

International competition and defensive R&D subsidies in growing economies*

Giammario Impullitti[†]

This draft: July 2006

Abstract

This paper studies the welfare effects of international competition in the market for innovations, and analyzes how competition affects the costs and the benefits of cooperative and non-cooperative R&D subsidies. I set up a two-country Schumpeterian growth model where the leader, the home country, has R&D firms innovating in all sectors of the economy, and the follower, the foreign country, has innovating firms only in a subset of industries. The measure of the subset of sectors where home R&D firms are challenged by foreign innovators pins down the scale of international Schumpeterian competition. The two governments engage in a strategic R&D subsidy game and respond optimally to changes in competition. I show that, first, increases in foreign competition produce a negative business-stealing effect that triggers an increase in the optimal R&D subsidy in the home country. Secondly, I find that the home country does not benefit from cooperation in R&D subsidies at low levels of competition. But, as foreign competitive threat grows home gains from cooperation become positive and increasing with competition. Finally, I show that innovation-driven growth increases the welfare effects of strategic subsidies.

JEL Classification: F12, F43, F43, O31, O38.

Keywords: international competition, endogenous technical change, growth theory, strategic industrial policy, international trade and growth.

*I thank Guido Cozzi, Jonathan Eaton, Boyan Jovanovic, and Gianluca Violante for guidance. I also thank Daron Acemoglu, Philippe Aghion, Lisa Bjorkman, Stefano Eusepi, Duncan Foley, A.J. Julius, Jinyong Kim, Guido Lorenzoni, Giovanni Maggi and seminar participants at SED Annual Meeting Vancouver, Fifth Villa Mondragone workshop in Economic Theory and Econometrics Rome, European Economic Association Meeting Amsterdam, New York University, University of Rome "La Sapienza", New School University, and IMT Lucca. The usual disclaimers apply.

[†]Giammario Impullitti, *Department of Economics New York University*. Email: gi4@nyu.edu.

1 Introduction

In the decades following World War II, U.S. firms were the undisputed world leaders in the production of innovation-intensive goods and services. In the 1970s and early 1980s, however, Japanese and European firms began to challenge American technological leadership in high-tech industries such as electronics, aircraft, scientific instruments, and medical equipment.¹ More recently, Asia's emerging giants, India and China, have reported record levels of exports in highly sophisticated products and services, and have become global players in those markets.² These facts have fueled debates on the welfare effects of increasing foreign competition in innovative markets and have led academics and policy makers to discuss the virtues and vices of strategic policy responses to competition³. Moreover, in groups of countries with strong institutional links the debate has focused on the impact of foreign competition on the scope for cooperative policies; this has been particularly relevant in the discussions on the Lisbon Agenda in the European Union.⁴

Economists have mainly approached these issues by focusing on the welfare effects of changes in product market competition (PMC) produced by foreign entry. This paper, by contrast, studies international competition in the market for innovations, and analyzes how competition affects the welfare costs and benefits of cooperative and non-cooperative R&D subsidies.

I set up a non-scale Schumpeterian growth model (Dinopoulos and Thompson, 1998, Howitt, 1999, Young, 1998, Peretto, 1998), with two countries having the same population, preferences and technology, but with different innovation subsidies and distribution of research efforts across industries. Trade is free and multinational corporations are active in all sectors of the economy. In this environment growth is driven by R&D investment of profit maximizing firms which compete to develop higher-quality products and obtain leadership in the global market.

¹Between 1980 and 1991 the global market shares of the U.S. in the high-tech markets declined by 16 percent, while Japan's share increased by about 30 percent (NSF 2006). Guerrieri and Milana (1991), using a classification scheme for high-tech sectors different from the OECD scheme, found that Japan's share of high-tech export doubled from about 7 percent in 1970-73 to about 16 percent in 1988-89, while the US share declined from 30 percent to about 21 percent. See also Tyson (1992).

²Rodrik (2006) provides a measure of China's export sophistication which shows that in the 1990s the Chinese export bundle was that of a country with an income per-capita level three times higher than China. Kochhar, Rajan, Surbamanian, and Tokatlidis (2006) document the increase in the skill content of India's export: they find that the share of export in skill-intensive goods has risen from 25 percent in 1970 to 65 in 2002.

³See Krugman (1996), Tyson (1992), Bergsten, Gill, Lardy, Mitchell (2006), and Prestowitz (2006)

⁴See Sapir (2003), and Katsoulakos et al. (2005).

I suppose that the domestic country is the leading economy in that its firms invest in R&D in all industries, while foreign firms innovate and compete with domestic leaders only in a subset of the entire spectrum of industries. The measure of this subset, where research from both countries overlaps, will be my index of foreign competition. As a consequence, increases in international competition is unidirectional in that it represents the penetration of foreign researchers into industries where only domestic innovators were previously active.

Increases in foreign competition have two opposite effects on domestic welfare: a *growth effect* (GE) and a *business-stealing effect* (BSE). First, since I assume that R&D technology has decreasing returns at the country level, the entry of foreign researchers into sectors previously dominated by domestic innovators produces a more efficient international division of research labor and increases innovation, growth, and welfare worldwide - this is the GE. Second, the entry of foreign R&D workers into new sectors implies that, with a probability proportional to their research effort, monopoly rents will shift from domestic to foreign firms. The shift of global market leadership in these sectors in favor of foreign firms will reduce aggregate domestic profits, income and welfare - this is BSE.

The first question I tackle in the paper focuses on the effects of competition on the optimal domestic subsidy. I am interested in understanding whether increases in the domain of foreign innovation trigger a more aggressive domestic R&D subsidy, thereby producing a sort of *defensive innovation policy* mechanism. In order to account for strategic policy complementarities I assume that each government sets its R&D subsidies so as to maximize national welfare given the level of the other country's subsidy and the level of competition. I find that increases in foreign competition rise the optimal domestic subsidy, and this is true even when competition increases home welfare. Intuitively, the intensifying threat of foreign business-stealing rises the importance of subsidies as rent-protecting devices.

The second question explores the effects of competition on the gains from international cooperation in R&D subsidies. I show that the leader, the domestic country, loses from cooperation at low levels of competition, while gaining at high levels. The foreign country, instead, always gains from cooperation, and these gains decline as it expands its innovation domain. Intuitively, when only few sectors are challenged by foreigners the domestic country has few incentives to internalize foreign business-stealing, and viceversa for the foreign country. The main implication is that, assuming that there is no ex-post compensation mechanism, policy

cooperation will prevail only at high levels of competition, or if one wishes, at low levels of technological heterogeneity. As I find that policy cooperation increases the world welfare at all level of competition, a corollary of this result is that the lack of policy cooperation produces a welfare loss for the global economy.

The BSE of R&D subsidies has its origins in the strategic trade and industrial policy literature. In a pioneering contribution, Spencer and Brander (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.⁵ Most of the contributions in this literature, in order to focus on the strategic motive for subsidies, limit the analysis to unilateral policies and to export to a third market. These assumptions are restrictive in that they allow neither an exploration of strategic policy complementarities, nor an account of the effect of R&D subsidies on consumer surplus. Moreover, the works that have studied the scope for R&D cooperation have focused on cooperation between firms rather than governments.⁶

Recently, Haaland and Kind (2004a and 2004b), have analyzed competition and cooperation in R&D at the policy stage. They have also overcome the limits of existing strategic policy models by allowing all countries to be active in innovation policy and by removing the simplifying assumption that all output is exported to a third market. They have studied the interplay of the business-stealing and the consumer surplus motive for R&D subsidies, as well as the scope for international cooperation in research policy. Finally, they have also introduced into the strategic policy literature the analysis of the effects of trade liberalization and of changes in PMC on private and public incentives to invest in R&D.

These papers, as well as the other works in the strategic trade and industrial policy literature, are confined to static models where the dynamic effects of innovation are not taken into account. Brander (1995) suggests that exploring the growth effects of strategic policies might increase the relatively small gains and losses from these policies estimated in one-shot games. In this paper I introduce a strategic industrial policy game into an endogenous growth model and account for both the BSE and the long-run GE of research subsidies.⁷ In a growing economy with intertemporal knowledge spillovers we can study the long-run implications of policy competition

⁵Eaton and Grossman (1986) showed that this result depends on whether firms engage in Bertrand or Cournot competition. Brander (1995) surveys the literature.

