International competition and U.S. R&D subsidies: a quantitative welfare analysis*

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Abstract

In the early 1970s U.S. firms were the uncontested world leaders in R&D investment in most manufacturing sectors. Later, led by Japan and Europe, foreign firms began to challenge American R&D leadership in many sectors of the economy. This period of increasing technological competition is contemporaneous to a substantial increase in U.S. R&D subsidies. What is the effect of the observed increase in international competition on US welfare? How does foreign competition affect the optimal R&D subsidy in the US and, consequently, how far is this from the subsidy observed in the data? This paper addresses these questions in a two-country quality ladder growth model.

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1 Introduction

Recent discussions on the economic costs and benefits of globalization have debated the welfare effects on leading economies of technological progress in trailing countries. Most of the attention has been dedicated to the consequences for advanced industrial countries of cost-driven and technology-induced offshoring to developing countries, and especially to Asia's giants, India and

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China.[1] Another similarly heated debate took place in the 1980s and early 1990s. At the time economists and political analysts warned the American public about the consequences of losing the "race" of the 21st century, the race for world technological leadership, to catching-up Japan and Europe.[2] Key issues in both debates are, on the one hand, the quantitative assessment of the welfare effect of foreign competition and, on the other hand, the identification of the optimal policy response to it. In this paper, I focus on the second debate studying the effects of Japanese and European technological catch-up on US welfare and on the optimal US R&D subsidy.

There are two main reasons for focusing on R&D subsidies: first, the World Trade Organization and other international institutions restrict the use of trade policy and of production subsidies, while individual countries are free to set their R&D subsidies autonomously. Secondly, R&D subsidies allow policy makers to protect the domestic economy without giving up gains from trade.

Two stylized facts provide the motivation for the paper: the evolution of foreign competition experienced by US firms, and the dynamics of US R&D subsidies from early 1970s to mid-1990s. The dimension of international competition on which this paper focuses is R&D rivalry among firms from different countries. A rough measure of this dimension of competition is represented by countries' share of global R&D investment. Using OECD ANBERD data on R&D investment in 2-digit and 3-digit manufacturing industries for the US, Japan, and 10 European countries, I find substantial changes in the geographical distribution of R&D investment in the period considered. More precisely, the US share of global R&D investment declines from 52 percent in 1973 to 39 percent in 1995, while Japan's share increases from 17 in 1973 to 28 percent in 1995. This suggests that US leadership in R&D activity was increasingly challenged by foreign firms. The second relevant piece of evidence is that estimates of R&D subsidies show an increase in the subsidy given to US firms starting with the introduction of the Research and Experimentation Tax Credit in 1981. The effective US subsidy is 13 percent in 1979 and reaches 30 percent in 1991, remaining constant the following years[3].

What is the effect of the observed increase in foreign R&D on US welfare? How does foreign competition affect the optimal R&D subsidy in the US and, consequently, how far is this from the subsidy observed in the data? To answer these questions I set up a quality ladder growth model where monopolistic competitive firms from two asymmetric countries compete

[1] See Baumol and Gomory (2000), Samuelson (2004), Bhagwati, Panagariya, and Srinivasan (2004), Blinder (2005).

[2] See Krugman (1993 and 1996) Tyson (1992) and Thurow (1992).

[3] See Bloom, Griffith and Van Reenen (2002). Estimates for earlier periods are not available.

for market leadership through investment in quality-improving R&D (Grossman and Helpman, 1991, Aghion and Howitt, 1992). The choice of a growth model is motivated by the nature of competition on which I focus, R&D rivalry, which is directly related to the growth engine of the economy, and by the possibility to account for the long-run effects of competition and policy on national welfare. Jones (1995) has criticized the first generation R&D-driven growth models for predicting a counterfactual effect of the scale of the economy on the steady-state growth rate. In order to address this criticism, I remove scale effects assuming that an increasing labor force 'dilutes' the research effort per variety of goods. There are two countries, domestic and foreign, sharing the same size, technology and preferences but with different allocations of R&D investment across sectors and different research subsidies. Following the evidence discussed above, I model foreign competition as follows: I assume that the domestic country is the world leader in that its firms invest in R&D in all sectors of the economy, while the foreign country is the follower, in that its R&D firms are concentrated only in few sectors. The share of sectors where R&D firms from both countries compete for innovation is used as a measure of international competition.[4]

Increases in competition, that is, increases in the share of sectors where domestic leaders are challenged by foreign innovators, produce two opposite effects on domestic welfare. First, competition has a positive effect on long-run growth: decreasing returns in R&D at the country level, motivated by the presence of fixed costs or by a fixed endowment of a workforce with heterogeneous ability (Eaton and Kortum, 1999), imply that increases in competition lead to a more *efficient* international allocation of research labor, thus spurring innovation and growth. This is the *growth effect* of competition which, by improving the quality of goods, raises domestic welfare via the consumer surplus channel.

This channel of growth through foreign entry in innovation is related to the literature on international technology diffusion. Technology diffusion can be one of the underlying forces driving changes in the dimension of competition studied in the paper. Helpman (1993) and Eaton and Kortum (2006) study the growth effects of lower barriers to technology diffusion for zero or a given level of trade barriers.[5] While in these papers technology diffusion is explicitly modeled as an exogenous process of learning and/or adopting, my paper is more

[4] This assumption is similar to the one in Krugman (1979), where the leading country is assumed to be able to produce virtually all the 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. As Krugman suggests, the source of the productive advantage of the leading economy might be related to a more skilled labor force, external economies, or to a difference in "social atmosphere". Other sources could be past policies, such as technology and industrial policies.

[5] For a recent survey on the vast literature on international technology diffusion see Keller (2004).

reduced form in that it focuses on the effects of diffusion without modeling the sources. In the North-South quality ladder model proposed by Helpman, only the leading country innovates and diffusion affects growth by reducing the cost of innovation (wages). In the Ricardian model by Eaton and Kortum, all countries innovate and faster diffusion spurs innovation by shifting the research activity in the more efficient country. The increase in research efficiency works through Ricardian specialization, while in my paper it operates simply through the concavity of the R&D technology.

The second effect of competition on domestic welfare is the *business-stealing* effect: when foreign innovators enter a market previously dominated by domestic firms, some monopolistic rents shift abroad. Foreign business stealing can affect national income through two potential channels: first, it reduces aggregate profits by destroying the rents of those domestic leaders that have been pushed out of the market. Second, when domestic firms are taken over by foreign firms, domestic jobs are temporarily lost and the labor market clears at a lower wage level. In this paper I focus on the profit-shifting effect, I assume that the presence of multinational corporations equalizes wages across countries, thus eliminating any negative effect of competition on wages.

The overall effect of competition on welfare depends on the relative strengths of the growth and business-stealing effect. In a calibrated version of the model I perform a quantitative evaluation of these two affects. This feature of the paper is methodologically related to the works on calibrated multi-country endogenous growth models, such as Eaton and Kortum (1999)[6].

In the quantitative analysis I construct an empirical index of the measure of competition presented in the model. Using ANBERD R&D data, I obtain a measure of the share of sectors where domestic and foreign firms compete effectively in R&D; the US is the domestic country and Japan and Europe the foreign countries. The sectors where US investment in research dominates global spending in innovation are considered non-competitive, while the sectors where the US and the rest of the world are more *neck-and-neck* in their innovation efforts are considered competitive; the share of neck-and-neck sectors will be the measure of international competition. The baseline version of the index shows that US global leadership in R&D was increasingly challenged by foreign countries in the 1970s, 1980s, and early 1990s. More precisely, I find an increase in the share of competitive sectors from 30 percent in 1973 to 68 percent in 1995. To the best of my knowledge, this is the first paper that highlights this trend in the geographical distribution of R&D investment across sectors.

[6] See also Klenow and Rodriguez-Claire (2005) and the literature surveyed in Eaton and Kortum (2008).

I use this index of competition and other long-run statistics to calibrate the model. Numerical simulations show that the effect of competition on welfare is negative but small, implying that the growth effect does not completely offset the negative business-stealing effect, but rather limits its impact substantially. More precisely, I find that the observed increase in foreign competition leads to a welfare loss for the US of 1.3 percent of lifetime consumption between 1979 and 1995 - when the competitive share of sectors rise from 0.42 to 0.68.

I then turn to the effects of foreign competition on the optimal domestic subsidy. There are two motives for R&D subsidies: first, the market failure related to the public good nature of R&D (e.g. Grossman and Helpman, 1991b, and Segerstrom, 1998). In the model, innovation-driven growth, by increasing the quality of goods or reducing their quality-adjusted price, raises consumer surplus. Thus, R&D subsidies can be used to maximize consumer surplus by correcting socially inefficient levels of R&D due to the presence of knowledge externalities. This is the *consumer surplus* (or growth) motive for subsidies. Secondly, there is a *strategic motive* related to international competition: R&D subsidies can be used to protect national income by helping domestic firms competing in global R&D races for market leadership (e.g. Spencer and Brander, 1983, Grossman and Eaton, 1986). The effect of foreign competition on the optimal domestic subsidy works through the impact of foreign entry in R&D on these two motives for subsidies.

Haaland and Kind (2008) study both the consumer surplus and the strategic motive for subsidies, and also explore the effect of increasing competition on innovation and on the optimal R&D subsidy. They focus on changes in product market competition and, as standard in the strategic trade policy literature, they present a static model of innovation. My paper instead focuses on international competition for innovation, and introduces strategic subsidies into an endogenous growth framework to account for dynamic effects of innovation on consumer surplus. Brander (1995) and Krugman (1994) suggest that taking into account long-run growth effects could increase the welfare gains associated with strategic trade and industrial policy. My paper is closely related to Grossman and Lai (2004) in which a two-country endogenous growth model is used to study strategic interaction in intellectual property rights (IPR) policy. While they present a theoretical analysis of IPR policy, I focus on a different policy tool, R&D subsidy, and perform a quantitative analysis applying the theoretical results to the US economy.

The main findings can be summarized as follows: first, increasing foreign competition strengthens both the strategic and the knowledge-spillovers (consumer-surplus) motive for subsidies, thus raising the optimal domestic R&D subsidy. Second, applying the model to evaluate the optimality of the US subsidy response to competition, I find that an increase in the competition index from 0.42 in 1979 to 0.68 in 1995 produces an increase in the optimal subsidy that is fairly close to that observed in the US data. Thus, the quantitative analysis suggests that R&D subsidies were set *as if* American policy makers were responding optimally to increasing international competition.

The quantitative analysis of the distance between the observed and the optimal R&D subsidy response to competition is related to the literature on calibrated models of strategic trade and industrial policy. Following the seminal work by Dixit (1988), several papers have performed calibration exercises to evaluate quantitatively the welfare gains implied by the gap between the observed policy and the optimal strategic policy (e.g. papers in Krugman and Smith 1994, and the work surveyed in Brander 1995)[7]. The present paper contributes to this literature in the following dimensions: first, existing papers focus on policies affecting specific industries, while this paper studies subsidies to R&D affecting all industries symmetrically. Secondly, the literature has dealt with trade policies or production subsidies, while this is the first attempt at a quantitative study of strategic R&D subsidies. Finally, while existing models are limited to the two-industry framework with static innovation, this paper is more general in that there is a continuum of industries and the dynamic effects of innovation are studied.

2 Features of the data

In this section I introduce and discuss the data that will function both as a motivation for the paper and as empirical support for the quantitative analysis performed later on. First, I explore the evolution of countries' shares of R&D investment in the period 1973-95 at the industry level. My interest is in international competition among technological leaders, hence, I restrict my attention to the US, Japan, and 10 European countries: Germany, France, the U.K., Italy, Sweden, Denmark, Finland, Ireland, Spain, and the Netherlands. In the period 1973-1995, R&D expenditures in these countries represent between 95 and 98 percent of global R&D investment in manufacturing (OECD ANBERD Rev.2, 2005). I then build an index of countries neck-and-neckness in R&D, that is, I construct a measure of the share of industries where domestic and foreign countries effectively compete for innovation. This allows me to obtain a measure for the definition of competition used in the model. Finally, I report the estimates of the effective R&D subsidy from Bloom, Griffith, and Van Reenen (2002) for a

[7] Quantitative analysis of strategic policy interactions among countries is also analyzed in the literature on tax competition. See Persson and Tabellini (1995) for a survey. Mendoza and Tesar (2005) set up a neoclassical growth model to study the effects of the integration of European financial markets in the 1980s on strategic factor taxes competition among E.U. countries. The calibrated version of the model shows that Nash equilibrium taxes are very close to the ones observed in the data.

smaller but representative group of countries in the period 1979-1995.[8]

2.1 Global R&D investment shares and the competition index

I use OECD ANBERD data on R&D investment for 21 two and three-digit manufacturing industries[9]. Grouping together the 10 European countries, figure 1 reports sectorial average R&D investment shares for the US, Japan, and Europe. The figure shows that, while European countries as a whole kept a fairly constant share, the US share declined substantially, from 52 percent in 1973 to 39 percent in 1995, while Japan's share increased from 17 percent in 1973 to 28 percent in the same period.[10] This suggests that the US position as the global leader in R&D investment was increasingly challenged by Japanese firms, while Europe's share is fairly constant.

[FIGURE 1 ABOUT HERE]

Table 1 reports countries' shares in each industry in 1973 and 1995. The US share declines in all sectors except for Drugs and Medicines, Paper and Paper Product, and Textiles, while Japan's share shows a substantial increase in all sectors but Paper and Paper Products. Japan's share scores record increases in the most innovative industries[11]: in Electrical Machineries the share rises from 16.6 in 1973 to 43.2 percent (a 160 percent increase), in Office and Computing Machineries from about 6 to about 30 percent (a 368 percent increase), and in Radio, TV and Communication Equipment from 13 to 25 percent (a 95 percent increase). Europe's share shows large increases in Wood (185 percent increase) and in Other Transportation Equipment (147 percent increase), and a mix of gains and losses in all other sectors, including the medium-tech and high-tech industries.

