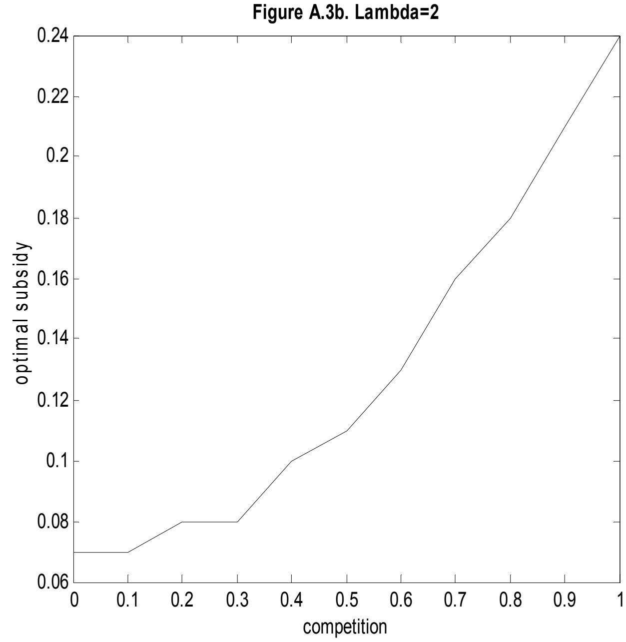

Figure A.4a. Rho=0.02

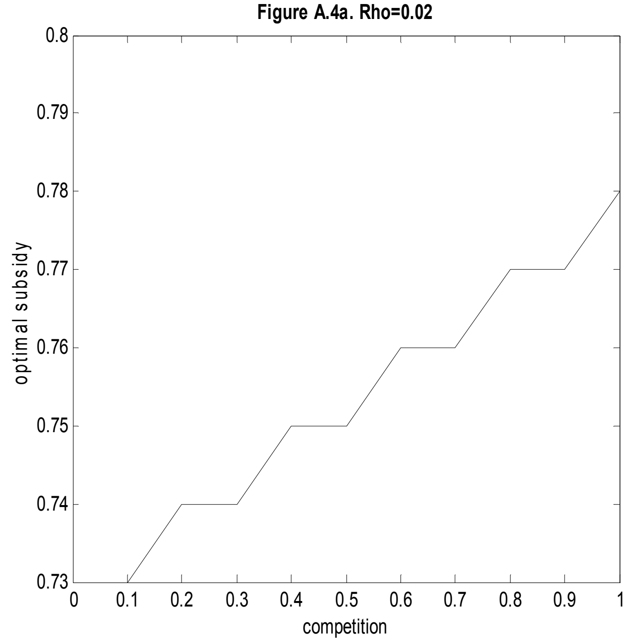

Figure A.4b. bis. Rho=0.1

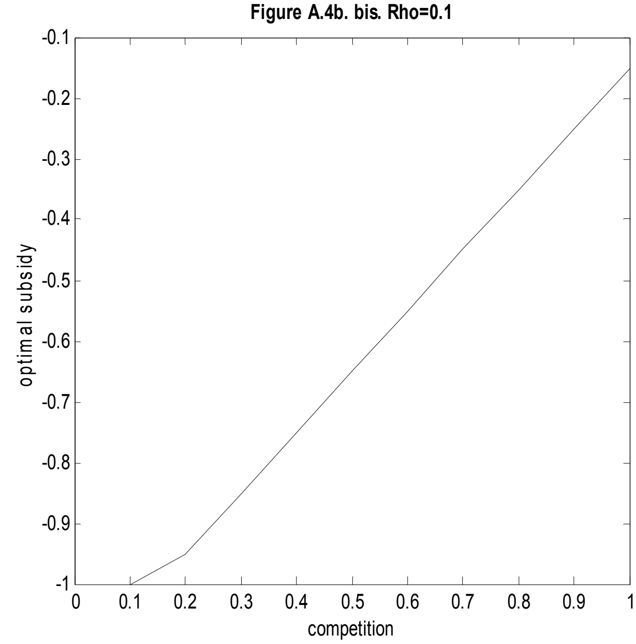

Figure A.5a. A=0.4