⁶See for instance Leahy and Neary (2004).

⁷In line with my work, Etro (2006) introduces a strategic R&D subsidy game into a quality-ladder growth model and, leaving aside changes in any dimension of competition, analyzes the case for international coordination of research policies.

and cooperation in R&D, as well as their interactions with international competition.

Other related works are those in the endogenous growth literature that explore the welfare effects of competition in growing economies (see for instance Kludert and Smulders 1997, and Tang and Waelde 2001). These works focus on the effects of changes in PMC on national welfare. The present paper, instead, studies a different dimension of competition, the international rivalry among producers of ideas, which Schumpeter believed to be the most relevant feature for long-run growth (Schumpeter, 1942).⁸ Moreover, it provides a complete analysis of the effects of competition on the optimal level of R&D subsidy.⁹ As a consequence, the core questions of the paper differ both from those explored in the growth literature on competition and welfare and from those in the strategic policy literature discussed above: it studies how optimal R&D subsidies, are influenced by international Schumpeterian competition, that is by foreign penetration in the market for innovations, when trade is free and the degree of PMC is given. Focusing on PMC does not allow a leader-follower representation of the global economy because changes in this dimension of competition affect all countries symmetrically. Thus, the existing frameworks are not suitable for analyzing the effects of entry of researchers from catching-up countries - such as Japan and Europe in the 1970s, and India and China in the 1990s - on welfare and on optimal innovation policy in leading countries.

The rest of the paper is structured as follows. Section 2 sets up the model. In section 3 I discuss the effects of foreign competition on domestic welfare. In sections 4 I study the effects of changes in foreign competition on the optimal domestic R&D subsidies, with no cooperation. Section 5 explores the role of competition in shaping the costs and benefits of international cooperation in R&D subsidies. In section 6, I first, discuss the role of introducing growth into a strategic industrial policy model; second, I suggest an application of the results in section 5 to the problem of R&D policy coordination in the E.U. Section 7 concludes.

2 The model

In this section I set up the model and derive the steady state equilibrium system of equations. As the system is not solvable analytically, I calibrate the model to match salient long-run facts

⁸Aghion and Howitt (1998) ch. 7. explore competition in the market for innovation introducing imperfect competition in the research sector. In the present paper, instead, R&D is perfectly competitive and technological competition is pinned down by the international allocation fo research efforts.

⁹This feature of the paper is related to the literature on optimal R&D subsidies in endogenous growth models (see for instance Segerstrom 1998, and Jones and Williams 2000).

of the U.S. economy and then solve it numerically.

2.1 Households

Consider a two-country economy in which population, preferences, technologies, and institutions are identical in both countries. Households have 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:

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

subject to

$$\begin{aligned} \log u(t) &\equiv \int_0^1 \log \left[\sum_{j=0}^{j^{\max}(\omega,t)} \lambda^{j(\omega,t)} q(j, \omega, t) \right] d\omega \\ c(t) &\equiv \int_0^1 \left[\sum_{j=0}^{j^{\max}(\omega,t)} p(j, \omega, t) q(j, \omega, t) \right] d\omega \\ W(0) + Z(0) - \int_0^\infty N_0 e^{-\int_0^t (r(\tau)-n)d\tau} T dt &= \int_0^\infty N_0 e^{-\int_0^t (r(\tau)-n)d\tau} c(t) dt \end{aligned}$$

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 $j \in \{0, 1, 2, \dots\}$, purchased by a household at time $t \geq 0$. $p(j, \omega, t)$ 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 $c(t)$ 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:

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

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

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

2.2 Product market

In each country, firms can hire workers to produce any consumption good $\omega \in [0, 1]$ under a constant return to scale (CRS) technology with one worker producing one unit of product. The wage rate is 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. I assume that technology is mobile, firms own the technology but can use it everywhere. It follows that multinational companies are free to establish subsidiaries in low wage countries to carry out the manufacturing of their products, so 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 (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.

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

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

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

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

where $c^D(t)$ and $c^F(t)$ are domestic and foreign expenditures at time t . The above equation says 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

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

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

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

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 a no-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.

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 $I(\omega, t)$, which 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 according to the following technology:

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

where $X(\omega, t) > 0$ measures the degree of complexity in the invention of the next quality product in industry ω , $\alpha > 0$ represents a negative externality, $L^K(\omega, t) = \sum_i l_i^K(\omega, t)$ 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 increase R&D in a sector, the probability of duplicative research effort also increases, thereby reducing the probability that any single firm will discover the next vintage of goods and appropriate the profit rent associated with it. Therefore, the sector-specific negative externality in research technology produces decreasing returns to scale (DRS) in R&D at the industry level. Moreover, I assume that this negative externality 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.¹⁰

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

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

with positive κ , thereby formalizing the idea that it is more difficult to introduce a new product in a more crowded market. The PEG rules out implausible “scale effects”. This formulation, in particular, allows for sustained per-capita growth without population growth and leads to a class of models also known as fully-endogenous growth frameworks (Aghion and Howitt 2005).¹¹

Governments subsidize R&D expenditures at the rate s^K . Each R&D firm chooses l_i^K in order to maximize its expected discounted profits.¹² Free entry into R&D races drives the

¹⁰Hall et. al. (1988), Pakes and Griliches (1984), and Kortum (1993) provide empirical evidence on the existence of DRS in R&D due to duplicative research and fixed costs. A typical microfoundation for this is attainable by relating the DRS in R&D at the country level 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 does not allow this type of microfoundation.

¹¹Acronym “PEG” refers to the “permanent effects on growth” of policy measures such as R&D subsidies and tariffs; they can alter the steady state growth rate. A different specification of the difficulty index, proposed by Segerstrom (1998), is $\frac{\dot{X}(\omega, s)}{X(\omega, s)} = \mu I(\omega, s)$, which 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, among others, Kortum 1997 and Jones 1995).

¹²The discounted profits equals

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

where s^k is the R&D subsidy

expected profits to zero, generating the following equilibrium condition:

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

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. Substituting for the value of the firm from (7) into (9) we get:

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

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.

2.4 Modeling international competition: the overlapping research support.

Before closing the model I need to formalize my 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 vintage of products. I choose $\bar{\omega} \in (0, 1)$ to be the measure of the subset of industries ξ_c . Therefore the composition of worldwide investment in innovation will be the following:

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

where $\kappa > 0$, $I_c^D(\omega, t)$ 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 the research investment of country F. The symmetric structure of the model leads us to study only symmetric allocations 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 $\omega \in (0, 1)$.

2.5 Balanced growth

In this section I derive the steady state properties of the model, where per-capita endogenous variables are stationary. To close the model I need to introduce the labor market clearing condition and the national resource constraints. 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 R&D technology (8) research labor can be expressed as a function of the innovation arrival rate.¹³ It follows that $\dot{L}^F(t)/L^F(t) = [1/(1 - \alpha)]\dot{I}^F/I^F + \dot{X}(t)/X(t)$ and $\dot{L}^D(t)/L^D(t) = [1/(1 - \alpha)]\left(\dot{I}_m^D/I_m^D + \dot{I}_c^D/I_c^D\right) + \dot{X}(t)/X(t)$; since in steady state the allocation of R&D labor is stationary, it means that $\dot{L}^K(t)/L^K(t) = \dot{X}(t)/X(t)$. Furthermore, using the specification of the R&D difficulty index (PEG) we obtain $\dot{v}^K(t)/v^K(t) = \dot{X}(t)/X(t) = n$, for $K = D, F$. Finally, from the Euler equation for consumption we get the steady state value of the interest rate, $r(t) = \rho$.