[TABLE 1 ABOUT HERE]

A preliminary measure of neck-and-neckness in the global competition for innovation can be obtained looking at the number of industries in which the US share is below a threshold representing a possible dominant position in the market. In 1973, only 8 out of 21 manufacturing

[8] Unfortunately, subsidy data do not cover the early 1970s; to date, Bloom et al. estimates represent the sole coherent set of estimates for effective subsidies for a sufficiently large group of OECD countries.

[9] For the remaining three sectors data are no available for all years and/or countries.

[10] Similar results are obtained with the weighted average, where sectors' shares of total R&D are used as weights. The U.S. weighted share, for instance, decreases from 57 percent in 1973 to 44 percent in 1995.

[11] The OECD classifies sectors in high-tech, medium high-tech, medium low-tech, and low-tech according to their R&D intensity (see Hatzichronoglou, 1997). High-tech and medium-high-tech industries represent 77 percent of total manufacturing R&D in the period considered.

sectors recorded a US share of less than 50 percent, while in 1995 this number doubled. When we consider the number of sectors where the US share was below 40 percent of the total, we obtain a similar picture: 6 industries in 1973, rising to 13 in 1995. Finally, if we choose the threshold according to which global shares are distributed equally between the US, Japan, and Europe, we see that US share is below the 33 percent threshold only in 2 industries in 1973 and in 9 in 1995.

A more accurate measure of neck-and-neckness can be constructed as follows: for each year, in the period 1973-95, I consider a sector *competitive* if the US share of total R&D investment in that sector is smaller than a competitive threshold (CT henceforth). The measure of the competitive set of industries, that I call $\overline{\omega}$, is the share of sectors with US R&D investment share below CT. The share is computed for different threshold values in the plausible set $CT \in (0.35, 0.55)$, and the final index is chosen taking the average across thresholds.[12]

[FIGURE 2 ABOUT HERE]

Figure 2 shows the measures of $\overline{\omega}$ obtained using the bottom threshold $CT = 0.35$ and the top threshold $CT = 0.55$; it also shows the average $\overline{\omega}$, which is computed taking the mean of all the $\overline{\omega}s$ obtained at each threshold levels in the set $CT \in (0.35, 0.55)$. All measures show an increasing trend; the average $\overline{\omega}$, which will be used in the calibration exercise, increases from 0.3 (30 percent of the sectors are competitive) in 1973 to 0.68 in 1995. Using the average index allows me to deal with the problem of sensitivity to small changes that fixing one specific threshold might produce.[13]

2.2 R&D subsidies

Next, I compute the R&D subsidy produced by tax policies in the US, Japan and some European countries using Bloom, Griffith, and Van Reenen (2002)'s corporate tax data. The data take into account the different tax and tax credit systems used in each country, and measure the

[12] This is the interesting range to study because from figure 1 we see that the average US R&D share is never above 0.55 and below 0.35.

[13] I checked the robusteness of this procedure by choosing the threshold level that maximizes the correlation between my measure of geographical R&D distribution $\overline{\omega}$ and other standard measures of geographical concentration. More precisely, I chose CT^* such that

$$CT^* = \underset{CT \in (0.35, 0.55)}{\arg\max} \left\{ cr(\overline{\omega}(CT), Gin) + cr(\overline{\omega}(CT), Hr) + cr(\overline{\omega}(CT), Thei) + cr(\overline{\omega}(CT), Cv) \right\},$$

where $cr(\overline{\omega}(CT), .)$ represent the correlation between my index computed at the threshold CT and the Gini coefficient, the Herfindhal index, the Theil index and the coefficient of variation. The resulting threshold is $CT^* = 0.5$ and the resulting evolution of $\overline{\omega}$ is similar to the one obtained above: competitive sectors are 38 percent of the total in 1973, rising to 76 percent in 1995.

reduction in the cost of \$1 of R&D investment produced by the tax system. The tax subsidy is the sum of depreciation allowances for R&D investment and of tax credits specifically aimed at reducing the cost of R&D. In all countries in the data there are depreciation allowances for R&D, and in most of the countries R&D costs are fully expensed; that is, depreciation allowances imply a complete write-off of R&D costs for tax purposes. Specific R&D tax credits, instead, are active in only a few countries.

The subsidy rate is computed following the procedure in Bloom et al. (2002) and it is aimed at obtaining a measure of the subsidy consistent with that in the model: let v be the before-tax present value of the marginal investment in R&D, τ_π be the corporate tax rate, a_d be depreciation allowances, and a_c be the specific tax credit rate. Equalizing the marginal benefits and costs of one additional unit of R&D investment, we obtain

$$v(1-\tau_\pi) = (1 - a_d - a_c)\,.$$

Assuming full expensing, that is setting $a_d = \tau_\pi$, and rearranging yields

$$v = 1 - \frac{a_c}{1-\tau_\pi}.$$

The subsidy to R&D is $s = (a_c/1-\tau_\pi)$ and represents the reduction in the unit cost of research produced by the tax system. This computation of the R&D subsidy follows the standard procedure used in OECD (2005) to compare the generosity of tax treatment for R&D in different countries. More precisely, the standard tax subsidy is computed as $1 - B\ index$, where $B\ index = (1-a_d-a_c) \,/\, (1-\tau_\pi)$; assuming $a_d = \tau_\pi$, it is easy to see that $s = 1 - B\ index$. This synthetic measure of subsidies has the drawback of not allowing for the distinction between depreciation allowances and tax credit. A more relevant problem with this measure is that it includes both the effects of changes in corporate tax rates and in the R&D tax credit.[14] In order to deal with both issues, I use $s = a_c$ as the subsidy rate, thus accounting only for the presence and effectiveness of R&D tax credits.[15] Figure 2 below reports the subsidy obtained from this calculation.

[FIGURE 2 ABOUT HERE]

The differences among countries are mainly due to the presence and effectiveness of a specific tax credit for R&D. In fact, we can see that a sudden increase in US subsidies takes place with

[14] This is also problematic because in the model there are no corporate taxes.

[15] For the U.S. this leads to subsidy levels close to those estimated in Hall (1993), who isolated the effect of the R&D tax credit on the cost of innovation.

the introduction of the Research and Experimentation Tax Credit on incremental R&D in 1981 and with the revision of the base defining incremental R&D in 1990;[16] and in Spain with the introduction of a tax credit for all new fixed assets in 1989. In Japan there is a fixed tax credit of limited effectiveness for the period considered. In the rest of the countries there are no special tax provisions or credits given on R&D expenditures, and the positive and fairly constant subsidy rates are produced by tax credits common to all assets.[17] The key feature emerging from figure 2 is the increase in the US R&D subsidy from 6 percent in 1979 to 18 percent in 1991, remaining constant in the following years.

3 The model

3.1 Households

Consider a two-country economy in which population, preferences, and technologies are identical in both countries. Each household is endowed with a unit of labor time whose supply generates no disutility. Dropping country indexes for notational simplicity, households are modelled as dynastic families that maximize intertemporal utility

$$U = \int_0^{\infty} N(0) e^{-(\rho - n)t} \log u(t) dt, \tag{1}$$

where population is specified according to $N(t) = N(0)e^{nt}$, with initial population $N(0)$ which I normalize to 1, and a constant growth rate n. The rate of time preference is ρ, with $\rho > n$. The utility per person $u(t)$ is given by

$$\log u(t) \equiv \int_0^1 \log \left[\sum_{j=0}^{j^{\max}(\omega,t)} \lambda^{j(\omega,t)} q(j,\omega,t) \right] d\omega, \tag{2}$$

where $q(j,\omega,t)$ is the per-person flow of good ω, of quality $j \in \{0,1,2,...\}$, 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. A new vintage of 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.

At each point in time households choose the quantity purchased of each good $q(j,\omega,t)$ in order to maximize (2) subject to the constraint

[16] Only "incremental" R&D is eligible for the U.S. R&D tax credit: incremental means above the level of the previous year in 1981, and in the following years the increase was measured over the average R&D in the previous three years. In 1990 the base was defined as the average of the last three years of the R&D-sales ratio.

[17] See Bloom et al. (2002) for an extensive description of tax systems in these countries.

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

where $c(t)$ is expenditure per person at time t. The 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 product lines and by purchasing in each line only the product with the lowest price per unit of quality[18]. Hence, the household's demand for each product is:

$$q(j,\omega,t) = \frac{c(t)}{p(j,\omega,t)} \quad \text{for } j = j^{\max}(\omega,t) \text{ and is zero otherwise.} \tag{3}$$

Given the optimal allocation of expenditures across different product lines at a given moment t in (3), the intertemporal optimization problem is equivalent to

$$\max \int_0^\infty e^{-(\rho-n)t} \log c(t) dt,$$

subject to the intertemporal budget constraint, $\dot{a}(t) = w(t) + (r(t) - n)a(t) - c(t) - \tau$, where $a(t)$ are assets per-capita, and τ is a per-capita lump-sum tax. The solution to this problem is represented by the Euler Equation

$$\frac{\dot{c}(t)}{c(t)} = r(t) - \rho, \tag{4}$$

and the transversality condition,

$$\lim_{t\to\infty} a(t) \exp\left[-\int_0^t (r(z) - n) dz \right] = 0 \tag{5}$$

3.2 Product market

In each country, firms can hire workers to produce any consumption good $\omega \in [0,1]$ under a constant return-to-scale 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. Due to the Arrow effect, in each industry only followers invest in R&D to discover the new top quality of a

[18] I assume that if there are two goods with the same quality-adjusted price, consumers will buy only the good with higher quality.

good.[19] Successful innovators attain the market leadership and earn monopoly profits; patents expire when further innovation occurs in the industry.

I assume that technology is mobile, firms own it but can use it everywhere. It follows that multinational companies can establish subsidiaries in the country with lower wage, thus equalizing wages in equilibrium, $w^D = w^F = w$. Assuming away wage differences restricts the analysis to the effects of international competition on profits. I assume the wage to be the numeraire, $w = 1$.

In each industry there is Bertrand competition among firms. Followers can produce goods one quality ladder below the leader at the price of one, the lowest price they can charge to cover their costs. The leader can obtain a profit $\pi(p) = (p-1)\, c(t)N(t)/p$, if $p \leq \lambda$ and zero otherwise. Hence, firms' profits are maximized by charging the limit price λ. It follows that the price $p^K(\omega, t)$ of every top quality good is:

$$p^K(\omega, t) = p(t) = \lambda, \text{ for all } \omega \in [0,1],\ K = D, F, \text{ and } t \geq 0, \tag{6}$$

From the static consumer demand (3), we can immediately conclude that the demand for each product ω is:

$$\frac{(c^D(t) + c^F(t))N(t)}{\lambda} = q(\omega, t) = q(t), \tag{7}$$

where $c^D(t)$ and $c^F(t)$ are domestic and foreign expenditures at time t. The above equation says that, in equilibrium, the supply and demand of every consumption good coincides. Since wages and prices are equal in both countries, the stream of monopoly profits accruing to the monopolist producing the state-of-the-art quality product in country $K = D, F$ will be equal to

$$\pi^K(\omega, t) = \pi(\omega, t) = q(\omega, t)\,[p(\omega, t) - 1] = (c^D(t) + c^F(t))N(t)\,(1 - 1/\lambda) \text{ for all industries } \omega. \tag{8}$$

3.3 R&D races

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

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

[19] An incumbent considering investing in R&D needs to subtract its present monopoly profits from the payoff of successful innovation. It follows that the value of innovation for the followers is higher than for the leader.

$$I_i^K(\omega,t) = \frac{A l_i^K(\omega,t)\left(\frac{L^K(\omega,t)}{X(\omega,t)}\right)^{-\alpha}}{X(\omega,t)}, \tag{9}$$

where $\alpha > 0$ and $X(\omega,t) > 0$ measures the degree of complexity in the invention of the next quality product in industry ω, $L^K(\omega,t) = \sum_i l_i^K(\omega,t)$ is the total labor used by R&D firms, and $I^K(\omega,t) = \sum_i I_i^K(\omega,t)$ is the total arrival rate of innovation in country K, industry ω. 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. The country-specific nature of decreasing returns in R&D can be motivated by the presence of fixed costs, such as lab equipment, by institutional and/or cultural differences, and finally by a given supply of workers with heterogeneous research abilities.[20] There is strong empirical evidence on the nonlinearity of the relation between innovation activity of a country (measured using patent data) and its R&D investment. Working with a large sample of US firm-level data, Hall et al. (1986) find an elasticity of patents to R&D of 0.5. The evidence surveyed in Kortum (1993) suggests point estimates for the patent/R&D elasticity in the range $0.1 - 0.6$. More recently, Blundell et al. (2002), find a long-run elasticity of 0.5.

The technological complexity index $X(\omega,t)$ is introduced to avoid the counterfactual prediction of the first generation R&D-driven growth models that the size of a country affects its steady-state growth (see Jones, 1995). Following Dinopoulos and Segerstrom (1999) I eliminate scale effects assuming $X(\omega,t) = 2\kappa N(t)$, with $\kappa > 0$, thereby formalizing the idea that it is more difficult to introduce a new product into a more crowded global market.[21] This specification of R&D technology allows one to remove the scale effects while preserving a fundamental prediction of the first generation models: policy measures have permanent effects on long-run growth.

Governments subsidize R&D expenditures at the rate s^K, financed with a lump-sum tax τ. Each R&D firm chooses l_i^K in order to maximize its expected discounted profits. Using R&D technology (9), free-entry in R&D yields

[20] While fixed costs and institutional differences can motivate the country-specific R&D externality in the model; the motivation based on heterogeneous workers requires the removal of the assumption of global labor markets. In a similar setup, but with local labor markets, Eaton and Kortum (1999) use the workers' heterogeneity motivation for decreasing returns in R&D at the country level: as investment in research increases in a country, workers of lower ability will be used and R&D productivity will decline.

[21] This specification is a reduced form version of the solution to the scale effects problem based on the assumption that aggregate R&D becomes more difficult over time as it is spread over more varieties (see e.g. Howitt, 1999). In the simplified version of this approach population growth mimics the expansion in the variety of goods.

$$v^K(\omega,t)\left(\frac{I(\omega,t)}{A}\right)^{\frac{-\alpha}{1-\alpha}}\left(\frac{A}{X(\omega,t)}\right)\leq(1-s^K),\text{ with equality if } I(\omega,t)>0, \tag{10}$$

where $v^K(\omega,t)$ is the value of the leading firm.