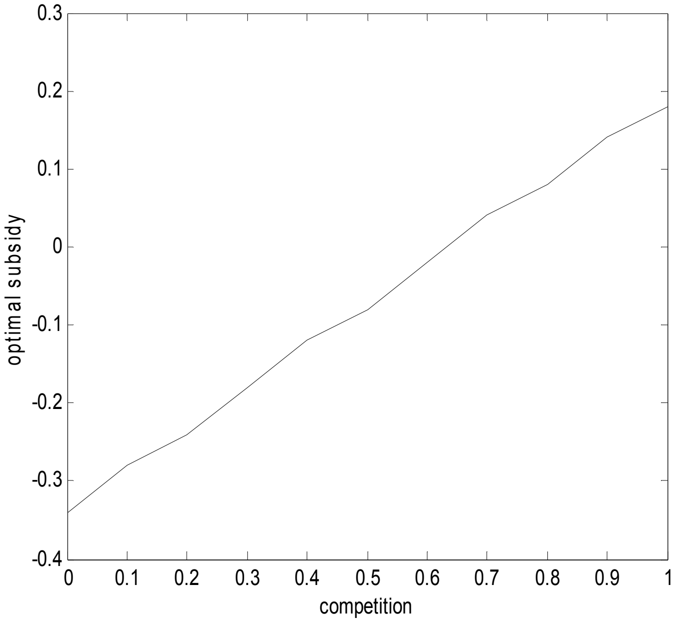

Figure A 5b. A=1.05

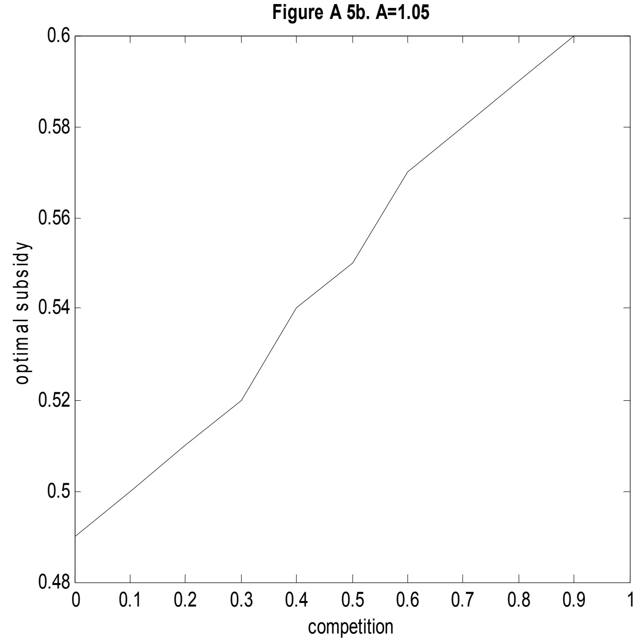

Figure A.6a. k=0.37

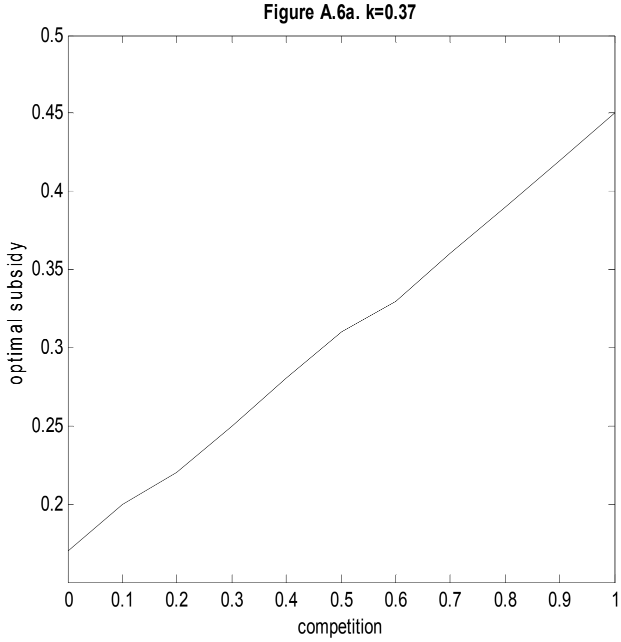

Figure A.6b. k=1.5