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 multinationals implies that both the labor and goods markets clear globally. Thus, the following condition clears both markets:

$$\left(\frac{c^D + c^F}{\lambda}\right) = 2 - 2\kappa \left[\bar{\omega} \left(\frac{I_c^D}{A}\right)^{\frac{1}{1-\alpha}} + (1 - \bar{\omega}) \left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}} + \bar{\omega} \left(\frac{I^F}{A}\right)^{\frac{1}{1-\alpha}} \right]. \quad (11)$$

The LHS represents the total demand for goods (labor), while the RHS is the total supply, given by total labor resources minus labor used in research. 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 national income, wages plus profits (or interest income on assets).¹⁴

$$2\kappa \left[\bar{\omega} \left(\frac{I_c^D}{A}\right)^{\frac{1}{1-\alpha}} + (1 - \bar{\omega}) \left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}} \right] + c^D = 1 + (c^D + c^F) \left(\frac{\lambda - 1}{\lambda}\right) \left[1 - \bar{\omega} + \bar{\omega} \frac{I_c^D}{I_c^D + I^F} \right] \quad (12)$$

¹³Using (8) we can express labor allocated to research as $L^D(t) = \bar{\omega}X(t) (I_c^D(t)/A)^{\frac{1}{1-\alpha}} + (1 - \bar{\omega})X(t) (I_m^D(t)/A)^{\frac{1}{1-\alpha}}$ for the domestic country and $L^F(t) = \bar{\omega}X(t) (I^F(t)/A)^{\frac{1}{1-\alpha}}$ for the foreign country respectively. From now on I will use these expressions in the place of the labor allocated to research.

¹⁴In a similar two-country quality-ladders model 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 does not change our qualitative results.

$$2\kappa \left[\bar{\omega} \left(\frac{I^F}{A} \right)^{\frac{1}{1-\alpha}} \right] + c^F = 1 + (c^D + c^F) \left(\frac{\lambda - 1}{\lambda} \right) \left[\bar{\omega} \frac{I^F}{I_c^D + I^F} \right]. \quad (13)$$

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 the 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 domestically and foreign firms are completely foreign-owned.¹⁵

The international division of research labor specified in the previous section leads to the following steady state expressions for the no-arbitrage and free entry conditions in (10):

$$\begin{aligned} \frac{2\kappa}{A}(1 - s^F) &= \frac{(c^D + c^F) \left(\frac{\lambda - 1}{\lambda} \right)}{\rho + I_c^D + I^F - n} \left(\frac{I^F}{A} \right)^{\frac{-\alpha}{1-\alpha}}, \quad \omega \in \xi_c \\ \frac{2\kappa}{A}(1 - s^D) &= \frac{(c^D + c^F) \left(\frac{\lambda - 1}{\lambda} \right)}{\rho + I_c^D + I^F - n} \left(\frac{I_c^D}{A} \right)^{\frac{-\alpha}{1-\alpha}}, \quad \omega \in \xi_c \\ \frac{2\kappa}{A}(1 - s^D) &= \frac{(c^D + c^F) \left(\frac{\lambda - 1}{\lambda} \right)}{\rho + I_m^D - n} \left(\frac{I_m^D}{A} \right)^{\frac{-\alpha}{1-\alpha}}, \quad \omega \in 1 - \xi_c, \end{aligned} \quad (14)$$

where, using the R&D technology (8) we have expressed research labor as a function of the innovation arrival rate. We have 6 equations and 5 unknowns $\{c^D, c^F, I_m^D, I_c^D, I^F\}$. The labor market clearing condition (11), turns out to be the sum of the two resource constraints (12) and (13), so the three equations are not linearly independent; I can omit one of them, and solve for the three eq.s. in (14), and the remaining (12), (13).

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

$$W^K \equiv \ln \frac{c^K}{\lambda} + \frac{g}{\rho - n} \quad (15)$$

where $g = [\bar{\omega}(I_c^D + I^F) + (1 - \bar{\omega}) I_m^D] \ln \lambda$ is the growth rate that, in our symmetric free trade economy, is common for both countries. In the present framework with quality improving

¹⁵This 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 and Germany.

goods, “growth” is interpreted as the increase over time of the representative consumer utility level.

Two-country endogenous growth models become complicated when either structural or public policy differences affect endogenous variables.¹⁶ Structural differences, in the form of asymmetric 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 explore the implications of the model numerically.

2.6 Calibration

In this section I calibrate the parameters of the model to match some basic long-run empirical regularities of the U.S. economy. I need to calibrate 6 parameters. Four of them, ρ , λ , n , and α will be calibrated using benchmarks that are standard in the growth literature, while the others, A and k , will be calibrated internally so that the model’s steady state matches salient facts of the U.S. economy.

Parameters calibrated “externally”- Some parameters of the model have close counterparts in real economies so that their calibration is straightforward. I set ρ , which in the steady state is equal to the interest rate r , to 0.07 to match the average real return on the stock market for the past century of 0.07, estimated in Mehra and Prescott (1985).¹⁷ I set λ to 1.2, to match an average markup over the marginal cost of 20 per cent. Since, estimates of average sectorial mark-up are in the interval (0.1, 0.4) (Basu 1996), I take an intermediate value in this range. I calibrate n to match the population growth rate of 1.14%, as in Jones and Williams (2000). Decreasing returns due to duplicative R&D at the country-level have been estimated to be between 0.1 and 0.6 (Kortum 1993), so as a benchmark I take an intermediate value and set the R&D externality coefficient α at 0.4.

Parameters calibrated “internally”- I simultaneously choose A and κ so that the numerical steady state solution of the model matches the following stylized facts: an average growth rate for the US economy of 2.3% in the period 1951-2000 (Penn World Table). An average R&D investment, as a share of GDP, of 2.5% in the period 1951-2000 (NSF S&E Indicators

¹⁶See for instance Lundborg and Segerstrom (2002).

¹⁷Jones 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.

2004); a consumption, as a share of GDP, of 0.67, in the period 1951-2004 (BEA NIPA tables). I also use an initial value for the subsidy of both countries of 0.044, which is the average effective R&D tax credit for the period 1981-90 estimated in Hall (1992). Table I below summarizes the benchmark parameters calibration.¹⁸

TABLE I
BENCHMARK PARAMETERS

parameter	value	moment to match	source
ρ	0.07	interest rate	Mehra and Prescott (1985)
λ	1.2	markup	Basu (1996)
n	0.014	population growth rate	Jones and Williams (2000)
α	0.4	returns to R&D	Kortum (1993)
A	0.4	internal	NSF, BEA, PWT
κ	0.65	internal	NSF, BEA, PWT

It is worth noting that by calibrating the model on U.S. data, I am implicitly assuming that the stylized facts presented above are similar in the two economies. Since I am studying competition for innovation among similar countries this does not appear to be a problematic assumption. If we consider OECD countries we find many similarities in the long-run facts described above.¹⁹

3 The business-stealing vs. the growth effect of competition on welfare

In this section I keep R&D subsidies in both countries constant and describe the two basic effects of increases in international competition - increases in \bar{w} - on domestic welfare. First, the presence of foreign R&D firms in a larger number of sectors leads to a better international division of research labor, thereby increasing the global innovation rate and benefiting consumers worldwide. This ‘growth effect’ (GE) of competition increases both domestic and foreign welfare by improving the quality of the goods consumed. Second, foreign firms replace domestic leaders in some of the newly competitive sectors and, as a consequence, monopolistic rents shift abroad and domestic aggregate profits, income, and welfare decline - this is the ‘business-stealing’ effect (BSE) of foreign competition.

¹⁸The parameters calibrated internally have been found by minimizing the quadratic distance between the model steady state and the stylized facts listed above.

¹⁹The results presented in the following sections are based on this benchmark calibration of the model. In the appendix I perform a detailed sensitivity analysis showing that the qualitative results are not affected by changes in the benchmark parameters.

The BSE reduces domestic aggregate profits because foreign firms, by innovating in more sectors, appropriate a larger share of the world market. Since, by assumption, the labor market is not affected by shifts in the global distribution of firms ownership, domestic income decreases along with profits. Using the domestic resource constraint (12) we can see that increases in the measure of competition $\bar{\omega}$ reduce domestic profits, thereby reducing the resources available for consumption, and negatively affecting home welfare given by eq. (15). Table II below reports the effects on the key variables of changes in competition, while holding both subsidies constant. The first two rows show the effect of profit-shifting on welfare.

