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optimal R&D subsidies

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**EUROPEAN UNIVERSITY INSTITUTE
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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 quality-ladder 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, shows innovating firms only in a subset of industries. The measure of the set of sectors where R&D workers from both countries compete for innovation determines the scale of international Schumpeterian competition. Both governments engage in a strategic R&D subsidy game and respond optimally to changes in competition. For a given level of subsidies, increases in foreign competition raise the quality of goods available (growth effect) and lowers domestic profits (business-stealing effect); the overall effect of competition on domestic welfare depends on the relative strength of these two counteracting forces. When governments play a strategic subsidy game, increases in foreign competition trigger a defensive innovation policy mechanism that raises the optimal domestic R&D subsidy. Cooperation in subsidies leads both countries to set higher subsidies. Finally, while cooperation is beneficial for the global economy, there exists a threshold level of competition below which the home country experiences welfare losses under cooperation.

Keywords

international competition, endogenous technical change, growth theory, strategic R&D subsidies, international policy cooperation

JEL Classification: O41, O31, O38, F12, F43.

International Schumpeterian competition and optimal R&D subsidies*

Giammario Impullitti[†]

1 Introduction

In the decades following World War II, U.S. firms were undisputedly the global leaders in the production and provision 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 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 developments have fueled debates on the welfare effects of increasing foreign competition in innovation-intensive industries, and have led academics and policy makers to discuss the virtues and dangers of different policy responses to competition³.

In this paper I study the effects of international competition on domestic welfare and on the double role of R&D subsidies in stimulating innovation and protecting national interests.

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¹Between 1980 and 1991 the U.S. global market shares in high-tech markets declined by 16 percent, while Japan's share increased by about 30 percent (NSF 2006). Moreover, 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. (Guerrieri and Milana, 1991, and 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 rose from 25 percent in 1970 to 65 percent in 2002.

³See Krugman (1996) and Tyson (1992) for a discussion of the "competitiveness debate" in the U.S. in the 1980s. For the current debate on the effects of technological catching-up see Baumol and Gomory (2000), Samuelson (2004), Bhagwati, Panagariya, and Srinivasn (2004), Blinder (2005).

While trade policies such as tariffs and export subsidies are restricted by the WTO and other international institutions, generalized subsidies to R&D are left to the discretion of single governments. Hence policy makers can use research subsidies to promote the competitiveness of national firms in the global economy. Moreover, the strategic nature of R&D subsidies leads naturally to consider possible national and global gains from policy cooperation. Therefore, I study the effects of international competition on cooperative and non-cooperative R&D subsidies.

I set up a non-scale, fully-endogenous, Schumpeterian growth model (Dinopoulos and Thompson, 1998, Howitt, 1999, Young, 1998, Peretto, 1998), with two countries, domestic and foreign, having the same population, preferences and technology, but different distributions of research efforts across industries, and autonomously choosing their innovation subsidy. 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 competing to develop higher-quality products and obtain leadership in the global market.

Economists have explored the welfare effects of competition focusing on changes in product market competition produced by foreign entry. I propose a different, and complementary, measure that focuses on competition in the innovation activity and is based on the geographical distribution of R&D investment. Precisely, 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 the subset where researchers from both countries compete will be the index of international competition.⁴ As a consequence, increases in international competition are unidirectional in that they represent the penetration of foreign researchers into industries where previously only domestic innovators had been active.⁵

The second component of the model is the introduction of a strategic R&D subsidy game in

⁴This idea is similar to that expressed in Krugman (1979) where the leading country is assumed to be able to virtually produce all goods in the economy, while the follower country can produce only the "old" goods. As in the present paper both countries have the same preferences, technology and environment, and the difference in production possibilities is exogenous. Krugman suggests that the source of the productive advantage of the leading economy can be related to more skilled labor force, external economies, or to a difference in "social atmosphere".

⁵Except for the distribution of research efforts the two countries have a similar structure. This implies that the model is more suitable to study the effect of foreign competition coming from countries that are structurally not too different from the domestic one. As I will discuss later, if one wants to analyze the effect of Indian and Chinese competition on advanced industrial countries, the setup must be modified accordingly.

the endogenous growth framework. Each government sets subsidies autonomously in order to maximize national welfare, thereby responding optimally both to changes in the other country's subsidy and in international competition. There are two basic motivations for R&D subsidies in this economy: the presence of knowledge spillovers, typical of R&D-driven growth models, leads to a non-efficient market allocation of research effort, so creating the scope for policy intervention. Second, the presence of foreign firms in innovation races produces a strategic motive for subsidies: R&D subsidies can be used to support national firms in the competition for global leadership.

Models of trade and growth turn out to be difficult to solve when countries are asymmetric in their economic structure and in their policy, thus I calibrate the model to the U.S. economy and explore its qualitative properties numerically.⁶ I focus on three specific issues: i) the effects of foreign competition on domestic welfare for a given level of domestic and foreign R&D subsidies; ii) the effects of competition on the optimal domestic subsidy, when countries play a non-cooperative subsidy game. iii) the influence of competition on domestic and foreign incentives to set R&D subsidies cooperatively.

The main results are as follows. Increases in foreign competition have two opposite effects on domestic welfare: a *growth effect* (henceforth *GRE*) and a *business-stealing effect* (henceforth *BSE*). The *GRE* is related to increases in research efficiency brought about by a more equal distribution of R&D investment in the global economy. Following Eaton and Kortum (1999), I assume that R&D technology has decreasing returns at the country level. This technology specification implies that entry of foreign researchers leads to a more efficient international division of research labor and increases innovation and global growth. As is common in quality-ladder models, growth increases welfare through the effect of quality improvements on consumer surplus. This is the *GRE* of competition, which benefits consumers in both countries.

Entry of foreign R&D workers into new sectors also implies that, with a probability proportional to their research effort, monopoly rents shift from domestic to foreign firms. "Home bias" in asset ownership documented in the literature implies that profit-shifting has a negative impact on domestic income and welfare - this is *BSE*.⁷ It follows that the effect of competition on domestic welfare depends on the relative strength of the *GRE* and the *BSE*: if the *GRE*

⁶See Lundborg and Segerstrom (2002) for a similar approach to the solution of quality ladders model with asymmetric countries.

⁷For evidence on "home bias" see for instance French and Poterba (1991) and Tesar and Werner (1995).

is stronger (weaker) than the *BSE*, competition raises (reduces) domestic welfare.

When both countries play a strategic subsidy game and respond optimally to changes in competition, I find that increases in competition raise the *scale* of foreign business-stealing, thereby increasing the scope for strategic subsidies in the home country. Hence, competition increases the role of subsidies as a rent-protecting device and triggers a sort of *defensive innovation policy* mechanism.⁸ Finally, I show that subsidy cooperation is beneficial for the global economy, but the domestic country loses from cooperation at low levels of competition. Assuming that there is no compensation mechanism, this implies that policy cooperation will not be implemented at low levels of competition.

This paper is related to two strands of literature. First, the *BSE* of R&D subsidies has its origins in the strategic trade and industrial policy literature. Since the seminal paper by Spencer and Brander (1983), works in this area have focused on the robustness of the results to different types of market structures, to the presence of government and firms commitment, and to the existence, and typology, of spillovers related to innovation activity (Eaton and Grossman, 1986, Bagwell and Staiger, 1994, Brander, 1995, Maggi, 1996, Neary and Leahy, 2000, and Leahy and Neary, 1999, and 2001).