Finally, innovation arrival rates determine the evolution of the average quality of goods in the economy:

$$Q(t)=\ln\lambda\int_0^1\left[\int_0^t I(\omega,\tau)d\tau\right]d\omega, \tag{11}$$

obtained from the preference structure specified in (2).

3.4 The stock market

The value of a monopolistic firm is determined on the stock market. An efficient stock market channels savings into firms investing in R&D and in equilibrium equates the expected rate of return from holding a stock of a quality leader to the return on a riskless asset $r(t)$. In a time interval of length dt, holding a stock of a quality leader pays dividends $\pi(\omega,t)\,dt$. With probability $I(\omega,t)dt$ an innovation occurs and the shareholder loses the entire value of the firm. With probability $1-I(\omega,t)dt$ no innovation occurs and the leader benefits from the appreciation in the value of the firm $\dot{v}(\omega,t)dt$. Efficiency in financial markets implies that $\pi(\omega,t)\,dt+(1-I(\omega,t)dt)\;\dot{v}(\omega,t)dt-I(\omega,t)dtv(\omega,t)=v(\omega,t)r(t)dt$. Taking limits as dt tends to zero, the market value of a firm producing good ω in country $K=D,F$ is

$$v^K(\omega,t)=\frac{\pi^K(\omega,t)}{r(t)+I(\omega,t)-\frac{\dot{v}^K(\omega,t)}{v^K(\omega,t)}}. \tag{12}$$

Using (12), the R&D technology (9) and the profit equation (8), the free-entry condition (10) becomes

$$\frac{(c^D(t)+c^F(t))N(t)\,(1-1/\lambda)}{r(t)+I(\omega,t)-\frac{\dot{v}(\omega,t)}{v(\omega,t)}}\left(\frac{A}{X(\omega,t)}\right)\left(\frac{I^K\omega,t)}{A}\right)^{\frac{-\alpha}{1-\alpha}}=(1-s^K). \tag{13}$$

3.5 International competition

Next, I introduce the concept of international competition for innovation and specify the geographical structure of $I(\omega,t)$. 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 $\overline{\omega}\in(0,1)$ be this set of industries, then the composition of worldwide innovation will be the following:

$$I(\omega,t) = I_c^D(\omega,t) + I^F(\omega,t) \qquad \text{for } \omega \leq \overline{\omega}$$
$$I(\omega,t) = I_m^D(\omega,t) \qquad \text{for } \omega > \overline{\omega} \tag{14}$$

where $\kappa > 0$, $I_c^D(\omega,t)$ and $I_m^D(\omega,t)$ are country D's innovation in the competitive and in the non-competitive sectors respectively, and $I^F(\omega,t)$ is innovation in country F.

Since goods are symmetric (same technologies, both in production and R&D, and enter symmetrically in the utility function), the only source of structural asymmetry between the two countries is produced by the partition of sectors between competitive and non-competitive. Therefore we can write, $I_m^D(\omega,t) = I_m^D(t)$ for all $\omega > \overline{\omega}$, $I_c^D(\omega,t) = I_c^D(t)$ and $I^F(\omega,t) = I^F(t)$ for all $\omega \leq \overline{\omega}$. The other source of asymmetry is institutional: countries can potentially differ in R&D subsidies.

3.6 Market clearing conditions

The unit cost of production for every good implies that total production of goods in a country is equal to total labor used for manufacturing in that country. Total manufacturing labor is given by labor supply minus 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:

$$\left(\frac{c^D(t)+c^F(t)}{\lambda}\right) = 2 - 2\kappa\left\{\overline{\omega}\left[\left(\frac{I_c^D(t)}{A}\right)^{\frac{1}{1-\alpha}} + \left(\frac{I^F(t)}{A}\right)^{\frac{1}{1-\alpha}}\right] + (1-\overline{\omega})\left(\frac{I_m^D(t)}{A}\right)^{\frac{1}{1-\alpha}}\right\}, \tag{15}$$

where I have used $X(\omega,t)/N(t) = 2\kappa$. The left-hand side is total labor allocated to production and the right-hand side is total labor minus labor resources allocated to research.

Finally, I consider the resource (budget) constraint of the two countries: in each country total expenditures plus savings (investment in R&D) must equal national income, wages plus profits.

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

$$2\kappa\left[\overline{\omega}\left(\frac{I^F(t)}{A}\right)^{\frac{1}{1-\alpha}}\right] + c^F(t) = 1 + (c^D(t)+c^F(t))\left(\frac{\lambda-1}{\lambda}\right)\overline{\omega}\,(1-\beta(t))\,. \tag{17}$$

where $\beta(t)$ is the fraction of competitive industries with a domestic leader. Notice that R&D investment is the wage bill of R&D workers and that the appropriation of global monopoly rents works as follows: in the non-competitive share of industries $1-\overline{\omega}$, all global profits are appropriated by domestic firms, while in the competitive sectors $\overline{\omega}$, domestic firms obtain profits only in a fraction $\beta(t)$ of them.[22] The structure of global innovation activity specified above implies that $\beta(t)$ evolves according to the following law of motion

$$\dot{\beta}(t) = (1-\beta(t))\, I_c^D(t) - \beta(t) I^F(t), \tag{18}$$

where the first term is the flow into β-type industries and the second term is the flow out.

4 Equilibrium

An equilibrium for this economy is represented by time paths of per-capita expenditures and innovation rates $\left[c^K(t), I^K(t)\right]_{t=0,\ K=D,F}^{\infty}$ that satisfy (13), (14), (16) and (17)[23]; paths for prices and quantities of top-quality goods $[p(t), q(t)]_{t=0}^{\infty}$ given by (6) and (7); and paths for the average quality of goods, the interest rate, the value of the monopolistic firm, and the share of competitive industries with domestic leader $\left[Q(t), r(t), v^K(t), \beta(t)\right]_{t=0,\ K=D,F}^{\infty}$ satisfying (4), (5), (11)-(14), and (18).

A balanced growth path for this economy is an equilibrium in which per-capita variables are constant, the share of industries with domestic leaders is constant, and the average quality of goods grows at a constant rate. Using (10) , (9), and $X(\omega,t) = 2\kappa N(t)$, it is easy to show that in steady state $\dot{v}^K(t)/v^K(t) = \dot{X}(t)/X(t) = n$, for $K = D$, F, and, since per-capita expenditure are constant in steady state, the Euler equation (4) yields $r(t) = \rho$. It follows that

[22] I assume complete "home bias" in asset ownership, in that domestic firms are owned domestically and foreign firms are foreign-owned. This assumption is supported by empirical evidence. 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 percent in the U.S. and Japan and around 80 percent in the UK and Germany. I have also performed the quantitative exercises in the next sections with partial home biases calibrated at 90 and 95 percent and, while the quantitative results are not dramatically altered, the model becomes less tractable.

[23] The market clearing condition (15) can be obtained as a combination of (16) and (17).

the no-arbitrage and free entry conditions in (13) become:

$$\begin{aligned}
\frac{\left(c^D+c^F\right)\left(\frac{\lambda-1}{\lambda}\right)}{\rho+I_c^D+I^F-n}\frac{A}{2\kappa}\left(\frac{I^F}{A}\right)^{\frac{-\alpha}{1-\alpha}} &= \left(1-s^F\right), \text{ for } \omega\leq\overline{\omega} \\
\frac{\left(c^D+c^F\right)\left(\frac{\lambda-1}{\lambda}\right)}{\rho+I_c^D+I^F-n}\frac{A}{2\kappa}\left(\frac{I_c^D}{A}\right)^{\frac{-\alpha}{1-\alpha}} &= \left(1-s^D\right), \text{ for } \omega\leq\overline{\omega} \\
\frac{\left(c^D+c^F\right)\left(\frac{\lambda-1}{\lambda}\right)}{\rho+I_m^D-n}\frac{A}{2\kappa}\left(\frac{I_m^D}{A}\right)^{\frac{-\alpha}{1-\alpha}} &= \left(1-s^D\right), \text{ for } \omega>\overline{\omega}\ .
\end{aligned} \tag{19}$$

The steady-state version of (16), (17) can be obtained by simply dropping the time index and exploiting the fact that in steady state (18) implies $\beta=I_c^D/\left(I_c^D+I^F\right)$. We have five equations, three in (19), plus (16) and (17), and five unknowns $\left\{c^D,c^F,I_m^D,I_c^D,I^F\right\}$.

Before solving the equilibrium system, I complete the description of the model by deriving the long-run growth rate. In the present framework with quality-improving goods, growth is interpreted as the increase over time of the representative consumer's utility level. The utility function (2) can be written as

$$\ln u^K(t)=\ln\left(\frac{c^K(t)}{\lambda}\right)+\ln\int_0^1\lambda^{j(\omega,t)}d\omega=\ln\left(\frac{c^K(t)}{\lambda}\right)+Q(t).$$

Since trade is free, consumers from both countries benefit from quality-improving innovation performed worldwide. Considering (14) and that investment in R&D is constant in the steady state, the average quality of goods in both countries is equal to $Q(t)=\ln\lambda\int_0^1\left[\int_0^t I(\omega,\tau)d\tau\right]d\omega=\ln\lambda\left[\overline{\omega}t\left(I_c^D+I^F\right)+\left(1-\overline{\omega}\right)tI_m^D\right]$. Differentiating $\ln u^K(t)$ with respect to t we obtain the growth rate

$$g=\frac{\dot{u}}{u}=\frac{\dot{Q}(t)}{Q(t)}=\left[\bar{\omega}(I_c^D+I^F)+\left(1-\bar{\omega}\right)I_m^D\right]\ln\lambda. \tag{20}$$

5 Foreign competition and domestic welfare

In this section I present the analytical results of the paper, namely I prove the existence of the steady-state equilibrium for an economy with symmetric subsidies and I study the effects of an increase in foreign competition on domestic welfare. Symmetric subsidies allow me to isolate the effects of competition on welfare and derive them analytically. The exercise is performed in steady state, the transitional dynamics is discussed in the next section.

With symmetric subsidies (19) implies $I_c^D = I^F = I_c$; substituting this into (19) and the steady-state versions of (16) and (17) we obtain a system of four equations and four unknowns, I_c, I_m^D, c^D, c^F. Summing up the new versions of (16) and (17), solving for $\left(c^D + c^F\right)$ and substituting into the new version of (19), the equilibrium system can be summarized by the following equations:[24]

$$\left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}} \left(\rho + I_m^D - n\right) = \left(\frac{I_c}{A}\right)^{\frac{1}{1-\alpha}} \left(\rho + 2I_c - n\right) \tag{I}$$

$$\left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}} = \frac{1}{\kappa(1-\overline{\omega})} - \left[\frac{\rho + 2I_c - n}{A\left(\lambda - 1\right)\left(1-\overline{\omega}\right)}\left(\frac{I_c}{A}\right)^{\frac{\alpha}{1-\alpha}} + \frac{2\overline{\omega}}{\left(1-\overline{\omega}\right)}\left(\frac{I_c}{A}\right)^{\frac{1}{1-\alpha}}\right]. \tag{II}$$

Proposition 1 *In an economy with symmetric subsidies, a steady-state equilibrium exists and is unique.*

Proof. See appendix. ■

Intuitively, since $\rho > n$, equation (I) is upward sloping and equation (II) is downward sloping in the space $\left(I_m^D, I_c\right)$. The intersection of the two curves determines the equilibrium level of I_m^D and I_c, as shown in figure 4. These equilibrium values can be substituted back into (19) to obtain the balanced growth path of c^D and c^F.

[FIGURE 4 ABOUT HERE]

Using (1) and (20), the effects of increases in foreign competition $\overline{\omega}$ on domestic welfare in steady state can be computed as follows:

$$\frac{dU^D(0)}{d\overline{\omega}} = \frac{d}{d\overline{\omega}}\int_0^\infty e^{-(\rho-n)t}\left[\ln\left(\frac{c^D(t)}{\lambda}\right) + Q(t)\right]dt = \left(\frac{1}{\rho - n}\right)\left[\frac{d\ln\left(c^D/\lambda\right)}{d\overline{\omega}} + \frac{1}{\rho - n}\frac{dg}{d\overline{\omega}}\right]. \tag{21}$$

Thus, the welfare effects of competition are pinned down by the effects of an increase in $\overline{\omega}$ on growth and on domestic consumption.

Proposition 2 *Increases in foreign competition have two counteracting effects on the steady-state growth rate: the efficiency effect that increases growth, and the obsolescence effect which reduces innovation arrival rates per-sector, thereby slowing down growth. The efficiency effect dominates and competition has a positive overall effect on growth*

[24] To keep the algebra simple I assume $s^D = s^F = 0$, results do not change under positive symmetric subsidies but the derivation is more cumbersome and does not add much to the intuition.

Proof. See appendix. ■

The *efficiency* effect is produced by the R&D externality α in (9). The competitive sectors can accommodate a larger total investment in R&D: the country-level concavity of the R&D technology implies that in each industry, two researchers from two different countries are more productive than two researchers from the same country. Thus, a higher $\overline{\omega}$ leads to a larger number of sectors with higher arrival rate of innovation and, consequently, to higher growth. Differentiating the growth equation (20) with respect to $\overline{\omega}$ we can see how this effect operates on the growth rate:

$$\frac{\partial g}{\partial \overline{\omega}} = \left\{ \underbrace{\left(2I_c - I_m^D\right)}_{\texttt{efficiency}\text{ effect}} + \underbrace{\left[2\overline{\omega}\frac{\partial I_c}{\partial \overline{\omega}} + (1-\overline{\omega})\frac{\partial I_m^D}{\partial \overline{\omega}}\right]}_{\texttt{obsolescence}\text{ effect}} \right\} \tag{22}$$

The source of the efficiency effect is the difference between innovation intensity in competitive and non-competitive sectors. This effect can be offset by a negative impact of competition on the sectorial levels of innovation I_c and I_m^D. As we can see in figure 4, an increase in $\overline{\omega}$ raises the intercept of $II(\overline{\omega})$, thus raising I_c and I_m^D, but it increases the slope of $II(\overline{\omega})$ as well, thereby reducing I_c and I_m^D. If the latter force dominates, there will be a negative effect of competition on innovation per-sector. This is the case drawn in the figure and, as shown in the appendix, it is possible to prove that $\partial I_c/\partial\overline{\omega}$ and $\partial I_m^D/\partial\overline{\omega}$ are always negative. Intuitively, foreign R&D presence in more sectors tends, in equilibrium, to render innovation obsolete, thereby reducing the incentives to innovate: this is the *obsolescence* effect. In the appendix, I show that the obsolescence effect cannot completely offset the positive efficiency effect, which implies that the overall *growth* effect of competition is positive.[25] Since growth increases welfare through improvements in the quality of goods, we can conclude that competition has a positive effect on welfare through the growth channel.