TABLE II

STEADY STATE WITH CONSTANT SUBSIDIES						
$\bar{\omega}$	0	0.2	0.4	0.6	0.8	1
Income D	1.346	1.311	1.276	1.241	1.206	1.171
Income F	1.000	1.034	1.069	1.103	1.137	1.171
I_m^D	0.154	0.154	0.154	0.153	0.153	0.153
I_c^D	0.106	0.106	0.106	0.106	0.106	0.105
I^F	0.106	0.106	0.106	0.106	0.106	0.105
R&D Spending D	0.266	0.241	0.216	0.191	0.166	0.142
R&D Spending F	0	0.028	0.057	0.085	0.113	0.142
Growth rate	0.028	0.030	0.032	0.034	0.036	0.038
Welfare D	0.398	0.426	0.454	0.481	0.509	0.536
Welfare F	0.320	0.364	0.407	0.450	0.493	0.536

The innovation or GE of competition depends entirely on the presence of local decreasing returns in R&D. Intuitively, the negative country-specific R&D externality α in (8) implies that research labor is more productive when spread more evenly around the globe than when concentrated in one country. More precisely, the decision to invest in innovation is determined by two margins: the allocation of labor between production of goods and R&D, and the allocation of R&D 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 constant wage rate.²⁰ Consider now the marginal benefits of investing in research - marginal productivity of R&D times the present value of the monopolistic firm - in a competitive and a non-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 requires the two marginal benefits to be equal:

²⁰In fact, as we can see rows 3 to 5 of table II, innovation per-sector does not change with competition. The little changes reported are the result of computation errors in the numerical solution.

$$\frac{(c^D + c^F) \left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_m^D - n} \left(\frac{I_m^D}{A}\right)^{\frac{-\alpha}{1-\alpha}} = \frac{(c^D + c^F) \left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_c^D + I^F - n} \left(\frac{I_c^D}{A}\right)^{\frac{-\alpha}{1-\alpha}}. \quad (16)$$

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 $v^K(\omega, t)$ 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 arrival rate of innovation, it follows that innovation in the competitive sectors must be higher than in non-competitive sectors. Hence, from (16) we conclude that in equilibrium we have $I_c^D + I^F > I_m^D$. As showed in table II innovation per sector does not change with competition, that is $\partial I_c^D / \partial \bar{\omega} = \partial I^F / \partial \bar{\omega} = \partial I_m^D / \partial \bar{\omega} = 0$. Thus, competition simply increases the share of industries with an higher arrival rate of innovation, thereby producing a positive effect on the aggregate growth rate of the economy - $\partial g / \partial \bar{\omega} = [(I_c^D + I^F) - I_m^D] \log \lambda > 0$ for all $\alpha > 0$.

In conclusion, the welfare effects of competition depends on parameters' values and, in particular, on the strength of the R&D externality pinned down by the value of α . In table II we can observe that in the benchmark calibration, where α is 0.4, the GE is larger than the BSE, and foreign competition leads to welfare improvements in the home country.

4 Foreign competition and optimal non-cooperative subsidies

Next, I use the calibrated model to compute numerically the optimal strategic R&D subsidy for both countries and to explore the impact of increasing foreign competition on the optimal domestic subsidy. A two-stage policy game between the two countries is set up: at stage 1, governments set their subsidies; at stage 2 R&D and manufacturing firms choose their profit-maximizing level of activity, and households choose their utility-maximizing consumption bundles and assets holdings. For each level of competition and for each level of the other country's subsidy, policy makers set their subsidy according to the following best-response functions

$$s_n^D(s_n^F; \bar{\omega}) = \left\{ \arg \max W^D(s_n^D, s_n^F; \bar{\omega}) \right\}, \quad (17)$$

$$s_n^F(s_n^D; \bar{w}) = \{ \arg \max W^D(s_n^D, s_n^F; \bar{w}) \}. \quad (18)$$

Below I show that if there is strategic policy complementarity this policy game yields a Nash equilibrium pair of subsidies, $s_n^{*D}(s_n^{*F}; \bar{w})$ and $s_n^{*F}(s_n^{*D}; \bar{w})$, as a function of the level of competition.²¹ Figures 3 to 5 show the Nash equilibrium for different levels of competition.

[FIGURES 1–3 ABOUT HERE]

The best-response functions confirm the presence of strategic policy complementarity, with a Nash equilibrium existing at each level of competition. In order to explain why R&D subsidies are strategic complements, we need to understand how changes in a country's subsidy affect the marginal conditions used by the other country's policy makers to set its optimal subsidy. I do this by expressing the welfare equation in a form that facilitates the intuition, and by decomposing the marginal effects of subsidies on domestic welfare. The present value of national welfare in both countries can be expressed as

$$W^K = GE + \Pi^K + w - R^K, \quad (19)$$

where the growth effect (GE) equals the present value of the common growth rate, $GE = GE^D = GE^F = g/(\rho - n)$. Any time an innovation arrives, consumers can buy goods of a higher quality for the same price. These benefits last indefinitely because future innovations build on past innovations. Π^K are the logs of the per-capita aggregate real profits for the two countries²². The standard resource constraint effect of innovation is represented by the log of total real investment in research, $R^K = \ln(L^K/\lambda)$, that reduces resources available for consumption. Finally, labor income w is $\ln(1/\lambda)$. Using (20) we can express the different marginal effects of the R&D subsidy on domestic welfare as follows:

²¹The subscript n stands for non-cooperative subsidies.

²²The logarithm of the per-capita consumption aggregate profits are

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

and

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

for the domestic and the foreign country respectively.

$$\frac{\partial W^D}{\partial s^D} = \underbrace{\frac{\partial R^D}{\partial s^D}}_{\substack{\text{Resource constr.} \\ (-)}} + \underbrace{\frac{\partial GE}{\partial s^D}}_{\substack{\text{Growth effect} \\ (+)}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{\text{Business-stealing} \\ (+)}} \quad (20)$$

Here I discuss the effect of an increase in foreign subsidies on the marginal welfare effect of domestic subsidies, and later I explain the effect of increasing foreign competition on the optimal domestic subsidy. The main force driving strategic policy complementarity is the BSE of foreign subsidies. Higher foreign subsidies produce a higher *intensity* of foreign business-stealing, and so the role of subsidies in protecting domestic rents increases. An increase s^F improves the marginal effects of s^D on welfare, thus producing a positive effect on the optimal domestic subsidy.²³ The explanation for the best response of the foreign country is analogous and we can omit it.²⁴

Result 1. *Increases in foreign competition produce a defensive innovation policy response. More precisely increases in $\bar{\omega}$ rise the optimal strategic subsidy in the domestic country.*

In figures 1-3 we see that increases in competition shift the domestic best-response function upwards, while also making it steeper. The driving force of these changes is again the BSE. As international R&D rivalry rises, the foreign rent-stealing threat becomes more relevant and triggers higher domestic subsidies. It is possible to see in eq. (12) that the rent-protecting effect of s^D is zero at $\bar{\omega} = 0$, and increases with competition. 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. It follows that the role of domestic subsidies as a rent-protecting device rises. Moreover, the same force makes the domestic best response steeper,

²³Even though the BSE is the key force for this result, two other effects operates in the same direction. First, since DRS in R&D are country-specific, increases in the intensity of foreign research, triggered by higher R&D subsidies, do not affect the productivity of domestic R&D, and thus do not change the marginal impact of domestic subsidies on innovation. Second, the entry of foreign researchers 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, so that, at the margin, the innovation effect of domestic subsidies is stronger while the resource constraint is weaker.

²⁴It is worth noticing that when research supports are asymmetric ($\bar{\omega} < 1$) 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 fewer innovative sectors research will be concentrated in those sectors, innovation will have high obsolescence rate and R&D 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.

which implies that the sensitivity of the optimal s^D to changes in s^F rises.²⁵ Intuitively, as the scale of foreign competition grows each dollar of foreign subsidies represents a more serious threat to the domestic leadership.²⁶

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 GE. In fact, the presence of the country-specific R&D externality in (8) implies that research efficiency is higher in competitive sectors. Hence, an increase in the number of competitive sectors raises the aggregate productivity of domestic research labor thereby improving the marginal effect of subsidies on aggregate innovation. Since subsidies stimulate innovation, and the latter is produced more efficiently, it follows that competition increases subsidies also through its impact on the growth rate.

5 The gains from policy cooperation

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 the foreign growth rate (and consumer surplus); second, the negative BSE of national subsidies on foreign aggregate profits is not considered by governments in maximizing their own welfare. Hence, the need for policy coordination emerges.