This literature has not devoted much attention to the effects of international competition and trade liberalization on strategic R&D subsidies. As a consequence, the beneficial effect of trade on consumer' surplus - though price reduction and/or improvements in goods' quality- could not be taken into account.⁹ Secondly, the works that have studied the scope for R&D cooperation have focused on cooperation between firms rather than between governments.¹⁰

Recently Haaland and Kind (2007) have filled the gap by studying the effects of trade liberalization and of changes in PMC on private and public incentives for R&D investment within a strategic innovation policy framework. In view of the important effects of trade on relative prices and, consequently, on consumer surplus, they have studied the interplay of the business-stealing and the consumer surplus motive for R&D subsidies. Including the consumer surplus effect in the analysis is particularly relevant when both trade and strategic policies have effects on the innovation activity. Finally, the scope for cooperation in R&D at the policy stage

⁸As commonly occurs in quality-ladder models, the sign of the optimal subsidy depends on the model's features, especially on the specification of parameters. I show that the results in the paper hold also for parameters specifications leading to a negative optimal R&D subsidy.

⁹By assuming that all export is directed to a third country, the previous literature has focused mainly on the business-stealing motive.

¹⁰See for instance Leahy and Neary (2004).

was also analyzed.¹¹

These papers, as well as the others 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 this theoretical feature may be responsible for the small gains and losses from strategic policies found in the empirical tests of these models. He conjectures that exploring the growth effects of such policies might increase their quantitative relevance.

Following Haaland and Kind (2007) I study the impact of international competition on cooperative and non-cooperative R&D subsidies. I depart from this paper, as well as, from the existing strategic trade and industrial policy works in two ways: first, in my model innovation is a cumulative process affecting the long-run growth rate of the economy. Introducing endogenous growth allows me to take into account both the current and the future effects of competition on consumer surplus; the existing static models of innovation and strategic R&D policies cannot account for the long-run effects on consumer surplus.¹² One implication is that, as conjectured in Brander (1995), introducing endogenous growth magnifies the welfare effects of strategic policies. Second, while the existing literature has focused on the effects of changes in the market structure on innovation and optimal strategic subsidies, I study international competition in the innovation activity. The interaction between this dimension of competition and strategic policies cannot be analyzed in the two-sector models used in the strategic policy literature. The monopolistic competitive market structure of quality-ladder models proves more suitable for this target.¹³

The second strand of related works is the one exploring the welfare effects of competition in endogenous growth frameworks (i.e. Kludert and Smulders, 1997, and Tang and Waelde, 2001), as well as that studying the links between competition, national and/or international, and growth (i.e., Aghion et. al., 2006, Boldrin and Levine, 2005, Gustafsson and Segerstrom, 2007, Melitz, 2003, Navas and Licandro, 2006, Peretto, 2003). The efficiency effect of competition on growth is similar in the spirit to the *selection effect* formalized in the recent literature on trade, firms heterogeneity, and productivity. In Melitz (2003) exposure to trade induces the

¹¹On policy competition and cooperation see also the companion paper Haaland and Kind (2006).

¹²In 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.

¹³This advantage, though, is obtained at the expense of simplifying the interaction among firms in the product market. As pointed out by Neary (2001) using a monopolistic competitive framework does not allow accounting for strategic interaction among firms.

less productive firms to exit the market, thus increasing the average productivity level of the economy. Gustafsson and Segerstrom (2007) show that when a this mechanism is nested into a model of growth through expanding variety (Romer, 1992) foreign entry can affect the long-run growth rate of the economy. The growth effect of international competition in the present paper is, though, substantially different from those in the existing literature for the following reasons: first, the effect is produced by foreign entry in R&D and not by product market competition; second, the growth mechanism does not operate through the productivity gap between entrant and exiting firms - firms are homogenous in production - but through improvements in the efficiency of the innovation activity in the newly competitive sectors.

A final distinguishing feature of this paper is that it does not limit the analysis to studying the welfare effects of competition and informally drawing suggestions for policy interventions, as most existing works do, but it explores the optimal strategic R&D subsidy response to foreign competition.¹⁴

2 The model

In this section I set up the model and derive the steady state equilibrium system of equations.

2.1 Households

Consider a two-country economy in which population, preferences, technologies, and institutions are identical. 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

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

¹⁴This feature is related to the literature on optimal R&D subsidies in endogenous growth models (see for instance Segerstrom 1998, and Jones and Williams 2000). It allows us to obtain separate results for the effects of competition on welfare and on the optimal subsidy. In most of the existing literature of the welfare effect of international competition (and of trade liberalization) policy intervention is only discussed, informally, in those cases when welfare is negatively affected.

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

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

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 $j \in \{0, 1, 2, \dots\}$, 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 $\omega \in [0, 1]$ using a linear technology; one worker produces 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, in the sense that a firm that owns the technology can use it everywhere. Hence, multinational companies are free to establish subsidiaries in low wage countries to carry out the manufacturing of their products so, in equilibrium wages will equalize. I choose the wage as the numeraire, that is: $w^D = w^F = 1$.

As is usual in Schumpeterian models with vertical innovation (e.g. Grossman and Helpman, 1991 and Aghion and Howitt, 1992), 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 that the patent becomes obsolete 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 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 implies that, in equilibrium, supply and demand of every consumption good coincides. It follows that monopoly profits accruing to global quality leaders from country $k = D, F$ in sector ω will be equal to

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

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 . Each R&D firm can produce a Poisson arrival rate of innovation according to the following technology:

$$I_i^K(\omega, t) = \frac{A l_i^K(\omega, t) \left(\frac{L^K(\omega, t)}{X(\omega, t)} \right)^{-\alpha}}{X(\omega, t)}, \quad (7)$$

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 research 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 national R&D investment in the industry. One motivation for this industry and country-specific externality in research technology could be the presence of fixed costs, such as lab equipment. Another motivation can be related to workers with heterogeneous ability. Eaton and Kortum (1999) show that this type of technology can be obtained assuming that all workers are equally productive in manufacturing goods, but higher skilled labor is more productive in research: as investment in research increases workers of lower ability will be used and R&D productivity will decline.¹⁵ In a multicountry quality-ladder growth model they estimate the degree of decreasing returns in R&D and find the technology to be far from the linear case assumed in many R&D-driven growth models.¹⁶

The technological complexity index $X(\omega, t)$ was introduced into endogenous growth theory after Jones' (1995) empirical criticism of R&D-driven growth models generating scale effects in the steady state per-capita growth rate. I will use the specification introduced by Dinopoulos and Thompson (1998), that is

$$X(\omega, t) = 2\kappa N(t), \quad (8)$$

with positive κ , thereby formalizing the idea that it is more difficult to introduce a new product in a more crowded market. This specification rules out implausible scale effects and allows for

¹⁵This microfoundation has been suggested in Phelps (1966), where a technology similar to (7) is obtained assuming that workers abilities are drawn from a Pareto distribution. In my model the simplifying assumption of global labor markets does not allow this type of microfoundation. In the companion paper Impullitti (2007) I remove this hypothesis and provide a microfoundation of the R&D technology based on heterogeneous workers skills. As I will discuss later, and as I show in the companion paper, removing the assumption of perfectly global labor markets strengthens my basic findings.

¹⁶Eaton and Kortum (1999) offers particularly appropriate empirical support for motivating this choice of technology because they use a multicountry quality-ladder model with international R&D spillovers similar to the one used here. For additional empirical evidence supporting the presence of decreasing returns to R&D, but limited to U.S. data, see Hall et. al. (1988), Pakes and Griliches (1984), and Kortum (1993).

sustained per-capita growth without population growth, leading to a class of models also known as fully-endogenous growth frameworks (see Aghion and Howitt 2005).