As foreign R&D firms enter some industries previously dominated by domestic firms, with a probability proportional to their research effort they will discover the next top-quality good and obtain global market leadership. This *business-stealing* effect reduces domestic aggregate profits because foreign firms appropriate a bigger share of the world market. Since, by assumption, the labor market is not affected by shifts in the global ownership distribution of firms, only the profit component of domestic income declines.

Proposition 3 *An increase in competition $\overline{\omega}$ shifts domestic profits abroad, thus reducing do-*

[25] In the numerical solution, we will see that the negative effect of competition on I_c and I_m^D is substantially of second order.

mestic income, consumption and welfare.

Proof. See appendix. ■

We can conclude that increases in competition have a positive growth effect and a negative business-stealing effect on welfare, and the overall effect depends their relative strengths In the quantitative analysis below I explore the set of plausible outcomes.

6 Transitional dynamics

A simple way to look at the dynamic properties of the model is to set $\alpha = 0$ in the symmetric economy studied above. This simplifying assumptions yields $I_c^D(t) = I^F(t) \equiv I(t)/2$ and $I_c^D(t) + I^F(t) = I_m^D(t) = I(t)$. The innovation rate in this economy is a jump variable and the share of competitive sectors with domestic leader $\beta(t)$ is the state variable. After some algebra the equilibrium dynamic system boils down to two equations:

$$\dot{\beta}(t) = (1-2\beta(t))\frac{1}{2}\left\{\frac{1+2(\lambda-1)(1-\overline{\omega}+\overline{\omega}\beta(t))-c_t^D(t)}{\frac{2\kappa}{A}\left[(\lambda-1)(1-\overline{\omega}+\overline{\omega}\beta(t))+(1-\frac{\overline{\omega}}{2})\right]}\right\}, \tag{23}$$

$$\frac{\dot{c}^D(t)}{c^D(t)} = \Psi - \left\{\frac{\lambda\left[1+2(\lambda-1)(1-\overline{\omega}+\overline{\omega}\beta(t))-c_t^D(t)\right]}{\frac{2\kappa}{A}\left[(\lambda-1)(1-\overline{\omega}+\overline{\omega}\beta(t))+(1-\frac{\overline{\omega}}{2})\right]}\right\}, \tag{24}$$

where $\Psi = (A/\kappa)(\lambda-1)-(\rho-n) > 0$. In the appendix I linearize around the steady state and show that

$$\frac{d\beta(t)}{d\overline{\omega}} = \left(1-e^{\gamma t}\right)\frac{d\beta}{d\overline{\omega}} + (\beta(0)-\beta)\frac{d\gamma}{d\overline{\omega}}te^{\gamma t} \tag{25}$$

where β and c^D are the steady-state values of the share of competitive sectors with domestic leaders and consumption, and $\gamma < 0$ is the stable eigenvalue. Since $I_c^D(t) = I^F(t)$, $\beta = 1/2$ and $d\beta/d\overline{\omega} = 0$. In equation (25) $\beta(0) > \beta$ because at the time of foreign entry domestic firms have the leadership in newly competitive sectors. When $\overline{\omega}$ increases, provided that $d\gamma/d\overline{\omega} > 0$, $\beta(t)$ is higher than its steady-state level and, as time goes by, it returns to the stationary level.[26] This slow transition in the share of competitive sectors led by the domestic country produces a slow transition in domestic income and welfare. Therefore the business-stealing effect of competition affects domestic welfare negatively, as shown in the comparative statics exercise of proposition 3, but its full effects take place slowly.

This simplified model provides the intuition for the dynamic effects of a change in the relative R&D subsidy as well. Once we introduce subsidies in the model, their relative value, s^D/s^F,

[26] As shown in the appendix $d\gamma/d\overline{\omega} = 0$ only in the case of the linear R&D technology, while in the general case $\alpha > 0$, $d\gamma/d\overline{\omega} > 0$.

affects the relative incentive to innovate in the two countries, thus affecting the steady-state share of competitive sectors with domestic leader $\beta = I_c^D(t) / \left(I_c^D(t) + I^F(t)\right)$. It follows that a shock in the relative subsidy triggers a slow transition in $\beta(t)$.

7 Quantitative analysis

I this section calibrate the full model, solve it numerically, and perform the following experiments: first, I measure the relative strength of the growth and business-stealing effects of competition on welfare. Secondly, I compute the optimal domestic subsidy and analyze the effects of changes in competition on its level.

7.1 Calibration

I calibrate the parameters of the model to match some basic long-run empirical regularities for the US economy. I need to calibrate six parameters: four of them, ρ, λ, n, and α are calibrated using benchmarks that are standard in the growth literature, while the others, A and k, are calibrated internally so that the model's steady-state matches salient facts of the US 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 0.05, slightly below the average real return on the stock market for the past century of 0.07 estimated in Mehra and Prescott (2003).[27] 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 a 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 in R&D at the country level have been estimated to be between 0.4 and 0.9 (Hall et al., 1986, Kortum, 1993, and Blundell et al., 2002).[28] I choose a value in this interval

[27] Jones and Williams (2000) suggest that the interest rate in R&D-driven growth models is also the equilibrium rate of return to R&D, and so it cannot be simply calibrated to the risk-free rate on treasury bills - which is around 1%. They, in fact, calibrate their R&D-driven growth model with interest rates ranging from 0.04 to 0.14.

[28] Empirical estimates of decreasing returns in R&D are usually obtained using a specification of the R&D technology slightly different from the one used in this paper. The general form for the technology used is , $I = AL_R^{\beta}$, where I is the innovation intensity, L_R is the research labor, and $0 < \beta < 1$. Estimates for β suggest values between 0.1 and 0.6 (see e.g. Kortum,1993). Using technology (9) the arrival rate of innovation in sector ω can be expressed as follows

$$I^K(\omega, t) = A \left(L^K(\omega, t) / X(\omega, t)\right)^{(1-\alpha)}.$$

Thus, estimates of β in the interval $(0.1, 0.6)$ using the general technology above, roughly traslates into values and set the R&D externality coefficient α to 0.4. Finally, I have set the two subsidies to the 1979 values estimated in Bloom et al. (2002), that is $s^D = s^F = 0.06$. I have also used the 1979 value for international competition shown in figure 2, $\overline{\omega} = 0.42$.

Parameters calibrated "internally". I simultaneously choose A and κ so that the numerical steady-state solution of the model matches a set of long-run stylized facts. Since the paper's focus is on R&D investment, it seems natural to use data from Corrado, Hulten and Sichel (2006, CHS henceforth), where US national account data have been revised to introduce investment in intangible capital, including R&D. Moreover, since there is no tangible capital in the model, all statistics used in the calibration need to be adapted to the model economy. More precisely, the two statistics targeted in the calibration, the growth rate of labor productivity and the R&D ratio to GDP, are obtained by subtracting investment in tangible capital from total income in the data. After this adjustment, CHS data report an average growth in labor productivity of 1.9% a year in the period 1973-2003. Since in the model all investment is in R&D, the targeted statistics for the R&D ratio to GDP is the investment in intangible capital share of total income; after subtracting tangible capital this leads to an average of 13.5% over the period 1973-2003. The parameters calibrated internally have been found by minimizing the quadratic distance between the model and the two long-run statistics reported above. The resulting values are $A = 0.18$ and $\kappa = 0.43$.

[TABLE 2 ABOUT HERE]

Table 2 shows how well the model fits the US data at the initial date, 1979. The calibrated model fits the targeted as well as some relevant non-targeted statistics closely enough.[29]

7.2 Foreign competition and welfare

Calibrated parameters allow us to obtain quantitative expressions for (21) and compute the overall effect of competition on domestic welfare, for subsidies constant at their benchmark level $s^D = s^F = 0.06$. I focus on the steady-state, in appendix C I numerically simulate the dynamics of the model to a shock in $\overline{\omega}$ and show that qualitative results do not change and that

for α in the interval $(0.4, 0.9)$ with my specification of the R&D technology. It follows that $\alpha = 0.4$ is the lower bound of the empirical estimates; this is a conservative choice in that it allows the benchmark model to be as close as possible to the textbook case of linear technology. In the robustness analysis I will explore an exhaustive set of values for α.

[29] Table II shows all steady-state variables and their counterpart in the data: consumption as a share of GDP (data from BEA NIPA tables and CHS), R&D in competitive industries as a share of total U.S. R&D (OECD ANBERD), the labor share (CHS), and the two targeted statistics, the growth rate and U.S. R&D as a share of income (data described above).

the transition is sufficiently fast.[30] The first result shown in figure 5 is that when competition rises from its theoretical minimum value, $\overline{\omega} = 0$, to its theoretical maximum, $\overline{\omega} = 1$, domestic income decreases by 14.7 percent. This is the business-stealing effect of foreign entry.

[FIGURE 5 ABOUT HERE]

Second, the growth effect of competition is positive: going from a zero level of competition to $\overline{\omega} = 1$, growth increases from 1.6 to 2.2 percent (a 37 percent increase). Notice that, as shown analytically in proposition 2, the *obsolescence* effect reduces R&D investment in all types of industries, I_c^D, I_m^D, I^F, but the change is very small and the *efficiency* effect prevails, thus pushing the growth rate up. Thirdly, the welfare effect of competition depends on the relative strength of the two counteracting effects: the growth effect only partially offsets the business-stealing effect and the overall effect of competition on welfare is negative: increasing $\overline{\omega}$ from 0 to 1 leads to a welfare loss of 5.2 of quality-adjusted per-capita consumption.

[FIGURE 6 ABOUT HERE]

Figure 6 shows that these results are sufficiently robust to changes in the specification of parameters. Precisely, it shows how the results are affected by doubling and halving, one at a time, the parameters from their baseline calibration values. The results of the sensitivity analysis are discussed in appendix C.

7.3 Foreign competition and optimal R&D subsidies

Next, I use the calibrated model to compute the effect of foreign competition on the optimal domestic subsidy. Since I am interested in studying the effect of foreign competition on the domestic subsidy, I keep the foreign subsidy fixed at its average value in the period of analysis, that is $s^F = 0.68$.[31] I restrict the analysis to the steady state.[32]

The timing of the subsidy game is the following: at stage 1 the domestic government sets the subsidy; 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 a given level of the foreign subsidy, the domestic policy maker sets the subsidy according to the following best-response function:

[30] Appendix C is available upon request.

[31] In Impullitti (2007), I consider the full strategic policy game with both countries active in R&D subsidies and responding optimally to changes in competition.

[32] Introducing dynamic considerations in the optimal subsidy exercise complicates the analysis substantially, thus I stick to the steady-state comparison and discuss the key implications of the dynamics in appendix C.

$$s^D(\bar{s}^F;\bar{\omega}) = \arg\max\left\{W^D(s^D,\bar{s}^F;\bar{\omega})\right\}. \tag{26}$$

Figure 7 below shows that higher foreign competition increases the optimal domestic R&D subsidy.

[FIGURE 7 ABOUT HERE]

To grasp the economic mechanism we need to understand how changes in competition affect the marginal effects of subsidies on national welfare. For this purpose it is convenient to write the present value of domestic welfare as follows

$$W^D \equiv (\rho - n)U^D(0) = \ln\frac{c^D}{\lambda} + \frac{g}{\rho - n} = \ln\left[\frac{(1+\Pi^D) - R^D}{\lambda}\right] + G, \text{ for } K = D, F, \tag{27}$$

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

In quality ladder models of closed economies, innovation has two external effects on the optimal R&D subsidy: a *consumer-surplus* or growth effect and a *business-stealing* effect (see e.g. Grossman and Helpman 1991b, and Segerstrom, 1998). The consumer surplus effect 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. They also benefit from the new good 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 are a source of underinvestment in innovation.

Every time a firm innovates it drives another firm out of business; the appropriation of the incumbent firm's monopoly profits reduces aggregate profits and consumption, thereby reducing national welfare. This is the business-stealing effect and in (27) 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, thus leading to overinvestment in R&D.

The externality represented by α in technology (9) produces a third external effect of innovation: R&D investment by a national firm increases the sectorial level of research and reduces the productivity of other firms investing in that industry. This is the *resource constraint* effect 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 are also reduced, resulting in even lower consumption. Since firms do not take these effects into account, they produce another bias toward overinvestment. Both components affect welfare through the resource constraint: in the metric of the welfare function (27) they affect the total labor resources allocated to R&D, $R^D = \ln(L^D/\lambda)$, and total profits Π^D. Using (27) we can express the different marginal effects of the R&D subsidy on domestic welfare as follows:

$$\frac{\partial W^D}{\partial s^D} = \underbrace{\underbrace{\frac{\partial (R^D, \Pi^D)}{\partial s^D}}_{\substack{RC \\ (-)}} + \underbrace{\frac{\partial G}{\partial s^D}}_{\substack{CS \\ (+)}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{BS \\ (-)}}}_{\text{closed economy}} + \underbrace{\frac{\partial \Pi^D}{\partial s^D}}_{\substack{IBS \\ (+)}}, \tag{28}$$

where RC represents the resource constraint effect, CS the consumer surplus effect, BS the domestic business-stealing effect. 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.