In this section, I introduce a R&D policy coordination that internalizes the BSE and takes into account the GE of subsidies in both countries. I consider a form of cooperation where subsidies are set separately by governments in order to maximize global welfare; that is,

$$\{s_c^D, s_c^F\} = \arg \max \{W^W(s_c^D, s_c^F; \bar{\omega})\},$$

²⁵This result does not rely on the fact that the optimal subsidy is positive. The sensitivity analysis in the appendix shows that when the model is also solved for parameters specifications that give negative optimal subsidies and result 1 still holds qualitatively. More precisely, with those specifications an increase in international competition reduces the optimal domestic R&D tax.

²⁶In this paper I am interested in studying the domestic country, the former leader that experiences increasing competition from the foreign follower. Thus, I comment only briefly on the latter. The smaller change in foreign optimal subsidies is the result of a general equilibrium effect. On the one hand, an increase in $\bar{\omega}$ rises 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; indeed, the foreign best-response function shifts left - as we see in the figures. On the other hand, the fact that the domestic best-response function shifts upward, as $\bar{\omega}$ increases, triggers strategic complementarity: the foreign policy maker reacts by rising its subsidy - this is a movement along the foreign country's best-response function. The relatively minor effect of competition on foreign subsidies is the general equilibrium result of these two counteracting forces.

where

$$W^W = 2GE + \Pi^D + \Pi^F + 2 - R^D - R^F \quad (21)$$

is the global welfare equation. I 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) . I assume that there is no ex-post compensation scheme according to which the winner can compensate the loser. Therefore, cooperation will be implemented only when it benefits both countries.

Result 2. *The optimal domestic cooperative subsidy increases with competition. At each level of competition, cooperation leads to optimal R&D subsidies that are higher than those obtained under no cooperation.*

TABLE III
GAINS FROM COOPERATIVE R&D POLICY

	Coop		Non-Coop		Gains D	Gains F	Global gains
\bar{w}	s_c^D	s_c^F	s_n^D	s_n^F	$W_c^D - W_n^D$	$W_c^F - W_n^F$	$W_c^W - W_n^W$
0.2	0.65	0.775	0.12	0.275	-0.0576	0.2573	0.1997
0.3	0.67	0.775	0.1450	0.28	-0.0229	0.2402	0.2173
0.4	0.695	0.775	0.17	0.28	0.0005	0.2346	0.2351
0.6	0.73	0.78	0.215	0.285	0.0648	0.2063	0.2711
0.8	0.77	0.79	0.255	0.29	0.1131	0.1946	0.3077
1	0.8	0.8	0.29	0.29	0.1729	0.1729	0.3458

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. (22) below shows the effects of domestic subsidies on world welfare.

$$\frac{\partial W^W}{\partial s^D} = \underbrace{\frac{\partial R^D}{\partial s^D}}_{\substack{\text{resource constr.} \\ (-)}} + 2 \underbrace{\frac{\partial GE}{\partial s^D}}_{\substack{\text{growth effect} \\ (+)}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{\text{business-stealing} \\ (+)}} + \underbrace{\frac{\partial \Pi^F}{\partial s^D}}_{\substack{\text{business-stealing} \\ (-)}} \quad (22)$$

Comparing (22) with (20) we can observe that two additional effects appear in the case with cooperation. First, we see the internalization of the negative BSE of domestic subsidies on foreign profits. Second, domestic subsidies have a double GE because policy cooperation takes into account the positive innovation 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 BSE on foreign income that is internalized when the domestic government maximizes global welfare, and which reduces the optimal domestic subsidy; and the positive GE on foreign welfare which increases the optimal domestic subsidy. This second effect is stronger than the first and the optimal domestic subsidies rises with cooperation. Intuitively, the BSE that drives strategic subsidies produces a prisoner dilemma type of outcome that leads both countries to under-subsidize R&D.

The intuition for the relationship between the optimal domestic subsidy and competition is as follows: the BSE is neutralized by cooperation, so we focus on the two remaining effects shown in (22). We have a standard resource constraint effect and a double GE. The fact that the optimal domestic subsidy increases with $\bar{\omega}$ is related to the specification of R&D technology: when competition is low research is performed mainly by domestic workers, and the presence of a negative country-specific R&D externality implies that their productivity will be low. With increases in competition, a larger share of research is conducted by foreigners. Thus, research efforts are more evenly spread among countries and, as a consequence, domestic R&D labor is more productive and the GE of subsidies is higher. It follows that the optimal domestic subsidy will be larger with higher levels of competition.

Result 3. *For a country facing increases in foreign competition - the domestic country - the incentives to cooperate increase with competition but are negative for $\bar{\omega} < 0.38$. For the foreign country, gains from cooperation are positive and decreasing in $\bar{\omega}$. Overall, policy cooperation increases global welfare for every $0 < \bar{\omega} < 1$ but, in the absence of a compensation scheme, it will not be implemented at levels of competition below 0.38.*

As foreign competition increases the leading country's incentives to cooperate rise. In the sixth column of table III we can see that domestic gains from cooperation are negative at $\bar{\omega} = 0.3$ and are positive at $\bar{\omega} = 0.4$ - precisely they become positive at $\bar{\omega} = 0.38$. The domestic government has little incentive to cooperate when competition is low because foreign business-stealing does not represent a sufficient threat. Hence, when the competitive threat is low the home country benefits less from internalizing foreign business-stealing while the opposite happens in the foreign country.

The intuition for the positive global welfare gains from cooperation is the same as that explains result 2. The R&D subsidies war leads to a coordination failure that does not allow

countries to fully exploit the growth potentials of the global economy. The positive global gains from cooperation reported in the last column of table III show that policy competition yields subsidies that are too low from a global perspective.²⁷ We assume that there is no ex-post compensation mechanism, so the global gains from cooperation will not be exploited at low levels of competition.

6 Discussion

In this section I will briefly discuss two issues related to the results presented above, one that qualifies the properties of the model, and the other that suggests a possible application of the last section's results. Precisely, I will first explore the importance of introducing growth in a strategic industrial policy game. Secondly, I will discuss the relevance of my results for issues of international policy coordination, and in particular for the debate on innovation policy in the E.U.

Growth and strategic R&D policy. Strategic trade and industrial policies have important effects on economic growth that have not been explored in the existing literature. Brander (1995) claims that understanding the interaction between strategic policy and growth is a promising field of future research: "The static one-shot gains or losses from trade policy changes that are estimated in strategic trade policy models are larger than in traditional trade policy models, but still seem to be of modest size. It is possible that the effect of trade policy on growth might be more important still" (p. 1450). Here I explore the role of growth on the welfare effects of strategic policy.

In the previous section I showed that there are positive gains from cooperative R&D subsidies at all levels of competition. The BSE of subsidies that drives strategic policy leads both countries to under-subsidize R&D, thereby reducing the long-run effects of innovation on welfare. Here I want to show that reducing the importance of innovation-driven growth will reduce the effect of strategic policy on welfare, thus diminishing the gains from cooperation in R&D policy.

In order to understand the growth effects of strategic policy we need to focus on the external

²⁷I do not compare the welfare under strategic subsidies with the that under *laissez-faire* because the "internal" calibration of A and κ links these parameters to a specification of the model with both countries active in R&D policy. As a consequence we cannot compare the welfare outcome of a model with no subsidies and a model with strategic subsidies.

effects generated from a successful innovation in the model. More precisely, we have to explore those external effects that have an impact on the growth (consumer surplus) component of the welfare equation (19). There are two positive spillover effects that accrue to households: the spillover for consumers of the innovative product - the direct consumer-surplus effect - and a further external benefit due to the knowledge spillover to later innovators - the intertemporal spillover effect. The direct consumer-surplus effect benefits consumers that pay the same price for a good of higher quality. The intertemporal spillover is realized when future generations of innovation build on the present innovation: consumers benefit from a higher-quality product when it is introduced by the current innovator and also after it has been replaced by the next innovators who build on the previous quality ladder. It is easy to show that the expected value of these two benefits combined is equal to $\ln \lambda / (\rho - n)$.²⁸ In a static model, the absence of intertemporal knowledge spillovers does not allow us to account for the dynamic effects of innovation: investments in R&D have a positive effect on consumers' surplus through cost reductions or quality improvements, but this effect does not last forever.