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. Free entry into R&D races drives the expected profits to zero, generating the following equilibrium condition:

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

where $v^K(\omega, t)$ is the present value of a firm that produces good ω in country $K = D, F$. The presence of efficient financial markets implies that the expected rate of return of a stock issued by an R&D firm is equal to the riskless rate of return $r(t)$. It follows that the expected value of a firm is:

$$v^K(\omega, t) = \frac{\pi^K(\omega, t)}{r(t) + I(\omega, t) - \frac{\dot{v}(\omega, t)}{v(\omega, t)}} = \frac{q(\omega, t)(\lambda - 1)}{r(t) + I(\omega, t) - \frac{\dot{v}^K(\omega, t)}{v^K(\omega, t)}}, \quad (10)$$

where $I(\omega, t)$ denotes the worldwide Poisson arrival rate of an innovation that will destroy the monopolist's profits in industry ω . In the absence of any cost advantage in doing R&D, the usual Arrow effect (Aghion and Howitt 1992) implies that the monopolist does not find it profitable to undertake any R&D. Substituting for the value of the firm from (10) into (9) we obtain:

$$\frac{N(t)(c^D(t) + c^F(t)) \left(\frac{\lambda-1}{\lambda} \right) \left(\frac{L^K(\omega, t)}{X(\omega, t)} \right)^{-\alpha}}{r(t) + I(\omega, t) - \frac{\dot{v}(\omega, t)}{v(\omega, t)}} = \frac{(1 - s^K)X(\omega, t)}{A}, \quad (11)$$

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.

2.4 International R&D competition

The scale of foreign competition in this model is determined by the measure of the set of sectors where firms from both countries compete in R&D. Let $\bar{\omega} \in (0, 1)$ be the set of industries where domestic and foreign researchers compete to discover the next vintage of products. Therefore the composition of worldwide investment in innovation will be the following:

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

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 $\omega \in (0, 1)$. Finally, the R&D difficulty index is proportional to the size of the global market, that is $X(\omega, t) = 2\kappa N(t)$.

2.5 Balanced growth

In this section I derive the steady state properties, 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 (7) research labor can be expressed as a function of the innovation arrival rate.¹⁷ 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 (8) 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:

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

¹⁷Using (7) we can express labor allocated to research as $L^D(t) = \bar{\omega}X(t)(I_c^D(t)/A)^{1/(1-\alpha)} + (1 - \bar{\omega})X(t)(I_m^D(t)/A)^{1/(1-\alpha)}$ for the domestic country and $L^F(t) = \bar{\omega}X(t)(I^F(t)/A)^{1/(1-\alpha)}$ for the foreign country respectively. From now on I will use these expressions in the place of labor allocated to research.

The left hand side represents the total demand for goods (labor), while the right hand side is the total supply, given by total labor resources minus labor used in research.

In each country total expenditures plus savings (investment in R&D) must equal national income, wages plus profits (or interest income on assets).¹⁸

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

$$2\kappa \left[\bar{\omega} \left(\frac{I^F}{A} \right)^{\frac{1}{1-\alpha}} \right] + c^F = 1 + (c^D + c^F) \left(\frac{\lambda - 1}{\lambda} \right) \left[\bar{\omega} \frac{I^F}{I_c^D + I^F} \right]. \quad (14)$$

Notice that R&D investment is the wage bill of R&D workers and that each country appropriates the monopoly rent in industries where that country is the world leader. Moreover, I am assuming complete “home-bias” in asset ownership, in the sense that domestic firms are completely owned domestically and foreign firms are completely foreign-owned.¹⁹

The international division of research labor specified in the previous section leads to the following steady state expressions for equilibrium conditions (11):

$$\begin{aligned} \frac{2\kappa}{A}(1 - s^F) &= \frac{(c^D + c^F) \left(\frac{\lambda - 1}{\lambda} \right)}{\rho + I_c^D + I^F - n} \left(\frac{I^F}{A} \right)^{\frac{-\alpha}{1-\alpha}}, \quad \omega \leq \bar{\omega} \\ \frac{2\kappa}{A}(1 - s^D) &= \frac{(c^D + c^F) \left(\frac{\lambda - 1}{\lambda} \right)}{\rho + I_c^D + I^F - n} \left(\frac{I_c^D}{A} \right)^{\frac{-\alpha}{1-\alpha}}, \quad \omega \leq \bar{\omega} \\ \frac{2\kappa}{A}(1 - s^D) &= \frac{(c^D + c^F) \left(\frac{\lambda - 1}{\lambda} \right)}{\rho + I_m^D - n} \left(\frac{I_m^D}{A} \right)^{\frac{-\alpha}{1-\alpha}}, \quad \omega > \bar{\omega}, \end{aligned} \quad (15)$$

where, using R&D technology (7), 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 (12) turns out to be the sum of the two resource constraints (13) and (14),

¹⁸In a similar two-country quality ladder 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 expenditure does not change our qualitative results.

¹⁹This 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. I have also worked out a version of the model with partial home bias and the qualitative results are unaffected, but the model becomes a bit less tractable.

so the three equations are not linearly independent; I can omit one of them, and solve for the three equations. in (15), and the remaining (13), (14).

I 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,

$$W^K \equiv \ln \frac{c^K}{\lambda} + \frac{g}{\rho - n} \quad (16)$$

where $g = [\bar{\omega}(I_c^D + I^F) + (1 - \bar{\omega}) I_m^D] \ln \lambda$ is the global growth rate that, which in our economy with perfect international knowledge spillovers increases consumer surplus in both countries. In the present framework with quality improving goods, “growth” is interpreted as the increase over time of the representative consumers’ utility level.

Two-country endogenous growth models become complicated when either structural or public policy differences affect endogenous variables. 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. Therefore a simpler model with symmetric country, while analytically tractable, would not allow me to analyze either this dimension of competition based on countries’ research asymmetries, or the strategic policy game with two countries active in subsidizing R&D. For this reason in the following sections I explore the implications of the model numerically.²⁰

2.6 Calibration

In this section I calibrate the parameters of the model to match long-run empirical regularities of the U.S. economy. I calibrate 6 parameters. Four of them, ρ , λ , n , and α are calibrated using benchmarks from the growth and business cycle literatures, while the others, A and k , are calibrated internally in order for the model’s steady state to match facts of the U.S. economy.²¹ This calibration exercise is exclusively targeted at understanding the qualitative properties of

²⁰Lundborg and Segerstrom (2002) for similar approach to the solution of quality ladders models of trade and growth with asymmetric countries. Even when countries are symmetric models of trade and growth might require the numerical solution when analyzing particularly rich market structure and its interaction with the innovation process (see i.e. Costantini and Melitz, 2007, and Atkinson and Burnstein, 2007)

²¹Notice 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.

the model.²²

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).²³ I set λ to 1.2, to match an average markup over the marginal cost of 20 per cent. This is consistent with the range 10 – 40 percent reported in Basu (1996) estimates of average sectorial mark-up. I calibrate n to match the population growth rate of 1.14%, which is the average business sector labor force growth rate in the period 1948-97 (Bureau of Labor Statistics, 1999). 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 0.4.²⁴

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 2004); 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). The parameters values obtained minimizing the quadratic distance between the model steady state and the statistics listed above are $A = 0.4$ and $\kappa = 0.65$.

²²Both the model and the calibration exercise in Impullitti (2007) are more specifically targeted to explore quantitative issues.

²³Jones 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.

²⁴Eaton and Kortum (1999) estimate of the degree of decreasing returns to R&D is 0.18 for the fully-endogenous model. The empirical literature find estimates in the range (0.1, 0.6), hence I choose an intermediate value as a benchmark and later perform sensitivity analysis in this range. See Hall et. al. (1988), Pakes and Griliches (1984), and Kortum (1993) for more on empirical results on returns to R&D.

3 The basic trade-off: 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 on domestic welfare. Figure I below reports the numerical simulation of the effects of competition on the key variables of the model.