In closed economies the policy maker sets the optimal subsidy balancing at the margin these three effects. Whether it is optimal to tax or subsidize R&D generally depends on the specification of parameters (see e.g. Segerstrom, 1998, and Jones and Williams, 2000). The novelty introduced by my two-country version of the model is to add a *strategic motive* for subsidies: in sectors led by a foreign quality leader, innovation by domestic firms drives foreign firms out of the market, shifting monopolistic rents to the domestic country. As it is the case for the domestic business-stealing analyzed above, this *international business-stealing* effect (IBS above) is not taken into account by domestic innovators, leading to underinvestment in R&D. It follows that the presence of foreign innovators produces an additional role for subsidies, that of stimulating innovation to protect domestic profits. In the welfare metric (27) this effect works through Π^D.

The main force driving the results in figure 7 is the strategic motive for subsidies: as international competition rises, the foreign rent-stealing threat becomes more relevant and triggers higher domestic subsidies. It is possible to see in equation (16) that the domestic policy maker has no rents to protect at $\overline{\omega} = 0$, while as the share of sectors exposed to international competition increases, the scope for a strategic use of subsidies broadens.

The country-specific negative R&D externality in (9) implies that competition affects the other motives for subsidies as well. By increasing the productivity of domestic R&D, competition improves both the resource constraint and the consumer surplus effect of home subsidies.

The country-level concavity of the R&D technology implies that research efficiency increases in newly-competitive sectors. Since this effect is external to the firm, the single domestic investor does not take it into account, and underinvestment in R&D increases. This channel works directly through the consumer surplus effect of subsidies. Similarly, competition raises the aggregate productivity of domestic research labor, and reduces the labor resources required to maintain the steady-state level of innovation. This reduces the overinvestment in innovation produced by the resource constraint effect.

Figure 7 shows an extensive robustness analysis of the effect of competition on the optimal subsidy. It shows how the results are affected by doubling and halving, one at the time, parameters λ, α, ρ, A, κ, and n from their baseline calibration values. This sensitivity analysis is only meant to show the robustness of the qualitative results to changes in each parameter. On the quantitative side, the effects shown here do not have to be taken at the face value because parameters A and κ have been calibrated internally[33]. The figure shows that the results are fairly robust. A detailed discussion of the sensitivity analysis can be found in appendix C.

Finally, in section 6 I showed that $\beta(t)$ has a transitional behavior when competition and/or the relative R&D subsidy change. It follows that both the business-stealing that triggers the strategic motive for subsidy, and the effects of an increase in domestic subsidy on welfare do not take place fully on impact, but slowly along the transition. Hence, along the transition to the steady state we can expect the optimal subsidy to lie below its steady-state level shown in figure 7.[34]

8 Foreign competition, welfare, and R&D subsidies in the US

Next, I apply the calibrated model to, first, quantify the welfare effects of the increase in foreign competition observed in the data shown in figure 2, keeping R&D subsidies in both countries constant at their initial (1979) level. Secondly, I quantify the welfare gains obtainable if the US had implemented an optimal R&D subsidy response to foreign competition in the period 1979-95. I compare domestic welfare under optimal subsidies with that under the actual subsidies

[33] For the model to produce values sufficiently close to the data, changes in each of the externally calibrated parameters would involve a re-calibration of A and κ. Thus, the standard procedure for robustness of changing one parameter at the time, without re-calibrating A and κ, affects the fit of the model obtained in table 2 and may yield implausible levels of the optimal subsidy. Nevertheless, this procedure allows me to single out the qualitative effect of each parameter; while re-calibrating A and κ any time one of the externally calibrated parameter changes would make the effect of each parameter harder to isolate.

[34] In appendix C I show that considering the transitional paths does not affect the qualitative results; and that the transition of the economy to both competition and subsidy shocks is sufficiently fast.

observed in the data, for each level of international competition.

In figure 2, we can see that competition increases from $\overline{\omega} = 0.42$ in 1979 to $\overline{\omega} = 0.68$ in 1995. According to the numerical results presented in figure 6 and 7, this change in competition produces an increase in the US growth rate from 1.86 to 2.02 percent (an 8 percent increase) and a decrease in US income of 3.7 percent. These two effects combine to an overall reduction in US welfare of 1.3 percent of quality-adjusted lifetime consumption in the 16-year period. Thus, we can conclude that although the positive growth effect of competition does not completely offset the business-stealing effect, it limits the negative overall effect of competition on welfare substantially.[35]

Next, I compute the difference between the optimal and the observed subsidy and its welfare implications, while setting the foreign subsidy at its average value in the period of analysis, $s^F = 0.68$. The welfare gains from the optimal subsidy is measured in terms of equivalent compensating variation of per-capita lifetime consumption. Table 3 below reports welfare gains.

[TABLE 3 ABOUT HERE]

Surprisingly, the optimal subsidy turns out to be close to that in the data and, consequently, the welfare gains brought about by optimal policy are negligible. This suggests that in this period the US subsidy behaves *as if* the policy makers are responding optimally to the increase in international competition.

As discussed in the previous section, since I am restricting the analysis to the steady state, I underestimate the distance between the optimal and the observed subsidy. Hence, considering the dynamic adjustment of the share $\beta(t)$ to both changes in $\overline{\omega}$ and s^D may lead to welfare gains from the optimal response to competition larger than those in table III.[36]

9 Discussion

I discuss two basic features of the model: the assumption that the share of competitive sectors is exogenously given and the choice of a fully-endogenous growth model.

[35] The simulation of the transitional dynamics in appendix C shows that more than 90 percent of the welfare response to the change in competition takes place in the first period after the shock.

[36] In appendic C I show that domestic welfare experiences a fast transition to both competition and subsidy changes. Therefore, quantitatively the steady-state computation performed above represents a sufficiently good approximation.

9.1 Endogenizing international competition

There are two reasons for treating $\overline{\omega}$ as an exogenous variable: first, this paper is motivated by the evidence discussed in section 2 showing that the US leadership in R&D investment is increasingly challenged by Japan and Europe in the period considered; the main purpose of the paper is to study the effects of the observed change in the geographical distribution of R&D investment on US welfare. For this purpose I set up a model allowing me to directly exploit that empirical evidence and perform a quantitative analysis with that data. The second reason for working with exogenous competition is simplicity: growth models with asymmetric countries playing a policy game are quite difficult to solve and to analyze, I thus choose a framework allowing me to obtain a fair balance between depth and breadth.[37]

Nevertheless, understanding the source of changes in foreign competition is an important issue. I now briefly discuss a simple way to endogenize international competition, and suggest that the basic model used in the paper represents a reduced form of this extended framework. Suppose that there is country and sector-level heterogeneity in the R&D productivity parameter A taking the following form:

$$A^F(\omega) = \begin{cases} (1-\Delta(\omega))\, A^D(\omega) & \text{if } 0 \leq \Delta(\omega) < 1 \\ 0 & \text{otherwise,} \end{cases} \tag{29}$$

where $0 \leq \Delta(\omega) \leq \overline{\Delta}$ with $\overline{\Delta} \geq 1$, is a measure of the *distance* from the technological frontier (represented by domestic technology). This stylized representation of technological heterogeneity embodies the idea that firms in the foreign country must reach a threshold level of technology (distance to frontier) in order to efficiently enter global R&D races. In steady state the free entry conditions in R&D (19) become

$$\begin{aligned} v_c^D(\omega)\frac{A^D(\omega)}{2\kappa}\left(\frac{I_c^D(\omega)}{A^D(\omega)}\right)^{\frac{-\alpha}{1-\alpha}} &= 1-s^D, \\ v^F(\omega)\frac{(1-\Delta(\omega))\,A^D(\omega)}{2\kappa}\left(\frac{I^F(\omega)}{(1-\Delta(\omega))\,A^D(\omega)}\right)^{\frac{-\alpha}{1-\alpha}} &= 1-s^F. \end{aligned}$$

Since $v_c^D(\omega) = v^F(\omega) = (c^D + c^F)(1-1/\lambda)\,/\left(\rho + I_c^D + I^F - n\right)$, and taking (29) into account, these two conditions lead to

[37] My paper is the first to introduce strategic subsidies into a dynamic model of innovation and growth. The literature is confined to static models in which innovation is a one-shot decision. Introducing innovation as a continuous process complicates the analysis substantially. This is in line with Grossman and Lai (2004) which represents the first attempt at studying strategic intellectual property rights policy in an endogenous growth framework. To keep the analysis tractable and isolate the main effects, both papers choose a fairly parsimonious growth model.

$$
I^F(\omega) = \begin{cases} (1-\Delta(\omega))^{\frac{1}{\alpha}} \left(\frac{1-s^D}{1-s^F}\right)^{\frac{1-\alpha}{\alpha}} I_c^D(\omega) & \text{if } 0 \leq \Delta(\omega) < 1 \\ 0 & \text{otherwise} \end{cases} \tag{30}
$$

Hence, foreign innovation takes place only in those industries in which the distance from the frontier is not too large. The basic model is a reduced form of this one in that the competition measure $\overline{\omega}$, that is exogenous there, is now determined by a primitive of the economy (R&D technology) and is pinned down by the share of industries in which $\Delta(\omega) < 1$. Any time a sector experiences a reduction in the technological distance that brings $\Delta(\omega)$ below one, $I^F(\omega)$ becomes positive and $\overline{\omega}$ increases. Changes in the technology gap $\Delta(\omega)$ can be produced by changes in the cost of imitating or adopting the frontier research technology: education, technology and intellectual property rights policy are all possible sources of reduction in adoption costs.[38]

The effects on domestic welfare and optimal subsidy will be similar to those derived in the basic model with exogenous $\overline{\omega}$. The mechanisms through which this new dimension of foreign competition affects the domestic economy are similar to those through which a change in $\overline{\omega}$ affects the economy in the basic model. From (30) a decrease in $\Delta(\omega)$, provided that it goes below one, triggers foreign entry in innovation, thus producing a positive growth effect and a negative business-stealing effect on domestic welfare. Moreover, as before, the business-stealing effect increases the strategic motive for subsidizing domestic R&D.[39]

Working with this augmented model requires the support of an empirical evidence different from that presented in section 2: the analysis must start from the observation that in the period considered industries show a progressive reduction in the R&D technology gap between the US and the lagging countries. In order to do that, one needs to find data on R&D productivity at the sectorial level for the set of countries considered, and document technological catch-up of Japanese and European firms. While TFP-based measures of distance from the technological frontier are available for some countries (see Aghion and Griffith 2005 for a survey), I am not aware of similar data for R&D productivity. Putting together such data set, and using it to perform quantitative analysis with the augmented model is an interesting area to be explored

[38] For instance, a possible source of entry of Japanese firms into global R&D races could be the interaction between market forces and the aggressive technology policy implemented by the Ministry of International Trade and Industry (MITI). A similar story can be observed for some industries in Europe: Airbus is the typical example. For an historical account of the role of policy in the evolution of 'national innovation systems' in major industrialized countries see Nelson (1993).

[39] Notice that this extension not only allows for the possibility of measuring changes in the share of competitive sectors, as in the basic model, but also accounts for changes in the intensity of competition within such sectors, which is pinned down by $\Delta(\omega)$. This implies that in the extended framework, a business-stealing and a growth effect will be observed any time a competitive sector experiences a reduction in $\Delta(\omega)$, even when the share of competitive sectors $\overline{\omega}$ does not change.

in future research.

A different, but related, way to endogenize the level of international technological competition would be to introduce an explicit imitation activity leading firms from the lagging country to copy the technology of the advanced country (see e.g. Grossman and Helpman, 1991b, and Dinopoulos and Segerstrom, 2007). In this case, only firms in the leading country innovate and firms in the follower country invest resources in copying the frontier quality good. This is the typical structure of a North-South trade and growth model. In this type of models, it is assumed that Southern firms pay lower wages; it follows that, once a firm from the South succeeds in imitating the top-quality good, it obtains global market leadership because of lower production costs. The problem with using this framework to study the issues analyzed in my paper is that the leapfrogging produced by foreign competition would not be technological in nature: the foreign firm never introduces a new top-quality good and it drives the domestic firm out of the market only because of wage differences. While this would well describe a North-South type of competition, it does not capture the nature of competition between Japanese, European and American firms in the 1970s and 1980s.[40]

9.2 Model choice

The specification of the R&D difficulty index $X(\omega, t)$ that I have chosen allows me to remove scale effects and preserve the long-run effects of policy on growth. This type of model is known as non-scale, *fully-endogenous* growth model. An alternative way to eliminate the scale effects prediction is based on the idea that early discovery fish out the easier inventions first, leaving the most difficult ones for the future (e.g. Segerstrom, 1998, Kortum, 1997 and Jones, 1995). In my framework this solution can be implemented assuming $\dot{X}(\omega, t)/X(\omega, t) = \mu I(\omega, t)$, as in Segerstrom (1998). This specification of the difficulty index allows one to eliminate scale effects without preserving the policy effectiveness of the first generation R&D-driven growth models (Aghion and Howitt, 1992, and Grossman and Helpman, 1991a). Policy, in fact, only affects the growth rate along the transition to the steady state, while long-run growth is exogenously pinned down by population growth. For this reason, frameworks using this alternative solution are commonly referred to as *semi-endogenous* growth models.

The empirical literature has not reached a consensus on which model fits the data better. On the one hand, Jones (2005) suggests that the fairly constant post World War II US growth rate

[40] One interesting first step in introducing technological leapfrogging in models of trade and growth with imitation can be found in Connolly and Valderrama (2005) which introduces a mechanism allowing successful imitators to innovate on the existing frontier technology.

provides a case for the semi-endogenous framework. On the other hand, Ha and Howitt (2007) and Madsen (2007) conducting econometric tests on the two versions of the no-scale R&D-driven growth model conclude that the fully-endogenous version provides a better representation of the data.

My choice of model is motivated by the following: first, working with the semi-endogenous version would not affect the basic results of the paper; it would only eliminate the effects of competition and R&D subsidy on the steady-state growth rate, while the level effect (the business-stealing effect) will still be there, and the growth effect would appear along the transition to the steady state. As long as the transition period is not too short, the growth effect would be substantial.[41] The second reason is that the semi-endogenous version of my model would have two additional state variables, $X_c(\omega, t)$ and $X_m(\omega, t)$, which would complicate the analysis substantially.