To show how the presence of intertemporal spillovers affects the impact of strategic policy on welfare, in table IV I compute the gains from cooperation when consumers become more impatient. I increase the intertemporal discount factor ρ from 0.07 to 0.1 to represent a situation where consumers care less about the welfare effect of a marginal innovation today on the future innovation.

TABLE IV
GROWTH DYNAMICS AND STRATEGIC R&D POLICY

$\rho = 0.1$	Gains D	Gains F	Global gains
\bar{w}	$W^D(C) - W^D(NC)$	$W^F(C) - W^F(NC)$	$W^W(C) - W^W(NC)$
0.2	-0.0553	0.1096	0.0543
0.4	-0.0341	0.1021	0.068
0.6	-0.0093	0.0927	0.0834
0.8	0.0179	0.0718	0.0897
1	0.0485	0.0485	0.097

In the previous section we saw that policy competition leads to equilibrium subsidies at which the economy as a whole under-invests in innovation. The global gains reported in table III are explained by that fact that cooperation, internalizing the BSE of subsidies, allows policy makers to better exploit the local and the cross-border GE of subsidies. When consumers care less about the future the GE of R&D subsidies on welfare becomes less important. Since under

²⁸See Grossman and Helpman (1991) p. 110.

policy cooperation the BSE is internalized and subsidies are motivated only by their GE, the global gains from cooperation will be lower. In fact, comparing tables III and IV, we can see that with a higher ρ cooperation becomes beneficial for the leading country only at higher level of subsidies; the competition threshold for cooperation to be beneficial raises from 0.38 to 0.66. Comparing the last column of the two tables, we see that the gains from cooperation for the global economy are lower with a higher intertemporal discount factor at each level of competition.

Similar results can be obtained by increasing the population growth rate n . With higher population growth the long-run welfare gains from innovation will be spread among a larger number of consumers and innovation will yield lower benefits to the representative household.²⁹

Innovation policy coordination in an economic union. The results on the interactions between competition and the leader's incentive to cooperate may be relevant for issues of international policy coordination, and in particular for the debate on innovation policy in the European Union. In fact, the E.U., more than for instance NAFTA, ASEAN, and the WTO 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 tends to leave innovation policy to national governments. As 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 E.U. 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).

In Europe we can observe some national economies such as Germany, Sweden, and France innovating in a broad variety of sectors, while in others, especially the newer members from eastern Europe, innovation is scanty and concentrated in fewer sectors. For instance, Impulitti (2006) computes the Herfindahl index of geographical R&D concentration in the period 1973-89 for the U.S., Japan, and 10 European countries: Germany, France, U.K., Italy, Sweden, Denmark, Finland, Ireland, Spain, and the Netherlands. In the period considered, R&D expenditures in these countries represented between 95 and 98 percent of the global R&D investment in manufacturing. The index shows a steady decline of R&D concentration in those years, which can be interpreted as an increase in international R&D competition in the global econ-

²⁹See appendix.

omy.³⁰ Interestingly, when excluding R&D investment from Italy, Ireland, Denmark, Spain, Finland, and the Netherlands, the index does not show substantial changes in the measure of concentration.³¹

In those cases where innovation asymmetries among countries are strong this paper could provide a basic framework for evaluating the welfare gains of cooperative R&D policies. The results suggest that leading-edge countries would experience a welfare loss when cooperating with followers, and would gain when they coordinate their R&D policy with other leading countries. As a consequence, the E.U. Commission's laissez-faire approach might be motivated by the reluctance of the leading countries - those with a wider distribution of innovation efforts and a greater decision-making power - to coordinate their policy with the laggards. The enlargement of the E.U. to include Eastern European countries has most probably increased geographic innovation asymmetries in the area and, in so doing, might have further 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 a sufficient number of 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 interpretation.

7 Conclusion

In this paper I have analyzed the interaction between international technological competition and the optimal - competitive and cooperative - R&D subsidies in two asymmetric growing economies. The dimension of competition that I explore is based on a leader-follower representation of the global economy where the leading country innovates in a broader set of industries than the follower. This set up is ideal to answer the following questions: i) What are the effects of foreign penetration in the market for innovations on the optimal domestic R&D subsidy? ii) How do changes in foreign competition affect the incentives for the leading country to cooperate in R&D policy?

³⁰Impullitti (2006) also builds an empirical measure for $\bar{\omega}$, the index of international Schumpeterian competition used in this paper, and find that in 1973 35% of 2-digit manufacturing sectors were competitive and this number increases until reaching 70% in 1989. The index is computed by considering the U.S. as the leading economy, the domestic country, and Japan and the E.U. as the follower, the foreign country.

³¹This result might be size-biased as these are countries with low levels of R&D investment compared to the U.S. and Japan. Although even when the index is computed including only E.U. countries, these 6 countries do not seem to have a considerable impact on it. See also the evidence in Archibugi and Coco (2005).

I have shown that increasing foreign competition triggers a ‘defensive’ R&D policy in the home country. The optimal domestic subsidy increases with the number of sectors where domestic and foreign firms compete in innovation. This defensive innovation policy mechanism is driven by the interaction between the BSE of foreign competition and research subsidies: as competition increases the role of subsidies in protecting domestic rents becomes more relevant. The basic idea is that even though foreign innovation by catching-up countries can provide increases in the efficiency of global innovation, thus benefiting consumers worldwide, the profit-shifting effect involved is sufficient to justify an aggressive policy response in the leading countries. The result provides a preliminary theoretical guideline to past and present debates on the policy response to foreign competition.³²

The presence of strategic policy complementarity suggests the importance of evaluating the gains from cooperation in R&D policy. I have found that the leading country loses from cooperation at low level of competition, and begins to gain when a sufficiently high number of sectors is competitive. This result might help to explain the current absence of cooperation in innovation policy among E.U. countries. Here the implication is that the presence of innovation asymmetries between member states can create obstacles to the implementation of cooperative R&D subsidies. One question that I have left unanswered is whether other innovation policy tools, different from R&D subsidies, might provide better incentives for cooperation at low levels of competition. Further research along these lines can extend and qualify the results presented in this paper.

I have also discussed the importance of introducing growth in a strategic R&D subsidy game. In a framework where innovation affects long-run growth, the effects of strategic R&D policy interactions are amplified. In particular, the higher is the role of intertemporal knowledge spillovers in affecting consumers’ surplus, the larger will be the global welfare losses of strategic policy competition.

I have assumed the scale of international competition to be exogenous. Introducing imitative R&D, or letting the set of competitive sectors depend on institutional changes or on social norms can provide a link between competition and economic decisions, thereby endogenizing

³²Impullitti (2006) measures the distance from optimality of the U.S. R&D subsidy response to the increases in international competition in the 1970s and 1980s - produced by the technological catching-up of Japan and European countries. Using an empirical index for \bar{w} the paper shows that the gap between the optimal subsidy and the observed U.S. subsidy response to competition produced a welfare loss between 0.2 and 0.5 per cent of quality-adjusted per-capita consumption per year.

the degree of technological competition.³³

Finally, the assumption of global labor markets prevents any effect of competition on the labor market. Intuitively, international competition, by shifting monopoly rents from domestic to foreign firms, affects domestic workers only in that they will 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 business-stealing on welfare, thus understating the negative welfare effect of competition. If we were to remove the assumption of perfectly global labor markets, the BSE would reduce both profits and wages, thereby strengthening the negative impact of competition on national welfare.

References

- [1] Aghion, P., and P. Howitt, (1998). *Endogenous Growth Theory*, MIT Press, Cambridge, MA.
- [2] Archibugi D. and A. Coco (2005). "Is Europe Becoming the Most Dynamic Knowledge Economy in the World?" *Journal of Common Market Studies*, vol. 43, no. 3, pp.433-459]
- [3] Basu, S. (1996). "Procyclical Productivity: Increasing Returns or Cyclical Utilization?", *Quarterly Journal of Economics*, 111, 709-751.
- [4] Brander, A.J., and B.J. Spencer (1983). "International R&D Rivalry and Industrial Strategy", *The Review of Economic Studies*, Vol. 50, No. 4, 707-722.
- [5] Brander, A.J. (1995). "Strategic Trade Policy", in Grossman, G. and K. Rogoff (ed.), *Handbook of International Economics*, Vol. 3, North Holland.
- [6] Bergsten F., Gill B., Lardy N., and D. Mitchell, (2006). *China: the Balance Sheet*. IIE, Washington D.C.
- [7] Cozzi, G. (2005). "Can Social Norms Affect the International Distribution of Innovation?". mimeo "La Sapienza".