[FIGURE I ABOUT HERE]

Here I summarize the main findings:

Result 1. *Stronger foreign competition (higher $\bar{\omega}$) produces the following effects on the domestic economy:*

- i. *Reduces national profits and income - this is the BSE.*
- ii. *It does not affect innovation per-industry but it reduces total R&D spending.*
- iii. *For $\alpha > 0$ it increases the growth rate of the global economy - this is the GRE.*
- iv. *The effect on domestic welfare depends on the relative strength of the GRE and BSE.*

Below I discuss the economic intuition for this result. First, the *BSE* reduces domestic aggregate profits because foreign firms, by innovating in more sectors, appropriate a larger share of the world market. The presence of multinational corporations implies that the labor market is not affected by shifts in the global distribution of firm ownership, and domestic income decreases along with profits.²⁵ Using the domestic resource constraint (13) 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. (16).

Secondly, domestic innovation in the two types of sectors, competitive and non competitive, is pinned down by the free entry condition (9). Since the cost of R&D is fixed at $(1 - s^K)$, competition does not change the incentives to invest in R&D within each sector; it follows that investment in R&D, I_m^D , I_c^D , I^F do not change. Although per-sector investments are

²⁵The assumption of global labor market allows us to focus on the effect of competition on profits. Removing this assumption would introduce an additional negative effect of competition on domestic income, precisely a wage-stealing and/or a job-stealing effect. As I discuss later, adding this feature to the model will not affect the basic results.

constant, total domestic R&D expenditure, along with total innovation in the home country, decreases with competition for the *reallocation* effect produced by the increase in $\bar{\omega}$: foreign research increases innovation obsolescence and domestic followers adapt by reducing their R&D efforts. More precisely, when a sector experiences foreign entry, in equilibrium domestic R&D investment declines from the non-competitive level I_m^D to the competitive one I_c^D .²⁶

Digging deeper into the *GRE* of competition, we can observe that it depends entirely on the presence of local decreasing returns in R&D. Intuitively, the negative country-specific R&D externality α in (7) 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. As discussed above, the first margin is not affected by competition because. Using (15) consider now the marginal benefits of investing in research 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:

$$\frac{(c^D + c^F) \left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_m^D - n} \left(\frac{I_m^D}{A}\right)^{\frac{-\alpha}{1-\alpha}} = \frac{(c^D + c^F) \left(\frac{\lambda-1}{\lambda}\right)}{\rho + I_c^D + I^F - n} \left(\frac{I_c^D}{A}\right)^{\frac{-\alpha}{1-\alpha}}. \quad (17)$$

Since the productivity of R&D is higher in the competitive industries - due to the country-specific R&D externality - the present value of the firm in equilibrium must be lower in these industries. As the value of the firm is given by profits - equal in both industries - discounted with the interest rate and the innovation intensity, $v^K(\omega, t) = (c^D + c^F) (1 - 1/\lambda) / (\rho + I_m^D - n)$, investment in R&D in competitive sectors must be higher than in non-competitive sectors; that is, $I_c^D + I^F > I_m^D$. Since, as discussed above, innovation per-sector does not change, competition simply increases the share of industries with a 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 $\alpha > 0$.²⁷

Thus, we can conclude that the welfare effects of competition depend on the value of the parameters and, in particular, on the strength of the R&D externality pinned down by the

²⁶Notice that here, as in the benchmark quality ladder model, leading firms do not innovate. This happens because if we assume that leaders do not have any cost advantage in R&D over followers, the latter have higher incentives to innovate at the margin; this is known as the Arrow effect (see Aghion and Howitt, 1998). Later we will discuss possible implications of introducing innovation by leaders.

²⁷When $\alpha = 0$ it is easy to see that (17) implies $I_c^D + I^F = I_m^D$ and the growth effect disappears.

value of α . Figure I shows that in the benchmark calibration, where α is 0.4, the *GRE* is larger than the *BSE*, and foreign competition leads to welfare improvements in the home country. I have also performed simulations for lower levels of α and I found that for $\alpha < 0.2$ foreign competition reduces domestic welfare.

4 Foreign competition and optimal non-cooperative subsidies

Next, I compute the optimal strategic R&D subsidy for both countries and 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 asset 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

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

$$s_n^F(s_n^D; \bar{\omega}) = \arg \max \{W^F(s_n^D, s_n^F; \bar{\omega})\}. \quad (19)$$

Below I show that this policy game yields a Nash equilibrium pair of subsidies, $s_n^{*D}(s_n^{*F}; \bar{\omega})$ and $s_n^{*F}(s_n^{*D}; \bar{\omega})$, as a function of the level of competition.²⁸ Figures 1 to 3 show the Nash equilibrium for different levels of competition.

[FIGURES 2-4 ABOUT HERE]

Result 2. *Increases in foreign competition trigger a defensive R&D subsidy response: higher levels of $\bar{\omega}$ lead to higher optimal strategic subsidy in the home country $s_n^{*D}(s_n^{*F}; \bar{\omega})$.*

The first step in understanding this result is to explain that the best-response functions obtained in the simulation confirm the presence of strategic policy complementarity, with a Nash equilibrium existing at each level of competition. To show why R&D subsidies are strategic

²⁸The subscript n stands for non-cooperative subsidies.

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 the optimal subsidy. I do this by expressing the welfare equation in a form that facilitates intuition, and by decomposing the marginal effects of subsidies on national welfare. The present value of national welfare (16) in both countries can be written as

$$W^K \equiv (\rho - n)U = \ln \frac{c^K}{\lambda} + \frac{g^K}{\rho - n} = G + Y^K - R^K, \text{ for } K = D, F, \quad (20)$$

where G equals the present value of the growth rate, $G = g^K/(\rho - n)$; using the national budget (resource) constraints, consumption is rewritten as national income $Y^K = w^K + \Pi^K$ (wages w^K plus total profits $\Pi^K = \int_0^1 \pi^K(\omega, t)d\omega$) minus savings (investment in R&D $R^K = w^K \int_0^1 I^K(\omega, t)d\omega$).²⁹

I now focus on the domestic country and I will first explain the intuition for the result in figure 6. Innovation in this framework has four external effects affecting the level of optimal domestic subsidies: a *consumer-surplus* or *growth effect (GRE)*, a *domestic business-stealing effect (DBSE)*, an *international business-stealing effect (IBSE)*, and a *resource constraint effect (RCE)*. First, the *GRE* has two different components: the direct consumer surplus effect and the intertemporal spillover effect. Consumers benefit from a higher-quality product when it is introduced by the current innovator, this is the direct effect, and also after it has been replaced by the next innovators who build on the previous quality ladder, this is the intertemporal effect. Since R&D firms do not take these effects on consumer surplus into account, they lead to underinvestment in innovation.

Secondly, in industries with domestic leaders every time a home firm innovates it drives another home firm out of business. The appropriation of the incumbent firm's monopoly profits reduces aggregate profits and consumption, thus having a negative effect on welfare. This is the *DBSE* and in (20) it affects Π^D , the per-capita aggregate real profits of the innovating country. This effect is external to the decision of the innovating firm and so it leads to overinvestment in R&D.

Thirdly, in sectors with foreign incumbents successful domestic innovation drives foreign firms out of business and shifts monopolistic profits toward the home country, thereby increasing domestic income and welfare. This is the *IBSE*, which in our utility metric (20) works on Π^D .

²⁹All values for the new expression for consumption are in logs. The expressions in extensive form for wages, profits, and R&D expenditures for both countries can be found in (13) and (14).

Since home R&D firms do not take this effect into account when innovating, a bias toward underinvestment is produced.