10 Conclusion

In this paper I have shown that increases in international competition produce a *business-stealing* effect that reduces domestic profits and income, thus affecting welfare negatively, and a *growth* effect which raises welfare. The overall welfare effect is ambiguous and depends on the relative strengths of these two counteracting effects.

Although these two effects have opposite implications for national welfare, they work in the same direction on the core externalities determining the optimal domestic R&D subsidy: on the one hand, competition, by increasing the scale of international business-stealing, broadens the scope for the *strategic* use of subsidies. On the other hand, the higher R&D efficiency produced by foreign entry increases the *consumer surplus* (or growth) motive for subsidies. As a consequence, increases in foreign competition lead to higher domestic subsidies.

I have constructed an empirical index of international competition matching the dimension of competition analyzed in the model. This measure shows that US global leadership was increasingly challenged by foreign competition between the early 1970s and mid 1990s. Using this measure I have performed a quantitative analysis and obtained two main results: first, the growth and business-stealing effect of the observed increase in competition on US welfare substantially balance each other, thus leading to a negligible welfare loss of 1.3 percent of US lifetime consumption in the 1979-95 period. Secondly, using R&D subsidies data from Bloom

[41] Steger (2003) has computed the speed of convergence of Segerstrom's (1998) model, finding a half-life of 38 years; this leaves enough of time for policy to affect the growth rate.

et al. (2002), I have compared the optimal US subsidy with the subsidy observed in the data during this period of rapidly increasing foreign competition. The results show that the observed US subsidy is surprisingly close to the optimal subsidy response to competition produced by the model.

There is one important aspect that has not been considered in this paper: the effect of foreign competition on domestic wages. The impact of international business stealing on domestic income has been limited to the shift of profits abroad. Removing the simplifying assumption of perfectly global labor markets would increase the income losses associated with competition. The *wage-stealing* effect that would be observed in an economy where labor markets are partially local, would represent an additional negative welfare effect of competition which would strengthen the strategic motive for subsidies. On the other hand, a reduction in wages would increase domestic aggregate profits, thus moving welfare and subsidies in the opposite direction. Introducing the wage-stealing effect is an interesting task for future research.[42]

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A Proofs

The proof of proposition 2 and the comparative statics stated in proposition 3 can be derived analytically solving the equilibrium system for the following variables, I_m^D, I^F and $\left(c^D + c^F\right)$. In order to do this we consider the reduced system composed of (19), and the sum of (16) and (17) and obtain:

$$\frac{2\kappa}{A}\left(\frac{I_c}{A}\right)^{\frac{\alpha}{1-\alpha}} = \frac{\left(c^D + c^F\right)\left(\frac{\lambda - 1}{\lambda}\right)}{\rho + 2I_c - n} \tag{31}$$

$$\frac{2\kappa}{A}\left(\frac{I_m^D}{A}\right)^{\frac{\alpha}{1-\alpha}} = \frac{\left(c^D + c^F\right)\left(\frac{\lambda - 1}{\lambda}\right)}{\rho + I_m^D - n} \tag{32}$$

$$2\kappa\lambda\left[2\overline{\omega}\left(\frac{I_c}{A}\right)^{\frac{1}{1-\alpha}} + (1-\overline{\omega})\left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}}\right] = 2\lambda - \left(c^D + c^F\right) \tag{33}$$

Substituting $\left(c^D + c^F\right)$ from (31) into the other two equations we obtain (I) and (II) shown in the main text.

[42] Impullitti (2009) extends the model in this direction.

Proposition 1. Totally differentiating equations (I) and (II) with respect to (w.r.t.) I_c and I_m^D yields

$$\begin{aligned} \Phi_1 dI_c + \Phi_2 dI_m^D &= 0 \\ \Phi_3 dI_c + \Phi_4 dI_m^D &= 0, \end{aligned} \tag{34}$$

where Φ_1, Φ_2 are the derivatives of (I) w.r.t. I_c and I_m^D respectively, and Φ_3, Φ_4, are the derivatives of (II) w.r.t. I_c, I_m^D. It is easy to show that $\Phi_1 > 0$ and $\Phi_2 < 0$, thus $dI_m^D/dI_c = -\Phi_1/\Phi_2 > 0$, which proves that that equation (I) is monotonically increasing. Similarly, since Φ_3 and Φ_4 are both negative, $dI_m^D/dI_c = -\Phi_3/\Phi_4 < 0$, and equation (II) is monotonically decreasing. It follows that the two curves in figure 4 intersect only once and the steady-state equilibrium is uniquely determined.

Proposition 2. Totally differentiating equations (I) and (II) w.r.t. I_c and I_m^D and $\overline{\omega}$ yields

$$\begin{aligned} \Phi_1 dI_c + \Phi_2 dI_m^D &= 0 \\ \Phi_3 dI_c + \Phi_4 dI_m^D &= \Phi_5 d\overline{\omega}, \end{aligned}$$

where Φ_1, Φ_2 are the derivatives of (I) w.r.t. I_c and I_m^D respectively, and Φ_3, Φ_4, Φ_5, are the derivatives of (II) w.r.t. I_c, I_m^D, and $\overline{\omega}$ respectively. Rewriting these equations in matrix form we obtain

$$\begin{bmatrix} \Phi_1 & \Phi_2 \\ \Phi_3 & \Phi_4 \end{bmatrix} \begin{bmatrix} \frac{dI_c}{d\overline{\omega}} \\ \frac{dI_m^D}{d\overline{\omega}} \end{bmatrix} = \begin{bmatrix} 0 \\ \Phi_5 \end{bmatrix}.$$

Since the $\Phi_1 > 0$ and $\Phi_2 < 0$, Cramer's rule allows us to conclude that

$$\begin{aligned} \text{Sign}\left(\frac{dI_c}{d\overline{\omega}}\right) &= -\text{Sign}\left(\Phi_2 \Phi_5\right) = \text{Sign}\left(\Phi_5\right) \\ \text{Sign}\left(\frac{dI_m^D}{d\overline{\omega}}\right) &= \text{Sign}\left(\Phi_1 \Phi_5\right) = \text{Sign}\left(\Phi_5\right), \end{aligned}$$

and

$$\begin{aligned} \Phi_5 &= \frac{1}{(1-\overline{\omega})^2} - \frac{(\rho + 2I_c - n)}{(\lambda - 1)\, A (1-\overline{\omega})^2} \left(\frac{I_c}{A}\right)^{\frac{\alpha}{1-\alpha}} - \frac{2}{(1-\overline{\omega})^2} \left(\frac{I_c}{A}\right)^{\frac{1}{1-\alpha}} \\ &= \frac{1}{(1-\overline{\omega})} \left[\left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}} - 2\left(\frac{I_c}{A}\right)^{\frac{1}{1-\alpha}} \right]. \end{aligned}$$

where I have used (II) to obtain the second equality. The effect of competition on I_c and I_m^D is zero only if $\Phi_5 = 0$, which happens iff $I_m^D = 2^{1-\alpha} I_c$; but then for (I)

$$\begin{aligned}\left(\frac{I_c}{A}\right)^{\frac{\alpha}{1-\alpha}} (\rho + 2I_c - n) &= \left(\frac{2^{1-\alpha} I_c}{A}\right)^{\frac{\alpha}{1-\alpha}} \left(\rho + 2^{1-\alpha} I_c - n\right) \\ (\rho - n) &= 2^{\alpha} (\rho - n),\end{aligned}$$

and since $\rho > n$ we find $\Phi_5 = 0$ only for $\alpha = 0$, while $\Phi_5 < 0$ otherwise and, consequently, $dI_c/d\varpi$ and $dI_m^D/d\varpi$ are negative for $\alpha > 0$. This is the *obsolescence* effect, which is negative except for $\alpha = 0$, when it vanishes.

In this symmetric-subsidies economy $I_c^D = I^F$, thus the growth equation (20) becomes $g = \left[\varpi 2I_c + (1-\varpi) I_m^D\right] \ln \lambda$. Since we have established above that $I_m^D < 2^{1-\alpha} I_c$, this implies that $I_m^D < 2I_c$ and it is easy to see from the growth equation that increases in ϖ raises the number of sectors with higher innovation. This proves the positive *efficiency effect* in proposition 2. The next step is to show that this dominates the obsolescence effect of competition on I_m^D and I_c. Since $dI_c/d\varpi$ and $dI_m^D/d\varpi$ are negative, differentiating (31) and (32) w.r.t. ϖ we can see that $d\left(c^D + c^F\right)/d\varpi < 0$. Then, taking the derivative of (33) with respect to ϖ we obtain

$$\begin{aligned}2\left(\frac{I_c}{A}\right)^{\frac{1}{1-\alpha}} + \frac{2\varpi}{A(1-\alpha)}\left(\frac{I_c}{A}\right)^{\frac{\alpha}{1-\alpha}}\left(\frac{dI_c}{d\varpi}\right) - \left(\frac{I_m^D}{A}\right)^{\frac{1}{1-\alpha}} + \frac{(1-\varpi)}{A(1-\alpha)}\left(\frac{I_m^D}{A}\right)^{\frac{\alpha}{1-\alpha}}\left(\frac{dI_m^D}{d\varpi}\right) &= \\ -\frac{1}{2\kappa\lambda}\left[\frac{\partial(c^D + c^F)}{\partial\varpi}\right] &> 0.\end{aligned}$$

Rearranging the left hand side and simplifying yields

$$2I_c + \left(\frac{1}{1-\alpha}\right)\left(2\varpi\frac{dI_c}{d\varpi}\right) + \left(\frac{I_m^D}{I_c}\right)^{\frac{\alpha}{1-\alpha}}\left[\frac{(1-\varpi)}{(1-\alpha)}\left(\frac{dI_m^D}{d\varpi}\right) - I_m^D\right] > 0. \tag{35}$$

Since $\frac{1}{1-\alpha} > 1$ and $\frac{I_m^D}{I_c} > 1$ it is easy to see that (35) is a sufficient condition for

$$\frac{\partial g}{\partial \varpi} = \left\{\left(2I_c - I_m^D\right) + \left[2\varpi\frac{\partial I_c}{\partial\varpi} + (1-\varpi)\frac{\partial I_m^D}{\partial\varpi}\right]\right\}\ln\lambda > 0,$$

thus proving that that the overall effect of competition on growth is positive.

Proposition 3. In order to show the welfare effects of international business-stealing we need to derive the effects of competition on domestic consumption. Substituting $I_c^D = I^F$ into the right hand side of (16) leads to $\beta = 1/2$, so we obtain the following expression for domestic consumption

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

where the second equality has been obtained using (31) to get rid of (c^D+c^F). Since we have established above that $\partial I_c/\partial\overline{\omega}<0$, $\partial I_m^D/\partial\overline{\omega}<0$ and that that the value inside the square brackets is positive ($I_m^D<2^{1-\alpha}I_c$), a sufficient condition for $\partial c^D/\partial\overline{\omega}<0$ is that value inside the square brackets decreases with $\overline{\omega}$. The derivative of this value w.r.t $\overline{\omega}$ is

$$
\begin{aligned}
& \frac{1}{A\left(1-\alpha\right)}\left[2\left(\frac{I_c}{A}\right)^{\frac{\alpha}{1-\alpha}}\frac{\partial I_c}{\partial\overline{\omega}}-\left(\frac{I_m^D}{A}\right)^{\frac{\alpha}{1-\alpha}}\frac{\partial I_m^D}{\partial\overline{\omega}}\right] \\
&= -\frac{1}{A\left(1-\alpha\right)}\frac{\Phi_5}{D}\left[2\left(\frac{I_c}{A}\right)^{\frac{\alpha}{1-\alpha}}\Phi_2-\left(\frac{I_m^D}{A}\right)^{\frac{\alpha}{1-\alpha}}\Phi_1\right] \\
&= -\frac{1}{2\kappa\left(1-\alpha\right)}\frac{\Phi_5}{D}\left(c^D+c^F\right)\left(\frac{\lambda-1}{\lambda}\right)\left[-2\left(\frac{I_c}{A}\right)^{\frac{\alpha}{1-\alpha}}+\left(\frac{I_m^D}{A}\right)^{\frac{\alpha}{1-\alpha}}\right]<0,
\end{aligned}
$$

where I derived $\partial I_c/\partial\overline{\omega}$ and $\partial I_m^D/\partial\overline{\omega}$ from the proof of proposition 2, I defined $D=\Phi_1\Phi_4-\Phi_2\Phi_3$, and used (31) and (32) to obtain the third equality. Proceeding as above it is easy to show that the value in the square brackets is negative ($I_m^D<2^{\frac{1-\alpha}{\alpha}}I_c$) and, since $\Phi_5<0$, this a sufficient condition for $\partial c^D/\partial\overline{\omega}<0$.

B Transitional dynamics

Linearizing the system (23)-(24) yields

$$
\begin{bmatrix}\dot{\beta}(t)\\ \dot{c^D}(t)\end{bmatrix}=\begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix}\begin{bmatrix}\beta(t)-\beta\\ c^D(t)-c^D\end{bmatrix}.
$$

where

$$
\begin{aligned}
a_{11} &= -\left\{\frac{1+2\left(\lambda-1\right)\left(1-\frac{\overline{\omega}}{2}\right)-c^D}{\frac{2\kappa\lambda}{A}(1-\frac{\overline{\omega}}{2})}\right\}<0, \\
a_{12} &= 0, \\
a_{21} &= -\frac{\overline{\omega}\left(\lambda-1\right)\left[c^D+\left(1-\overline{\omega}\right)\right]}{\frac{2\kappa}{A}\lambda(1-\frac{\overline{\omega}}{2})^2}<0, \\
a_{22} &= \frac{1}{\frac{2\kappa}{A}(1-\frac{\overline{\omega}}{2})}>0.
\end{aligned}
$$

where I have substituted the steady-state value for β, that is $\beta = 1/2$. The solution to this system is

$$\begin{aligned} \beta(t) &= \beta + [\beta(0) - \beta]\, e^{\gamma t} \\ c^D(t) &= c^D + \left[c^D(0) - c^D\right] \Lambda e^{\gamma t}, \end{aligned} \tag{36}$$

where $\gamma < 0$ is the stable eigenvalue and $(1, \Lambda)^T$ is the correspondent eigenvector. Solving the characteristic equation we obtain

$$\gamma_{1,2} = \frac{1}{2}\left[(a_{11} + a_{22}) \pm (a_{11} - a_{22})\right].$$

Hence $\gamma_1 = a_{11} < 0$ and $\gamma_2 = a_{22} > 0$, and the system is saddle path stable. Differentiating (36) with respect to $\overline{\omega}$, we obtain (25). It is easy to show that $\gamma_1 = -I$, and as shown in the proof of proposition 2 above $dI/d\overline{\omega} < 0$ for $\alpha > 0$, while $dI/d\overline{\omega} = 0$ for the linear technology $(\alpha = 0)$.