³³Cozzi (2005) shows that in a tariff free world social norms might have a role in shaping the international distribution of innovation efforts. In an Shumpeterian framework with sunspot equilibria he suggests that industrial policies might have a role as R&D coordination devices.

- [8] Dinopoulos E. and P. Thompson. (1998). "Scale Effects in Schumpeterian Models of Economic Growth", *Journal of Evolutionary Economics*, 157-85.
- [9] Eaton, J., and S. Kortum. (1999). "International Technology Diffusion: Theory and Measurement", *International Economic Review*, 40(3), 1999, 537-570.
- [10] Eaton, J. and G. Grossman. (1986). "Optimal Trade and Industrial Policy under Oligopoly", *Quarterly Journal of Economics*, Vol. 101, No. 2 (May), pp. 383-406.
- [11] Etro, F. (2006). "Global Innovation and R&D Policy Coordination", mimeo INTERTIC.
- [12] French, K. and J. Poterba. (1991). "Investor Diversification and International Equity Markets," *American Economic Review* 81, pp. 222-226.
- [13] Gilley B, and E. Friedman (ed.)(2006). *Asian's Giants: Comparing India and China*, Palgrave.
- [14] Grossman G. M. and E. Helpman. (1991). *Innovation and Growth in the Global Economy*. Cambridge: MIT Press.
- [15] Guerrieri, P. and C. Milana. (1991). "Technological and Trade Competition in High-Tech Products". *BRIE Working Papers* 54. Berkeley: University of California.
- [16] Haaland, J. and Kind, H. (2004a). 'Cooperative and Non-Cooperative R&D Policy in an Economic Union'. *CEPR Discussion Paper* no. 4185. London, Centre for Economic Policy Research.
- [17] Haaland, J. and Kind, H. (2004b). "R&D Policies, Trade and Process Innovation", mimeo NSEBA.
- [18] Hall, B., Griliches, Z., and J, Hausman. (1988). "Patents and R&D: is there a Lag?", *International Economic Review*, June, 27, 265-83.
- [19] Hall, B. (1993). "R&D Tax Policy During the Eighties: Success or Failure?" *NBER Working Paper* No. 4240.
- [20] Howitt, P. (1999). "Steady Endogenous Growth with Population and R&D Inputs Growing." *Journal of Political Economy* 107, August: 715-30.

- [21] Impullitti, G. (2006). "The Welfare Costs of the U.S. R&D Subsidies Response to Foreign Competition in the 1970s and 1980s." mimeo NYU.
- [22] Jones C. and J. Williams (2000). "Too Much of a Good Thing? The Economics of Investment in R&D", *Journal of Economic Growth*, Vol. 5, No. 1, pp. 65-85.
- [23] Katsoulakos Y., Tsipouri L., and K. Guy, (2005). "The Impact of R&D State Aid and its Appraisal on the Level of EU research and Expenditures in the Context of the Barcelona European Council Objectives." Report to the EU Commission.
- [24] Klundert, T. and S. Smulders, (1997). "Growth, Competition and Welfare", *Scandinavian Journal of Economics* 99, 99-118.
- [25] Kochhar K., Rajan R., Kumar U., Surbamanian A., and I. Tokatlidis. (2006). "India's Pattern of Development: What Happened, What Follows", forthcoming, *Journal of Monetary Economics*.
- [26] Kortum, S. (1993). "Equilibrium R&D Ratio and the Patent-R&D Ratio: U.S. Evidence," *American Economic Review, Papers and Proceedings*, 83, 1993, 450-457.
- [27] Krugman, P.R.(1996). "Making sense of the competitiveness debate", *Oxford Review of Economic Policy*, 12, 3, pp. 17-25.
- [28] Lundborg P. and P. Segerstrom (2001). "The Growth and Welfare Effects of International Mass Migration," *Journal of International Economics*, January 2002, pp. 177-204.
- [29] Leahy, D., and P., Neary. (2005). "Symmetric research joint ventures: Cooperative substitutes and complements," *International Journal of Industrial Organization* 23:5-6, June, 381-397.
- [30] Mehra,R., and E.C.Prescott.(1985). "The Equity Premium: A Puzzle," *Journal of Monetary Economics* 15, 145-161.
- [31] Pakes, A., and Z., Griliches. (1984). "Patents and R&D at the Firm Level: a First Look", in Z. Griliches (ed.), *R&D, Patents and Productivity*, Chicago: Chicago University Press, pp. 55-72.

- [32] Peretto, P. (1998). “Technological change and population growth”, *Journal of Economic Growth*, Vol. 3, No. 4, pp. 283-311.
- [33] Pretowitz, B. (2006). *Three Billions New Capitalists: the Great Shift of Wealth and Power to the East*, Basic Books, New York.
- [34] Rodrick, D. (2006). “What’s So Special About China’s Exports?”, mimeo Harvard KSG.
- [35] Tang P. and K. Waelde. (2001). “International competition, growth and welfare”. *European Economic Review* 45: 1439-1459.
- [36] Tesar, L. and I.M. Werner (1995). “Home-Bias and High Turnover”, *Journal of International Money and Finance*, Vol. 14, no. 4, pp. 467-92.
- [37] Tyson L. (1992). *Who’s Bashing Whom? Trade Conflict in High-Tech Industries*. IIE Washington.
- [38] Sapir, A. (2004). *An Agenda for a Growing Europe: The Sapir Report*. A. Sapir (Ed.). Oxford. Oxford U. Press.
- [39] Schumpeter, J. A., (1942). *Capitalism, Socialism and Democracy*. New York: Harper & Brothers.
- [40] Segerstrom P. (1998). “Endogenous Growth Without Scale Effects”, *American Economic Review* 88, 1290-1310.

8 Appendix: sensitivity analysis

In this appendix I explore the sensitivity of the main results to changes in parameters’ specification. More precisely, I am interested in showing that the results presented in the paper are robust to changes in each of the six parameters ρ , λ , n , α , A , and κ , calibrated in section 2.6. For this purpose I will primarily focus on showing that the results are confirmed with different parameters specification, and I will briefly comment on some aspects of the many specific effects that may be related to each change in parameters. A more detailed analysis of the effects of

each parameter on the optimal subsidies and on welfare would require an analytical solution of the model and a complete welfare analysis which are not attainable in this framework. I will show the effects of halving the parameters of interest with respect to their benchmark value. I have also performed the sensitivity analysis for specifications in which the benchmark values are doubled and have obtained results that are symmetric to the one discussed below; I omit them for simplicity.

In table IIIA I study the robustness of results 1, 2 and 3 to a reduction in the R&D externality parameter α from the benchmark value 0.4 to 0.2. As we can see all results are confirmed. Comparing tables III and IIIA we can see that one remarkable effect of reducing the negative R&D externality, and so reducing the concavity of the R&D technology, is that gains from cooperation become higher at all levels of competition. This effect is due to the fact that weaker DRS in R&D increase the impact of government subsidies on innovation. It follows that global policy cooperation leading to higher equilibrium subsidies has a larger impact on welfare, and produces higher welfare gains.

TABLE III A
SUMMARY RESULTS WITH LOWER DRS IN R&D

$\alpha = 0.2$	Coop		Non-Coop		Gains D	Gains F	Global gains
\bar{w}	s_c^D	s_c^F	s_n^D	s_n^F	$W_c^D - W_n^D$	$W_c^F - W_n^F$	$W_c^W - W_n^W$
0.2	0.715	0.820	0.18	0.275	-0.044	0.297	0.252
0.3	0.745	0.820	0.205	0.280	-0.014	0.283	0.268
0.4	0.765	0.820	0.225	0.280	0.020	0.265	0.286
0.8	0.840	0.850	0.275	0.290	0.126	0.213	0.340
1	0.850	0.850	0.295	0.295	0.183	0.183	0.367

In table III B I explore the effects of a halving the TFP of R&D, A , from the benchmark 0.4 to 0.2. Qualitatively results 1, 2 and 3 are confirmed. It is worth to notice that when the efficiency of the R&D technology is reduced to global gains from cooperation are reduced as well - compared to those in the benchmark case. Intuitively, with a less efficient R&D technology the higher subsidies attainable with the cooperative solution produce a lower effect on innovation and global welfare. Another effect of this specification is that at low levels of competition the domestic non-competitive R&D subsidy is negative. This shows that result 1 is robust to a set-up where, at least for some levels of competition, it is optimal for the home country to tax R&D. More precisely, for those value of \bar{w} at which we observe a negative subsidy, increases in competition reduce the optimal tax level on R&D. It follows that the basic mechanism in the paper is not dependent on the choice of a benchmark set-up where it is optimal to subsidize

R&D.