Finally, because of the externality represented by α in technology (7), R&D investment by a national firm increases the sectorial level of research and reduces the productivity of future firms investing in that industry in that country. This is the *RCE* and has the following components: first, more resources must be allocated to R&D in order to maintain the steady state level of innovation, this makes fewer resources available for consumption. Second, as consumption is reduced, incumbent firms profits in all sectors will also be reduced, resulting in even lower consumption. Since R&D firms do not take this effect into account, this produces another bias toward overinvestment. Both components affect welfare through the resource constraint: in the metric of our utility function in (20) they affect $R^D = \ln(L^D/\lambda)$, total labor resources allocated to R&D, and the total profit Π^D respectively.³⁰ Using (20) we can express the different marginal effects of the R&D subsidy on domestic welfare as follows:

$$\frac{\partial W^D}{\partial s^D} = \underbrace{\frac{\partial(R^D, \Pi^D)}{\partial s^D}}_{\substack{RCE \\ (-)}} + \underbrace{\frac{\partial G}{\partial s^D}}_{\substack{GRE \\ (+)}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{IBSE \\ (+)}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{DBSE \\ (-)}} , \quad (21)$$

where the plus and minus signs signal that the external effect leads respectively to underinvestment, thereby motivating R&D subsidies, and overinvestment, thereby motivating R&D taxes.

The main force driving strategic policy complementarity is the strategic motive for subsidy: higher foreign subsidies produce a higher *intensity* of foreign business stealing, thereby strengthening the role of home subsidies in protecting domestic rents -this is indicated by *IBSE* in (21). It follows that an increase in s^F improves the marginal effects of s^D on welfare, thus raising the optimal domestic subsidy.

Next, I discuss the economic intuition for result 2. In figures 2-4 we can 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 *IBSE*. 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. (13) that the rent-protecting effect of s^D is zero at $\bar{\omega} = 0$, and increases

³⁰This effect is sometimes called in the literature ‘intertemporal R&D spillovers effect’ because it depends on the impact of current innovation on future R&D productivity.

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, which implies that the sensitivity of the optimal s^D to changes in s^F rises. Intuitively, the increase in foreign competition implies that each dollar of foreign subsidy represents an increasingly serious threat to the domestic leadership.³¹

Although the optimal subsidy increases primarily for the strategic reasons that I have just discussed, foreign competition, by increasing the productivity of domestic R&D, also improves both the *GRE* and the *RCE* of home subsidies. Indeed, the presence of the country-specific R&D externality in (7) implies that research efficiency is higher in competitive sectors. Hence, an increase in the number of these sectors raises the aggregate productivity of domestic research labor, and reduces the labor resources required to maintain the steady state level of innovation.

A final remark on the sign of the optimal R&D subsidy is necessary. In quality-ladder growth models whether the optimal R&D subsidy is positive or negative depends on the relative strength of the several externalities involved. Similarly to Grossman and Helpman (1991) and Segerstrom (1998), in this model the sign of the optimal subsidies depends on parameter specifications. In the section on robustness I will show that the main results of the paper are confirmed also when the parameter specification is such that the optimal R&D subsidy is negative.

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 foreign growth rate (and consumer surplus); second, the negative business-stealing effect of national subsidies on foreign aggregate profits is not consid-

³¹In 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 $\bar{\omega}$ 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; 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 raising 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.

ered 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 business-stealing effect and takes into account the growth effect of subsidies in both countries. I consider a form of cooperation where subsidies are set separately by governments in order to maximize a welfare function that is a linear combination of national and world welfare.

$$s_{co}^D(s_{co}^F; \bar{\omega}, \beta) = \arg \max \{T^D(s_{co}^D, s_{co}^F; \bar{\omega}, \beta)\},$$

$$s_{co}^F(s_{co}^D; \bar{\omega}, \beta) = \arg \max \{T^F(s_{co}^D, s_{co}^F; \bar{\omega}, \beta)\},$$

where

$$T^K = (1 - \beta)W^K + \beta W^W, \text{ for } K = D, F \quad (22)$$

is the the objective function of policy maker K and

$$W^W = W^D + W^F = 2G + (Y^D + Y^F) - (R^D + R^F) \quad (23)$$

is the global welfare equation. In the objective function (22) the degree of cooperation among countries is pinned down by β : with full cooperation, $\beta = 1$, each country sets subsidies to maximize global welfare; with no cooperation, $\beta = 0$, countries maximize their own welfare.

I numerically compute the optimal subsidies under cooperation, s_{co}^D and s_{co}^F , and compare the welfare outcome of cooperative and non cooperative policies. I assume that there is no ex-post scheme available to winners to compensate losers. Therefore cooperation will be implemented only when it benefits both countries. Table I below shows the result.

[TABLE I HERE]

In this exercise I explore a setup with partial cooperation because the internal calibration of parameters is done on the benchmark model with no cooperation. If we change the framework by introducing some degree of cooperation, the calibrated model does not to lead to realistic equilibrium values for our variables anymore; in particular we would obtain unrealistic subsidy levels. With low levels of cooperation, i.e. $\beta = 0.2$, we are able to compare two frameworks

that are too different, which allows us to explore the qualitative implications of the cooperative solution without obtaining unrealistic subsidy levels. As shown in the appendix on robustness analysis, qualitative results are not affected when the model with total cooperation is used.³²

The basic result can be summarized as follows:

Result 3. *For a country facing increases in foreign competition - the domestic country - the incentives to cooperate increase with competition but are negative for $\bar{\omega} < \bar{\omega}^* \in (0.1, 0.2)$. 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 $\bar{\omega}^*$.*

In order to understand the mechanisms at work here we need to examine the effects of domestic subsidies on the objective function T^K . Equation (24) below shows the effects of domestic subsidies on world welfare.

$$\frac{\partial T^W}{\partial s^D} = \underbrace{\frac{\partial R^D}{\partial s^D}}_{\substack{RCE \\ (-)}} + \underbrace{(1 + \beta) \frac{\partial G}{\partial s^D}}_{\substack{GRE \\ (+)}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{IBSE \\ (+)}} + \underbrace{\beta \frac{\partial \Pi^F}{\partial s^D}}_{\substack{IBSE \\ (-)}}. \quad (24)$$

Comparing (24) with (21) we can observe that two additional effects appear in the case with cooperation.³³ First, we see the internalization of the negative *IBSE* of domestic subsidies on foreign profits: a fraction β of the damage inflicted upon the foreign country by subsidy-led profit-stealing is internalized. Second, domestic subsidies have an additional growth effect, βGRE , because policy cooperation takes into account the positive innovation effect of home R&D subsidies on foreign welfare.

As foreign competition increases, leading country's incentives to cooperate rise. In the sixth column of table II we can see that domestic gains from cooperation are negative at $\bar{\omega} = 0.1$ and positive at $\bar{\omega} = 0.2$. Intuitively, 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.

³²The choice of the non cooperative framework as the benchmark is not relevant. The results would not be affected if the benchmark would be represented by a low level of cooperation, say $\beta = 0.2$, and I would compare it to a higher level of cooperation.

³³I have omitted the *DBSE* because it is not key for explaining the intuition.

The intuition for the positive global gains from cooperation is straightforward: on the one hand, in setting subsidies non-cooperatively neither government takes into account the *GRE* of its subsidies on the other country's welfare, thereby producing an incentive to free ride on innovation subsidies; on the other hand, competitive subsidies do not take into account the negative *IBSE* on the other country, thus creating a beggar-thy-neighbor effect. These two external effects produce a prisoner-dilemma type of outcome that leads to lower levels of global welfare.

Finally, there is another result in table II worthy of mention: optimal subsidies are higher under cooperation. Internalizing the negative *IBSE* on foreign income reduces the strategic motive for subsidies, thus reducing $s_{co}^{D*}(s_{co}^F; \bar{\omega}, \beta)$; whereas the positive *GRE* on foreign welfare increases the growth motive, thus increasing $s_{co}^{D*}(s_{co}^F; \bar{\omega}, \beta)$. Depending on the relative strength of these two effects the optimal cooperative subsidy can be higher or lower than the non-cooperative one. In the next section I will discuss the features of the model that are key for this result.³⁴

6 Discussion

In this section I briefly discuss some issues arising from the results obtained above. I first explore the implications of different degrees of substitutability among goods and of imperfect international knowledge spillovers. Secondly, I discuss the relation between competition and growth predicted by the model. Thirdly, I analyze the importance of introducing growth in a strategic industrial policy game.