TABLE 1

GLOBAL R&D SHARES AT THE SECTORIAL LEVEL

	1973			1995			% change 1973-95		
industry	US	JAP	EU	U.S.	JAP	EU	U.S.	JAP	EU
Aircrafts**	74.2	0.08	0.241	68.4	1.4	27.3	−7.76	81.6	13.3
Chem. no drugs*	39.7	18.5	39.8	35.9	26.1	36.3	−9.38	40.6	−8.68
Drugs and meds.**	41.3	14.5	42.2	45.5	16.8	34.6	10.1	15.7	−18
Electrical Machinery *	54.3	16.6	27.8	24.6	43.2	30.8	−54.5	160.3	10.6
Food, Beverages & Tobacco	40.4	20.2	34.6	32.7	30.6	29.8	−19	51.6	−13.7
Iron & Steel	27.0	37.7	31.9	9.43	53.4	29.2	−65.1	41.5	−8.45
Metal Products	58.7	15.9	21.9	35.08	23.8	36.0	−40.3	49.7	64
Motor vehicles*	56.5	13.6	28.8	45.01	20.1	33.51	−20.4	47.7	16.3
Non-Electrical Machinery	39.0	21.9	36.9	30.4	29.8	37.4	−21.9	36.1	1.47
Non-Ferrous Metals	43.8	23.2	23.0	20.6	50.3	14.6	−52.8	116.2	−36.4
Non-Metallic Mineral Prod.	43.7	23.3	29.7	18.8	49.5	29.2	−56.9	112.4	−2.04
Office and computing mach.**	76.5	6.4	16.1	53.7	30.2	13.98	−29.8	368.5	−13.2
Other Manufacturing, n.e.c.	59.4	19.5	19.4	36.6	34.5	17.91	−38.4	76.9	−8.13
Other Transport Equip.	54.1	14.3	17.3	43.2	17.08	42.6	−20	19	145.7
Paper, Paper Products	52.8	26.4	20.6	64.9	17.5	17.5	22.8	−.33.6	−15.4
Petroleum Refineries & Prod.	58.3	5.7	33.4	52.9	12	31.9	−9.17	109.5	−4.49
Professional Goods	74.7	9.1	15.1	71.2	12.4	15.3	−4.64	35.8	0.77
Radio, TV & Comm. Equi.*	54.2	13.1	29.9	40.3	25.6	28.76	−25.5	95.08	−3.93
Rubber & Plastic Products	53.4	19.8	25.3	31.9	37.03	29.11	−40.1	86.3	14.6
Textiles, Apparel & Leather	23.4	29.6	44.3	29.2	34.7	30.5	24.4	17.1	−31.1
Wood Products & Furniture	71.5	11.5	12.5	30.5	26.1	35.6	−57.2	125.4	185.2

Note: ** high-tech, * medium high-tech

TABLE 2

MODEL FIT US 1979

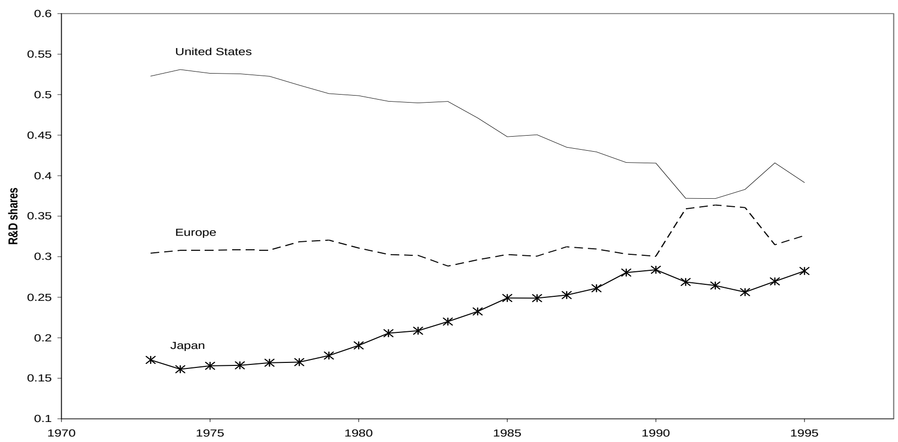
Moments	Data	Benchmark model
TARGETED		
growth	0.019	0.0187
R&D/GDP	0.135	0.16
NON TARGETED		
Labor share	0.67	0.78
cons/GDP	0.86	0.83
share of R&D in $\overline{\omega}$	0.23	0.28

TABLE 3

WELFARE GAINS WITH OPTIMAL SUBSIDY

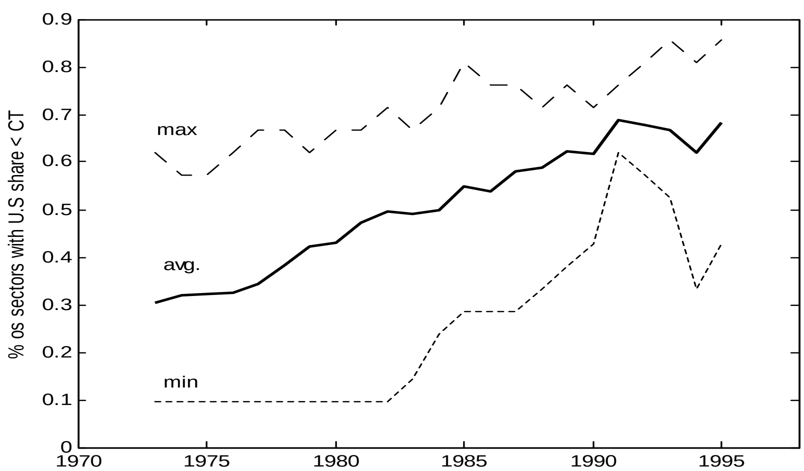
		1979	1981	1983	1985	1987	1989	1991	1995
competition	$\overline{\omega}$	.42	.47	.49	.54	.57	.62	.68	.68
observed subsidy	s^D	.066	.115	.115	.115	.12	.114	.188	.188
optimal subsidy	s^{D*}	.085	.10	.105	.12	.125	.135	.15	.15
welfare gain		.00005	.00004	.00002	.000003	.000008	.000008	.0003	.0003

Figure 1. Global R&D investment shares: sectorial average



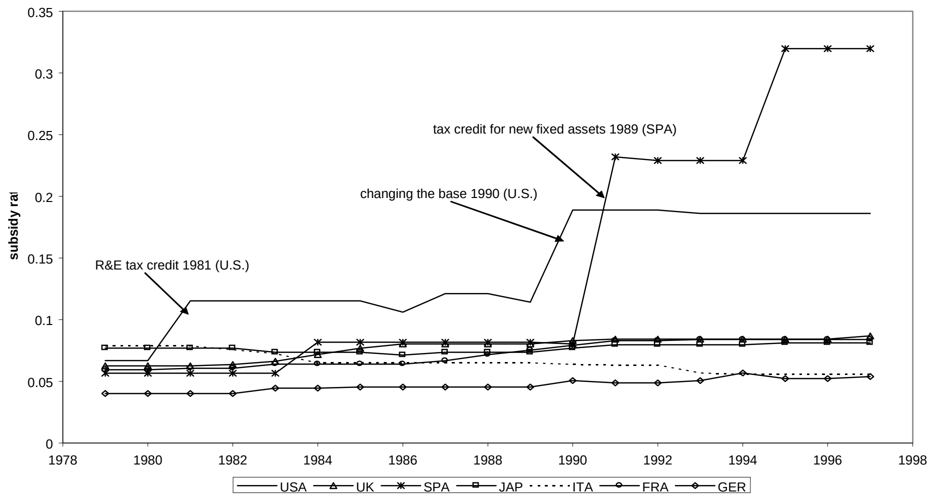
Source: OECD ANBERD (ISIC Rev.2)

Figure 2. International R&D competition



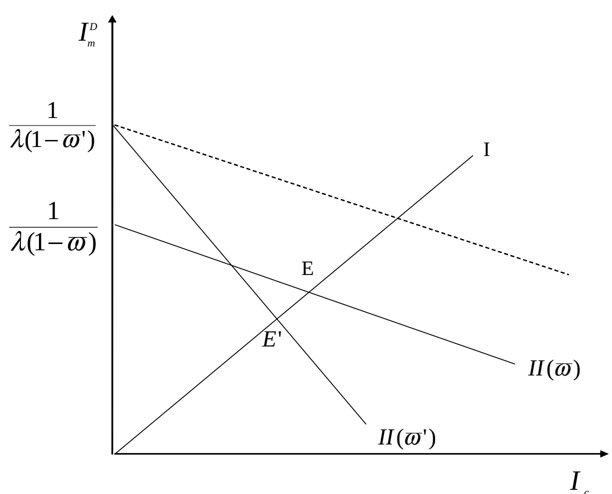
Source: author's calculations using OECD ANBERD (ISIC Rev. 2)

Figure 3. R&D subsidies



Source: author's calculations in Bloom, Griffith, and Van Reenen (2002)

Figure 4. Steady state equilibrium and the growth effect



Note: $\overline{\omega}' > \overline{\omega}$

Figure 5. Effects of competition on domestic economy (constant s)