TABLE III B
SUMMARY RESULTS WITH LOWER TFP OF R&D

A = 0.2	Coop		Non-Coop		Gains D	Gains F	Global gains
$\bar{\omega}$	s_c^D	s_c^F	s_n^D	s_n^F	$W_c^D - W_n^D$	$W_c^F - W_n^F$	$W_c^W - W_n^W$
0.2	0.2950	0.3800	-0.5750	-0.0050	-0.044 4	0.095 6	0.051 2
0.4	0.3300	0.3950	-0.3050	0.0400	-0.028 3	0.065 9	0.037 6
0.8	0.4150	0.4350	0.0200	0.1000	-0.000 8	0.028 1	0.027 3
1	0.4600	0.4600	0.1200	0.1200	0.013 8	0.013 8	0.027 6

The next step is to study the effects of a reduction in the R&D difficulty coefficient from its benchmark value, $\kappa = 0.65$, to 0.325. In table III C we can see that the main results are confirmed. Moreover, we observe that with a lower R&D difficulty index the gains from cooperation are larger than those observed in the benchmark simulation. The higher subsidies obtained with the cooperative solution produce a higher GE, thus increasing welfare more than in the benchmark case.

TABLE III C
SUMMARY RESULTS WITH LOWER R&D DIFFICULTY

$\kappa = 0.325$	Coop		Non-Coop		Gains D	Gains F	Global gains
$\bar{\omega}$	s_c^D	s_c^F	s_n^D	s_n^F	$W_c^D - W_n^D$	$W_c^F - W_n^F$	$W_c^W - W_n^W$
0.2	0.7450	0.8500	0.4200	0.4900	-0.011 7	0.363	0.351 3
0.4	0.7850	0.8500	0.4300	0.4800	0.096 5	0.374 7	0.471 2
0.8	0.8350	0.8500	0.4500	0.4650	0.287 3	0.390 1	0.677 4
1	0.8500	0.8500	0.4600	0.4600	0.383 3	0.383 3	0.766 6

In table IIID I explore the effects of a reduction of the population growth rate n from the benchmark set at 0.014 to half its value, 0.07. As explained in the paper changes in the population growth rate, together with changes in the intertemporal discount factor, affect the importance of intertemporal knowledge spillovers. In section 6, in fact, I suggested that with higher population growth the long-run benefits of innovation will be spread among a larger number of consumers and innovation will yield lower benefits to the representative household. It follows that the higher subsidies attainable in the cooperative solution produce larger welfare gains. Here I show the symmetric case, that is, the case where the population growth rate is halved with respect to the benchmark calibration. Clearly a reduction in population growth will have the opposite effect on the gains from cooperation.

TABLE III D

SUMMARY RESULTS WITH LOWER POPULATION GROWTH

$\mathbf{n = 0.07}$	Coop		Non-Coop		Gains D	Gains F	Global gains	
	\bar{w}	s_c^D	s_c^F	s_n^D	s_n^F	$W_c^D - W_n^D$	$W_c^F - W_n^F$	$W_c^W - W_n^W$
	0.2	0.6050	0.7300	0.0150	0.2150	-0.061 4	0.225 9	0.164 5
	0.4	0.6500	0.7300	0.0850	0.2250	-0.016 3	0.200 9	0.184 6
	0.8	0.7250	0.7450	0.2000	0.2400	0.077 3	0.155 2	0.232 5
	1	0.7650	0.7650	0.2500	0.2500	0.128 4	0.128 4	0.256 8

Finally in table III E I study the effects of halving the mark-up from the benchmark value of 20 per cent: a reduction of the mark-up to 10 per cent produces a reduction of the quality jump λ from 1.2 to 1.1.

TABLE III E

SUMMARY RESULTS WITH LOWER QUALITY JUMP

$\lambda = 1.1$	Coop		Non-Coop		Gains D	Gains F	Global gains	
	\bar{w}	s_c^D	s_c^F	s_n^D	s_n^F	$W_c^D - W_n^D$	$W_c^F - W_n^F$	$W_c^W - W_n^W$
	0.2	0.5500	0.6500	-0.2450	0.1250	-0.043	0.112 1	0.069 1
	0.4	0.5950	0.6650	-0.0850	0.1500	-0.023 1	0.092 9	0.069 8
	0.8	0.6750	0.6950	0.1250	0.1850	0.020 7	0.060 2	0.080 9
	1	0.7100	0.7100	0.1950	0.1950	0.045 5	0.045 5	0.091

As shown in above the main results are confirmed. The reduction in the quality-jump have two effects worth of discussion. First, as we saw in the simulation with a lower A above, the optimal domestic R&D subsidy is negative at low levels of competition; but again, competition affects the optimal domestic subsidies in the usual way, that is it reduces the tax on R&D until, for high values of \bar{w} , the optimal subsidy becomes positive and increasing in competition. Second, smaller quality-jumps reduce the gains from cooperation. This result relies on the reduced increase in the quality improvements following each innovation. The larger growth effect of the higher subsidies attained with cooperation is mitigated by the smaller contribution of each innovation the quality of goods.

Figure 1. Non-cooperative subsidies with 30 % of competitive sectors

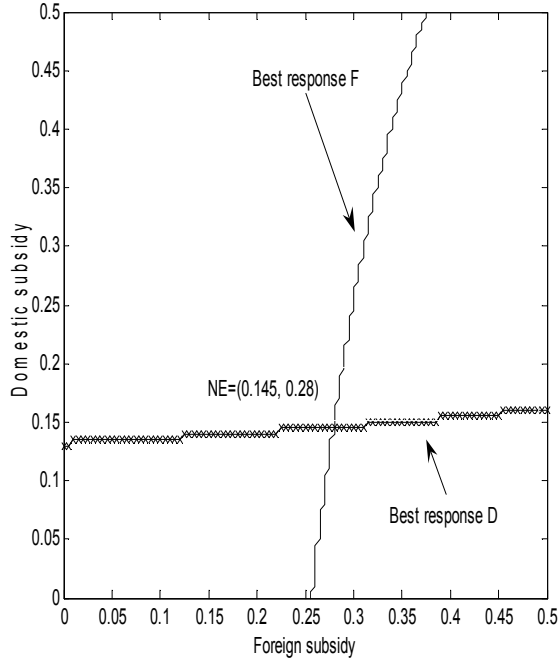


Figure 2. Non-cooperative subsidies with 60 % of competitive sectors

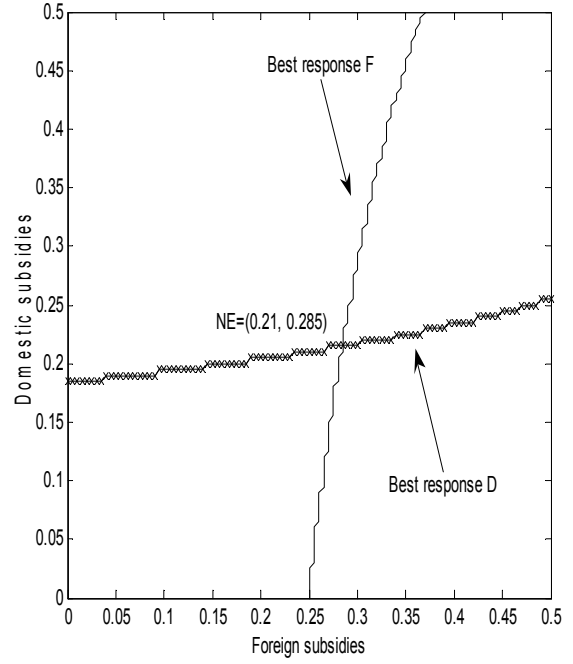


Figure 3. Non-cooperative subsidies with 100% of competitive sectors