Goods substitutability. Here I informally discuss how extending the model to account for different degrees of substitutability among goods would affect the results. If from the Cobb-Douglas benchmark I would increase the substitutability of goods that the two countries produce, the business stealing effect of subsidies (*IBSE*) becomes higher. As a consequence, the strategic motive for subsidy is higher and the positive effect of competition on the optimal domestic subsidy will be larger. Hence, higher (lower) substitutability among goods will strengthen (weaken) result 2; qualitatively the result will not hold only in the extreme case

³⁴The intuition for the relationship between the optimal domestic subsidy and competition is similar to that in result 1: on the one hand, the *IBSE* is partially neutralized by cooperation, so the strategic motive for subsidies is weaker; on the other hand, competition, by improving the efficiency of home R&D, improves the *RCE* and the *GRE* of home subsidies, thereby increasing optimal subsidies.

where substitutability among goods is zero. Secondly, result 3 will be affected as follows: as higher (lower) substitutability implies higher (lower) *IBSE*, cooperation will be beneficial at levels of competition lower (higher) than those shown in table II. Finally, a high *IBSE* implies that, by internalizing it through cooperation, the major motivation for subsidies, the strategic one, disappears, thus making cooperative subsidies lower than the non-cooperative ones; the opposite will happen when good become less substitutable.³⁵ The intuition provided here suggests that the two basic findings of the paper, result 2 and 3, should not be affected qualitatively by enriching the framework along these lines.

International knowledge spillovers. If we would depart from the assumption of perfect international spillovers the effect of domestic subsidy on foreign innovation, growth, and welfare becomes weaker. This will affect the results as follows: first, since foreign innovation will free-ride less on domestic R&D, the strategic role of domestic subsidies will be stronger and the positive effect of competition on optimal non-cooperative subsidies shown in result 2 will be reinforced. Second, for the same reason, the level of competition at which cooperation becomes beneficial for the domestic countries will be reduced. Finally, when the effect of subsidy-led domestic innovation on foreign growth is weaker, internalizing it through cooperation produces a smaller increase in the optimal domestic cooperative subsidy. It follows that the effect of the internalization of the *IBSE* will be higher and the optimal cooperative subsidy will be lower than the non-cooperative ones.³⁶

Competition and growth. Although, as specified above, the model does not attempt any quantitative analysis it is worth to briefly discuss the prediction of a positive relation between competition and growth shown in figure I. If we were to apply this model to the post-WWII world, in which, using our taxonomy, the U.S. would be the leading country and Europe and Japan the followers, the prediction would be that foreign catching-up in R&D increases growth both in the U.S. and in foreign countries. Provided that we observe a technological catching-up of Japan and Europe in the post-War period, the model would predict an increasing U.S. growth rate. This would be at odds with the lack of evidence of a positive trend in the U.S. growth rate in the post-War period (Jones 1995). A few remarks are necessary.

³⁵Haaland and Kind (2006) in a simpler set up with two countries, two goods and without neither knowledge spillovers nor growth show that the difference between cooperative and uncooperative subsidies depends on the degree of substitutability between goods.

³⁶Leahy and Neary (2001) introduce static knowledge spillovers and show that, depending on the degree of spillovers, national governments may undersubsidize or oversubsidize R&D.

First, as shown in figure I the efficiency effect of competition produces a reduction of total R&D investment in the leading country and an increase in the foreign country. Since international knowledge spillovers are perfect, growth in each country benefits equally from domestic and foreign innovation. Empirical evidence suggests substantial, but not perfect, international sharing of ideas.³⁷ Hence, one way to improve the empirical fit of the model could be to remove the simplifying assumption of perfect international spillovers. In this case, the increase in foreign sources of U.S. growth brought about by competition could be compensated by the reduction of domestic sources of growth, and the overall growth effect would be reduced. Impullitti (2007) constructs an index of international R&D competition to explicitly measure $\bar{\omega}$ in a two-country world with the U.S. as the leader and Europe and Japan as the followers and finds a substantial increase in competition in the period 1973 – 1991: $\bar{\omega}$ rises from 0.38 in 1973 to 0.76 in 1991. Partial international knowledge spillovers are calibrated using the evidence in Eaton and Kortum (1999) and the increases in the growth rate produced by the observed increase in $\bar{\omega}$ is substantially smaller than that observed in figure I.

Secondly, as the robustness analysis in the appendix shows, the basic results of this paper do not depend on the growth effect of competition. In fact, all simulations in the model can be repeated for $\alpha \rightarrow 0$ obtaining negligible effects on growth and still revealing a substantial positive effect of competition on optimal subsidies. This occurs because the driving force of result 2 is the *IBSE*, and not the *GRE*. Result 4 would also be confirmed because cooperation, by internalizing the *IBSE*, would always reduce the distortions produced by policy competition; the leader’s incentives to cooperate, and internalize the *IBSE*, are still going to be affected by the scale of foreign challenge along the same lines.³⁸ The assumption of an R&D technology subject to decreasing returns that drives the *GRE* makes the model more general, while allowing for the study of a richer interaction between competition, welfare and optimal subsidies.

Thirdly, the basic results could be also obtained in a semi-endogenous growth model (i.e.

³⁷Using patent data for the U.S., Japan, Germany, France, and the U.K., Eaton and Kortum (1999) estimate the extent to which these countries share their ideas. They find that each country adopts from one half to three fourths of the ideas generated abroad. Moreover, using a decomposition of productivity growth sources they provide an additional way of quantifying technology diffusion: they find that the U.S. and Japan contribute to two thirds or more to growth in each of the five countries, and only in the U.S. does most of growth come from domestic innovation.

³⁸Notice also that even when the growth effect of competition is eliminated, the paper still adds a new result to the existing studies on the strategic innovation policy: in an economy with a continuum of monopolistic competitive industries it studies the effect of foreign R&D entry into home-led industries on the business-stealing motive for subsidies and on the incentives for policy cooperation among asymmetric countries.

Segerstrom, 1998, Jones 1995, Kortum 1997), where competition and public policies do not affect steady state growth. In this case the growth effect of competition and subsidies would be observed only along the transition to the steady state. Unless the convergence to the steady state is immediate the effects of innovation on the levels of consumption, quantity and quality, would still be there and affect national welfare similarly to what has been shown above.

Growth and strategic R&D subsidies. Strategic trade and industrial policies can have substantial effects on economic growth that have not been explored in the existing literature. Brander (1995) suggests that understanding the interaction between strategic policy and growth is a promising field for 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). Leaving explicit quantitative analysis for future research, I briefly discuss here the mechanism through which growth could amplify the “size” of gains and losses produced by strategic policy interactions.³⁹

In the previous sections we have observed that the existence of positive gains from cooperative R&D subsidies results from the internalization of both the *GRE* and the *IBSE* of subsidies. Reducing the importance of innovation-driven growth in the model will reduce the distortions produced by the growth effect of subsidies, thus diminishing the gains from cooperation. To understand the economic mechanism we need to recall the two components of the external effect of innovation on consumer surplus. On the one hand, there is a direct consumer surplus effect, which benefits current consumers and, on the other hand, we have the intertemporal spillover effect, realized when future generations of innovators build on present innovations, thereby benefiting future consumption. In a static model, the absence of intertemporal knowledge spillovers does not allow for an account of 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. Hence, if the role of the cumulative nature of innovation is reduced, the welfare benefit from internalizing the *GRE* of subsidies through cooperation will also be lower.⁴⁰

³⁹Impullitti (2007) presents a version of this model extended to specifically fit a set of stylized facts and performs a quantitative welfare analysis of the R&D subsidy response to competition in the U.S..