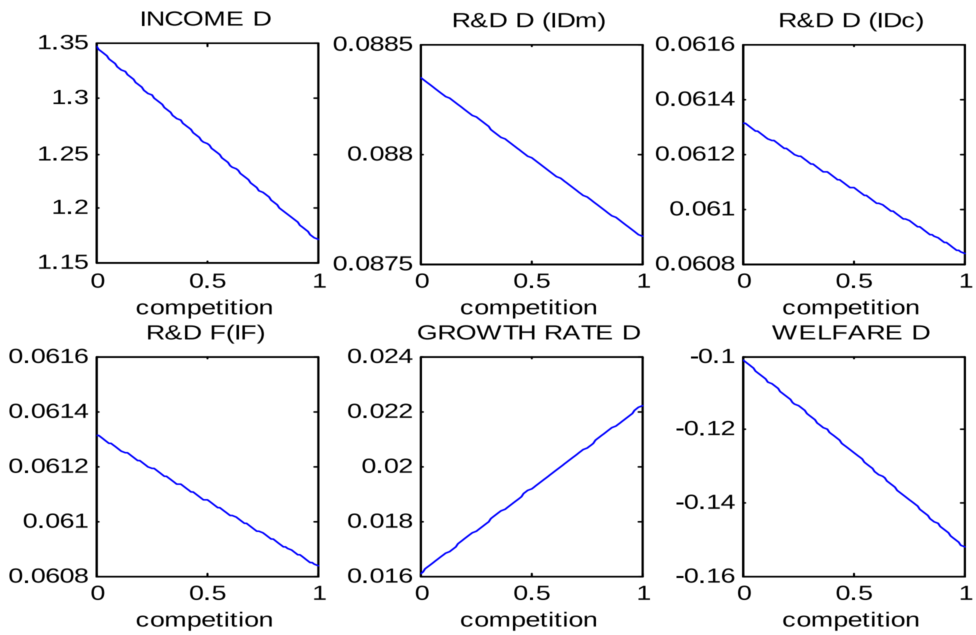


Figure 6. Foreign competition and the domestic economy: robustness

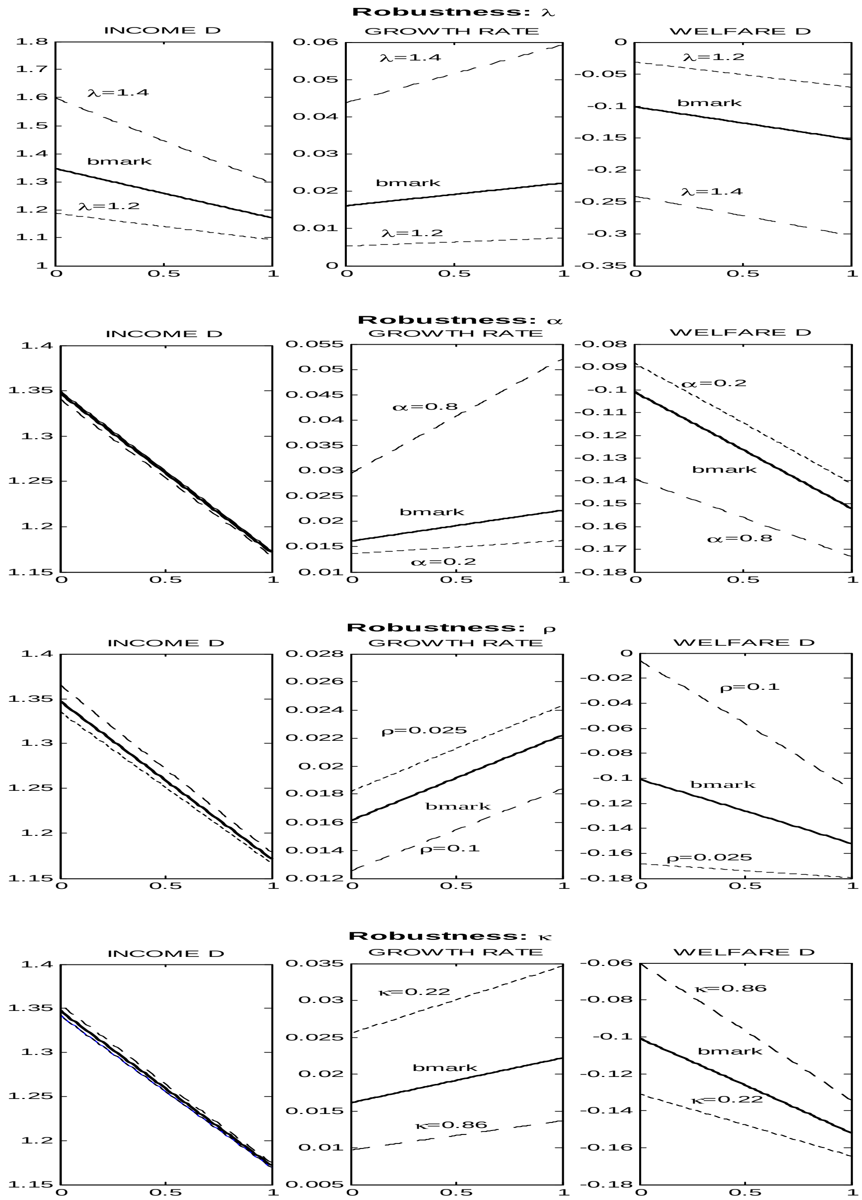
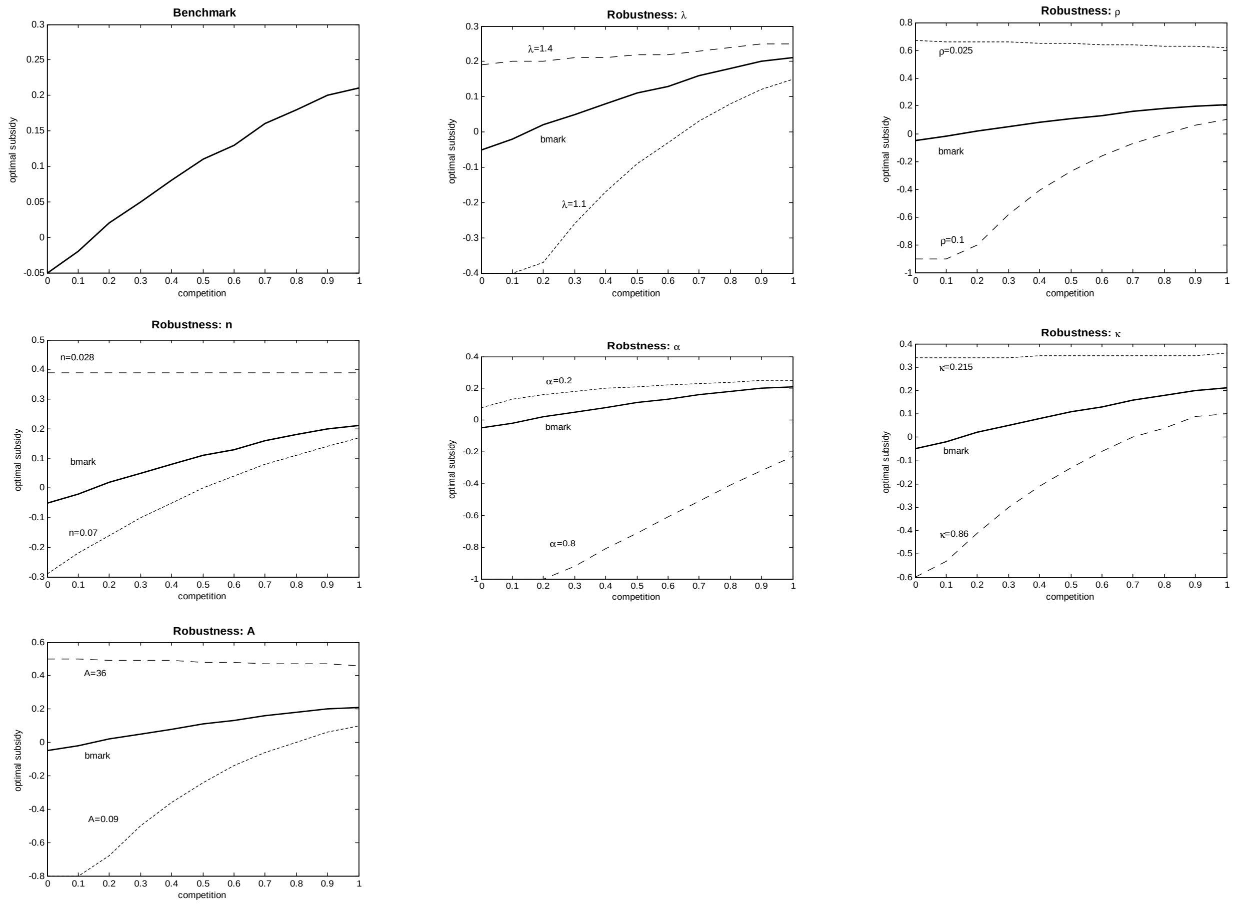


Figure 7. Foreign competition and optimal domestic subsidy



References

[1] Aghion P., and Howitt P., "A Model of Growth through Creative Destruction", *Econometrica* 60(2) (1992), 323-351.

[2] Aghion P., and P. Howitt, *Endogenous Growth Theory* (Cambridge Ma: MIT Press, 1998)

[3] Aghion, P., N. Bloom, R. Blundell, R. Griffith and P. Howitt, "Competition and innovation: an inverted U relationship", *Quarterly Journal of Economics* 120(2) (2005), 701-728.

[4] Aghion, P. and R. Griffith, *Competition and Growth: Reconciling Theory and Evidence* (Cambridge Ma: MIT Press, 2005)

[5] Basu, S., "Procyclical Productivity: Increasing Returns or Cyclical Utilization?", *Quarterly Journal of Economics*, 111 (1996), 709-751.

[6] Bhagwati, J, A. Panagariya, and T.N. Srinivasan, "The Muddles over Outsourcing," *Journal of Economic Perspectives* 18(4) (2004), 93-114.

[7] Blinder, A, "Offshoring: the next industrial revolution?", *Foreign Affairs*, 85(2) (2006), 113.128.

[8] Bloom, N., R. Griffith, and J. Van Reenen, "Do R&D Tax credit Work? Evidence from a panel of Countries 1979-97," *Journal of Public Economics* 85 (2002), 1-31.

[9] Blundell, R., R. Griffith, and F. Windmeijer, "Individual effects and dynamics in count data models", *Journal of Econometrics* 180 (2002), 113-131.

[10] Brander, A.J., and B.J. Spencer, "International R&D Rivalry and Industrial Strategy", *The Review of Economic Studies* 50(4) (1983), 707-722.

[11] Bureau of Labor Statistics, US Department of Labor, *Multifactor Productivity Trends, 1997,* (Washington D.C., 1999)

[12] Connolly, M., and D. Valderrama, "North-South Technological Diffusion: a New Case for Dynamic Gains from Trade", mimeo, Duke University, 2005.

[13] Corrado, C., C. Hulten, D. Sichel, "Intangible Capital and Economic Growth," *NBER Working Paper* 11948 (2006).

[14] Dixit, A, "Optimal Trade and Industrial Policies for the US Automobile Industry," in R. Feenstra, ed., *Empirical Methods for International Trade*, (Cambridge Ma: MIT Press, 1998), 141-65.

[15] Dinopoulos, E., and P., Segerstrom, "A Schumpeterian Model of Protection and Relative Wages," *American Economic Review* 89 (1999), 450-472.

[16] Dinopoulos, E., and P., Segerstrom, "North-South Trade and Economic Growth", mimeo Stockholm School of Economics, 2007.

[17] Eaton, J. and G. Grossman, "Optimal Trade and Industrial Policy under Oligopoly",*Quarterly Journal of Economics*, 101(2) (1986), 383-406.

[18] Eaton, J., and S. Kortum, "International Technology Diffusion: Theory and Measurement", *International Economic Review* 40(3) (1999), 537-570.

[19] Eaton, J., and S. Kortum, "Innovation, Diffusion, and Trade," *NBER Working Papers 12385*, National Bureau of Economic Research, 2006.

[20] Eaton, J., and S. Kortum. *Technology in the Global Economy: a Framework for Quantitative Analysis*, mimeo University of Chicago and NYU, 2008.

[21] French, K. and J. Poterba, "Investor Diversification and International Equity Markets," *American Economic Review* 81 (1991) 222-226.

[22] Gomory, R., and W.J. Baumol, *Global Trade and Conflicting National Interests*, (Cambridge Mass.: MIT Press, 2000).

[23] Grossman, G. M. and E. Helpman, "Quality Ladders in the Theory of Growth," *Review of Economic Studies* 58(1) (1991a), 43-61.

[24] Grossman, G. M. and E. Helpman, *Innovation and Growth in the Global Economy*, (Cambridge Ma: MIT Press, 1991b).

[25] Grossman, G.M. and E. Lai, "International Protection of Intellectual Property", *American Economic Review* 94(5) (2004). 1635-1653.

[26] Helpman, H.,"Innovation, Imitation, and Intellectual Property Rights," *Econometrica* 61 (1993), 1247-1280.

[27] Ha, J., and P. Howitt, "Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory," *Journal of Money, Credit, and Banking* 33 (2007), 733-74.

[28] Haaland, J, and H.J. Kind, "R&D Policies, Trade and Process Innovation", J*ournal of International Economics* 74(1) (2008), 170-187.

[29] Hall, B., Griliches, Z., and J, Hausman, "Patents and R&D: is there a Lag?," *International Economic Review*, 27 (1986), 265-83.

[30] Hall, B., "R&D Tax Policy During the Eighties: Success or Failure?," *NBER Working Paper* No. 4240, 1993.

[31] Hatzichronoglou, T., "Revision of the High-Technology Sector and Product Classification", *OECD STI Working papers* GD 97 (1997), 216.

[32] Howitt, P., "Steady Endogenous Growth with Population and R&D Inputs Growing," *Journal of Political Economy* 107 (1999), 715-30.

[33] Impullitti, G., "International Schumpeterian Competition and Optimal R&D Subsidies," *European University Institute Working Papers* 55 (2007).

[34] Impullitti, G., "Global Innovation Races and Wage Inequality", mimeo IMT Lucca, 2009.

[35] Jones C., "Time Series Tests of Endogenous Growth Models", *Quarterly Journal of Economics* 110 (1995), 495-525.

[36] Jones C. and J. Williams, "Too Much of a Good Thing? The Economics of Investment in R&D", *Journal of Economic Growth*, 5(1) (2000), 65-85.

[37] Jones, C. (2005). "Growth and Ideas" in P. Aghion and S. Durlauf (eds.) *Handbook of Economic Growth*, Vol. 1B, (Elsevier, 2005), 1063-1111.

[38] Keller, W., "International Technology Diffusion," *Journal of Economic Literature*, XLII (2004), 752–782.

[39] Klenow, P., and A. Rodriguez-Claire, (2005). "Externalities and Growth," in P. Aghion and S. Durlauf (eds.) *Handbook of Economic Growth*, Vol. 1A, (Elsevier, 2005), 817-861.

[40] Kochhar K., Rajan R., Kumar U., Surbamanian A., and I. Tokatlidis. (2006). "India's Pattern of Development: What Happened, What Follows," *Journal of Monetary Economics* 53 (2006), 981-1019.

[41] Kortum, S., "Equilibrium R&D Ratio and the Patent-R&D Ratio: US Evidence," *American Economic Review, Papers and Proceedings* 83 (1993), 450-457.

[42] Kortum, S., "Research, Patenting, and Technological Change," *Econometrica* 65(6) (1997), 1389-1420.

[43] Krugman, P.R., "A Model of Innovation, Technology Transfer, and the World Distribution of Income," *Journal of Political Economy*, 87(2) (1979), 253-266.

[44] Krugman, P.R., "The Narrow and Broad Arguments for Free Trade," *American Economic Review Papers and Proceeding*, May (1993).

[45] Krugman, P.R., and A. Smith, *Empirical Studies of Strategic Trade Policy* (Chicago: University of Chicago Press, 1994)

[46] Krugman, P.R., "Making sense of the competitiveness debate," *Oxford Review of Economic Policy* 12 (3) (1996), 17-25.

[47] Lundborg P. and P. Segerstrom, "The Growth and Welfare Effects of International Mass Migration," *Journal of International Economics*, 2002 (Jan) (2001), 177-204.

[48] Madsen, J.B., "Semi-Endogenous Models versus Schumpeterian Theory: International Evidence over a Century," *Journal of Economic Growth* 13 (2008), 1-26.

[49] Mehra,R., and E.C.Prescott, "The Equity Premium in Retrospect," *NBER working paper* 9525 (2003).

[50] Mendoza, E, and L. Tesar, "Why hasn't tax competition triggered a race to the bottom? Some quantitative lessons from the EU," *Journal of Monetary Economics* 52 (2005), 163-204.

[51] Nelson, R., *National Innovation Systems: a Comparative Analysis* (Oxford, Oxford University Press, 1993).

[52] OECD, *Science, Technology and Industry Scoreboard* (Paris: OECD Press, 2005).

[53] Persson, T., Tabellini, G., "Double-edged incentives: institutions and policy coordination". In Grossman, G., Rogoff, K. eds., *Handbook of International Economics* vol. III. (Amsterdam: North-Holland, 1995).

[54] Rodrik, D., "What's So Special About China's Exports?", *China & World Economy* 14(5) (2006), 1-19.

[55] Samuelson, P., "Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Supporting Globalization", *Journal of Economic Perspectives* 18(3) (2004), 135.146.

[56] Segerstrom P., "Endogenous Growth Without Scale Effects," *American Economic Review* 88 (1998), 1290-1310.

[57] Steger, T., "The Segerstrom Model: Stability, Speed of Convergence and Policy Implications," *Economics Bulletin* 15(4) (2003), pages 1-8.

[58] Tesar, L. and I.M. Werner, "Home-Bias and High Turnover," *Journal of International Money and Finance*, 14(4) (1995), 467-92.

[59] Tyson L., *Who's Bashing Whom? Trade Conflict in High-Tech Industries (*Washington: Institute for International Economics, 1992).

[60] Young, A., "Growth without Scale Effects," *Journal of Political Economy* 106 (1998), 41-63.