⁴⁰One simple way to show this is to increase the intertemporal discount rate ρ and show that gains from cooperation decline. This exercise is performed in the appendix and confirms that reducing the *GRE* of subsidies on welfare produces lower gains from policy cooperation.

7 Conclusion

In this paper I have analyzed the interaction between international technological competition and optimal competitive and cooperative R&D subsidy 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.

I have shown that the effect of foreign competition on domestic welfare depends on the relative strength of two effects: the standard business-stealing effect that, by switching monopolistic rents from domestic to foreign firms, reduces domestic profits, income, and welfare; the increase the efficiency of global innovation brought about by foreign entry raises the growth rate of goods quality, thus benefiting domestic welfare. The overall effect of competition on welfare depends on the relative strength of these two counteracting forces.

Secondly, I have found that increases in competition trigger a *defensive R&D subsidies* mechanism: the optimal domestic subsidy increases with the number of sectors where domestic and foreign firms compete in innovation. As competition increases, the role of subsidies in protecting domestic rents becomes more relevant. Thirdly, the strategic motive for subsidies suggests the importance of evaluating the gains from cooperation in R&D policy. Implementing the cooperative solution and comparing it to the non-cooperative outcome, I find that the leading country loses from cooperation at low levels of competition, and begins to gain when a sufficiently high number of sectors is competitive. Hence, the presence of innovation asymmetries among countries, in terms of distribution of research efforts across sectors, can create obstacles to the implementation of cooperative R&D subsidies.

The paper is amenable to many extensions. First, 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 and social factors, can provide a link between competition and economic decisions, thereby endogenizing the degree of technological competition.⁴¹

⁴¹A related issue here is that entry of foreign innovators in new sectors may be produced by favourable tax policies, such as R&D subsidies: this would imply that my measure of competition depends on R&D subsidies. Although this is a plausible case, entry into new industries is most probably related to structural innovation policies that allow firms to pay large initial start up costs. Examples of these policies are those implemented by MITI in Japan in the 1970s, and those introduced in the 1970s and 1980s in the U.S. to promote commercial innovation. In the U.S. experience policies like the Bayh-Dole, the National Cooperative Research, and the Federal Technology Transfer Acts, set the institutional framework that allowed firms, especially small firms, to avoid paying the high fixed initial costs of innovation. Tax breaks, like the Research and Experimentation Tax

Secondly, in order to isolate the role of the specific dimension of technological competition studied in the paper, I have omitted the interactions between foreign R&D entry and market structure. It is plausible that when a sector experiences entry of foreign researchers there could be a change in the structure of that market, with consequent changes in product market competition. Future research could explore this link and provide a richer analysis of the welfare effects of competition in global innovation races. Extensions in this direction could benefit from the adoption of the last generation quality-ladders models in which innovation by incumbents is introduced (e.g. Peretto 2003, Etro 2004, Segerstrom 2006, Aghion et al., 2006). In these frameworks foreign entry could trigger an *aggressive* innovation response by domestic leaders, thereby providing an additional channel for competition to affect growth.

Forth, the assumption of global labor markets implies that the labor market is not affected by changes in competition. The rent-shifting effect of competition affects only the international distribution of firm ownership; neither job-displacements nor wage adjustments take place; domestic plants are simply taken over by foreign owners. This conservative assumption reduces the impact of business-stealing on welfare, thus understating the negative welfare effect of competition. If we were to remove this assumption, the *BSE* would reduce both profits and wages, thereby increasing the negative impact of competition on national income and strengthening the strategic motive for subsidies.⁴²

Finally, in the model the asymmetry between countries is limited to the distribution of research efforts; introducing local labor markets, as well as other structural differences (e.g., production and innovation technology, skilled labor endowments), would make the model more suitable to study the effects of the arrival of China and India as global players in technologically advanced industries.

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Credit, were conceived as tools to keep high incentives once structural reforms had produced the entry of firms. For more on this see Impullitti (2006).

⁴²Impullitti (2007) extends the model to account for local labor markets and finds that adding the wage-stealing effect does not affect the qualitative results of this paper.

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8 Appendix: robustness analysis

In this appendix I explore the sensitivity of the results to changes in parameter specifications. In the comments I will focus on result 2 and 3, which are those where the effects of changing parameters are more significant.⁴³ First, I will show that the results are confirmed with full policy cooperation - that is with $\beta = 1$. Then I will analyze the effects of halving the parameters of interest with respect to their benchmark value.⁴⁴ Here I will only show the sensitivity of the results to changes in two key parameters, the R&D externality index α that produces the growth effects of competition, and the quality jump λ that determines the sign of the optimal subsidy.⁴⁵

Table II below shows that the results are confirmed with full policy cooperation.⁴⁶ As I mentioned above, the optimal cooperative subsidy levels are very high because the framework is very far from the benchmark on which the parameters have been calibrated. Nevertheless, in comparing table I and II, we can observe qualitatively similar findings. Two more things are of note: first, the competition threshold above which the home country starts benefiting from cooperation is higher than in table I, $\bar{\omega}^* \in (0.3, 0.4)$. This occurs because under full cooperation the home country internalizes the *BSE* inflicted upon the foreign country completely; thus, cooperation becomes beneficial only under a higher competitive threat. Second, global gains from cooperation are larger than in the partial cooperation case for all values of $\bar{\omega}$. Although quantitatively this result could be biased by the calibration issue discussed above, higher degrees of cooperation, by reducing inefficient subsidy competition, will always yield larger welfare gains.

[TABLE II HERE]

In table III I study the effects of a reduction in α from the benchmark value 0.4 to 0.2. As we can see, all results are confirmed. By comparing tables I and III we observe that one remarkable effect of reducing the negative R&D externality is that gains from cooperation become higher

⁴³Result 1 is fairly general in that changes in parameters only influence the business-stealing and the growth effects quantitatively, with no changes in the qualitative outcome shown in figure 1. Appendix B available upon request contains the complete robustness analysis.

⁴⁴I have also performed the sensitivity analysis for specifications in which the benchmark values are doubled and have obtained results that are symmetric to those discussed below; I omit them for simplicity.

⁴⁵The sensitivity analysis for other less crucial parameters is in appendix B.

⁴⁶For simplicity I will only show simulation results for the points in the grid for $\bar{\omega}$ that are relevant to the explanation.

at all levels of competition except the highest one. This effect is due to the fact that weaker decreasing returns in R&D raise the effect of government subsidies on innovation. It follows that global policy cooperation leading to higher equilibrium subsidies has a larger effect on welfare, and produces higher welfare gains. The effect of lower α on the global gains from cooperation is decreasing in competition, and disappear at $\bar{\omega} = 1$, because a lower negative country-specific R&D externality affects productivity of home researchers more when most of the innovation activity is performed by the home country - that is at low levels of competition.

[TABLE III HERE]

In table IV, I report 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. The main results are confirmed. One relevant effect of reducing the size of innovation is that at low levels of competition the home uncooperative R&D subsidy is negative. Competition, however, affects the optimal home subsidies in the usual way: it reduces the tax on R&D until, for high values of $\bar{\omega}$, the optimal subsidy becomes positive and increasing in $\bar{\omega}$. To explain the link between the optimal subsidy and the quality jump we need to focus on the external effects of innovation.

[TABLE IV HERE]

The explanation is based on the analysis of the external effects of subsidies discussed above. Following the same procedure as in Grossman and Helpman (1991) and Segerstrom (1998) but considering a one-country version of the model (a version where only domestic firms innovate, $\bar{\omega} = 0$), and also assuming $\alpha = 0$, it is possible to show that the expected value of the two positive external effects of subsidies on consumer surplus (the *GRE*) is equal to $\ln \lambda / (\rho - n)$.⁴⁷ Since R&D firms do not take these effects into account, they will underinvest in innovation. It follows that underinvestment rises with λ . With the same procedure we find that the expected value of the *BSE* is equal to $(\lambda - 1) / (\rho + I - n)$, which is increasing in λ . Because of the assumption of decreasing marginal utility in (1) $\ln \lambda / (\rho - n)$ is a strictly concave function, thereby rising levels of λ increase the bias toward overinvestment and reduce the level of the optimal subsidy. To compute the *RCE* it is necessary to keep the R&D externality, that is

⁴⁷See Grossman and Helpman (1991) p. 110, and Segerstrom (1998) appendix B.

to set $\alpha > 0$, but unfortunately in this case an analytical solution is not attainable even in the simple model. Therefore, I suggest an explanation based on economic intuition: in quality ladder models the private incentive to innovate is positively related to the size of innovation λ ; since the private incentive to innovate is the source of our externality, it is plausible to expect that the *RCE* increases with the size of quality jumps.⁴⁸

This sensitivity analysis on the quality jump λ shows that, even with parameter values that weaken the growth motive for subsidies and lead to optimal negative subsidies at low values of $\bar{\omega}$, the business-stealing motive still guarantees a positive relation between foreign competition and optimal home subsidies. Moreover, at sufficiently high level of $\bar{\omega}$ the *IBSE* is strong enough to more than compensate for the weak growth motive, thus making optimal home subsidies positive.

TABLE I
GAINS FROM (PARTIAL) COOPERATION

$\beta = 0.2$	Coop		No-Coop		Gains D	Gains F	Global gains
$\bar{\omega}$	s_{co}^D	s_{co}^F	s_n^D	s_n^F	$(W_{co}^D - W^D) / W^D$	$(W_{co}^F - W^F) / W^F$	$(W_{co}^W - W^W) / W^W$
0	.275	.4	.075	0.27	-.0175	.2328	.0961
.1	.285	.4	.1	0.27	-.0051	.2018	.0905
.2	.3	.4	.12	0.275	.0065	.1746	.0857
.4	.325	.4	.17	0.28	.0262	.1277	.0753
.6	.355	.4	.215	0.28	.0420	.1010	.0711
.8	.38	.4	.255	0.29	.0510	.0799	.0654
1	.405	.405	.29	0.29	.0654	.0654	.0654

TABLE II
GAINS FROM FULL COOPERATION

$\beta = 1$	Coop	No-Coop	Gains D	Gains F	Global gains
$\bar{\omega}$	s_{co}^D	s_n^D	$(W_{co}^D - W^D) / W^D$	$(W_{co}^F - W^F) / W^F$	$(W_{co}^W - W^W) / W^W$
0.2	0.65	0.12	-0.131	0.6603	0.2412
0.3	0.67	0.1450	-0.0500	0.5729	0.2475
0.4	0.69	0.17	0.0009	0.5231	0.2534
0.8	0.77	0.255	0.2006	0.3494	0.2745
1	0.8	0.29	0.2849	0.2849	0.2849

⁴⁸Segerstrom (1998) formalizes this result but with a different source of declining R&D productivity.

TABLE IIIGAINS FROM PARTIAL COOPERATION WITH $\alpha = 0.2$

$\beta = 0.2$	Coop	No-Coop	Gains D	Gains F	Global gains
$\bar{\omega}$	s_{co}^D	s_n^D	$(W_{co}^D - W^D) / W^D$	$(W_{co}^F - W^F) / W^F$	$(W_{co}^W - W^W) / W^W$
0.2	0.345	0.18	-0.0030	0.4582	0.1939
0.3	0.35	0.205	0.0099	0.2925	0.1388
0.4	0.35	0.225	0.0190	0.1999	0.1049
0.8	0.35	0.275	0.0462	0.0899	0.0678
1	0.355	0.295	0.0554	0.0554	0.0554

TABLE IVGAINS FROM PARTIAL COOPERATION WITH $\lambda = 1.1$

$\beta = 0.2$	Coop	Non-Coop	Gains D	Gains F	Global gains
$\bar{\omega}$	s_{co}^D	s_n^D	$(W_{co}^D - W^D) / W^D$	$(W_{co}^F - W^F) / W^F$	$(W_{co}^W - W^W) / W^W$
0.2	0.02	-0.245	-0.004	0.356	0.108
0.4	0.105	-0.085	0.011	0.176	0.077
0.5	0.145	-0.02	0.017	0.135	0.067
0.8	0.24	0.125	0.035	0.071	0.052
1	0.29	0.195	0.049	0.049	0.049

FIGURE 1. The effects of foreign competition on the domestic economy

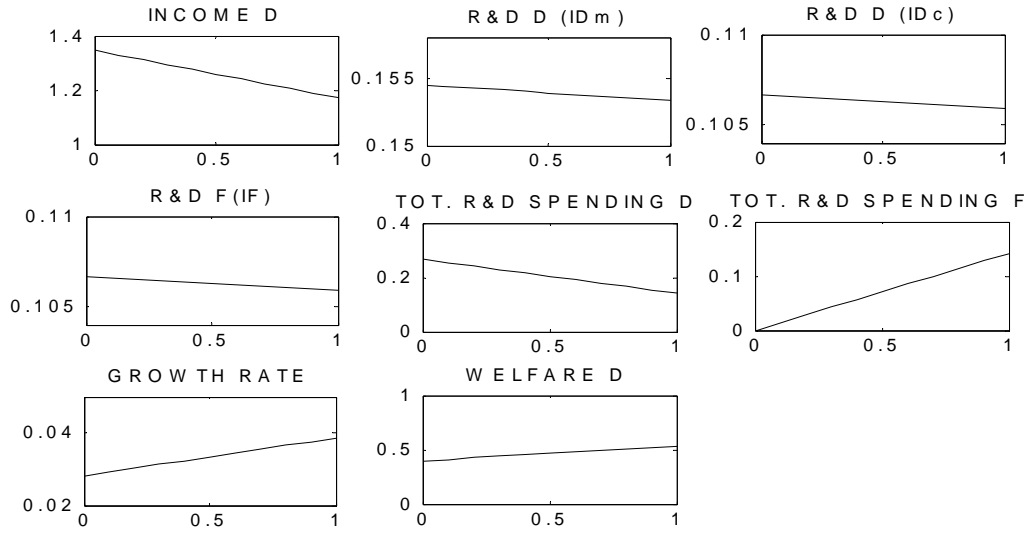


FIGURE 2. Optimal subsidies with 30 % of competitive sectors

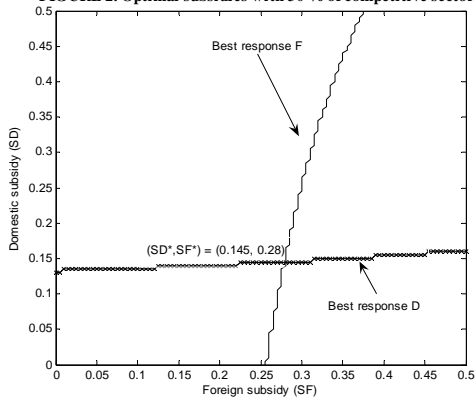


FIGURE 3. Optimal subsidies with 60 % of competitive sectors

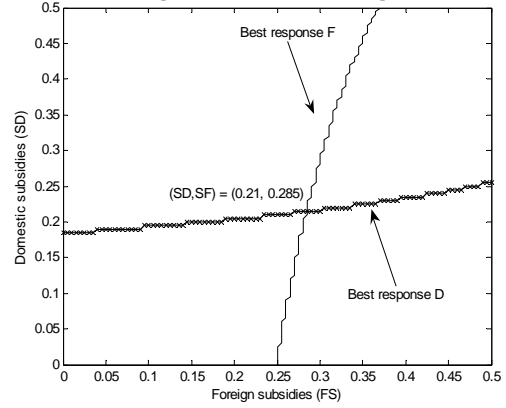


FIGURE 4. Optimal subsidies with 100% of competitive sectors

