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Abstract

International technological competition implied by the global distribution of R&D investment changed dramatically in the 1970s and 1980s. In the early 1970s the distribution is very skewed: US firms were the uncontested world leaders in research investment in most manufacturing sectors. Later, with Japan’s and Europe’s technological catching-up, foreign firms started challenging american leaders in many sectors of the economy. What was the effects on US national welfare of foreign innovators entering sectors previously dominated by american firms? What are the implications for the optimal US R&D subsidy? This paper builds an empirical measure of international R&D rivalry that tracks down these changes in international competition in innovation. In a version of the quality-ladders endogenous growth model the paper quantitatively evaluates the effects of the observed increase in competition on US welfare, and compute the welfare losses produced by the gap between the actual and the optimal R&D subsidy response to competition.

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1 Introduction

In the current debate on the economic costs and benefits of globalization some recent works battled over the welfare effects on leading economies of technical progress in catching-up countries. Most of the attention has been dedicated to the consequences on advanced industrial countries of technology-induced offshoring to developing countries, and especially to the Asia’s giants, India and China.1 Another similarly heated debate took place in the 1970s and 1980s, then economists and political pundits 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

In both situations there seems to be a substantial consensus among economists that in those cases where international technological competition could hurt leading countries restrictions to free trade are a cure ‘worse than the woe’. Innovation policy is instead seen as a more “respectable” candidate for helping national economies perform in the global market.3 A key issue is then the analysis of how international competition affects the public incentives to support innovation. This paper analyzes the quantitative effects of the European and Japanese technological catching-up in the 1970s and 1980s on the U.S. welfare and evaluate the gains associated with the optimal R&D subsidies response to foreign competition.

Two basic points are tackled: first, the paper uncovers the relevant trade-offs at stake and second, it measures their relative quantitative importance. The main ingredients are: the dimension of competition studied and the endogenous growth environment. The paper focuses on international competition for innovation pinned by the global distribution of research efforts. The framework is a no-scale fully-endogenous quality ladders growth model where monopolistic competitive firms compete for the world leadership in a continuum of industries through investment in quality-improving R&D. There are two countries sharing the same size,

3The standard argument is that since causes for intervention are market imperfections the remedies should directly deal with these market failures. In Krugman’s words. “What is wrong with markets is usually a domestic distortion, best fixed by a surgical policy directly aimed at the source of the market failure.” (Krugman 1993, p.364). More sophisticated arguments in favor of innovation policy can be found in Gomory and Baumol (1992) and (2000).
technology and preferences but with different allocation of R&D investment across sectors and different research subsidies. 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 subset of sectors where R&D firms from both countries compete for innovation is used as an index of international technological competition.\textsuperscript{4}

An exogenous increase in the number of sectors where domestic leaders are challenged by foreign innovators produces two counteracting effects on domestic welfare. Assuming that R&D technology shows decreasing returns at the country level, an increase in foreign competition improves the international distribution of research labor and spurs innovation and long-run growth in goods’ quality. It follows that the arrival of foreign innovators raises welfare in both countries by allowing consumers to buy goods of higher quality - or of lower quality-adjusted price. This is the \textit{growth effect} of competition on welfare. The second effect is standard \textit{business-stealing effect}: when foreign innovators enter a market previously dominated by domestic firms monopolistic rents in some sectors will shift abroad. As a consequence domestic profits will be reduced and competition will negatively affect income and welfare. Finally, there are two motives for R&D subsidies, or taxes: the market failures related to incomplete appropriability of knowledge typical of closed economy models, and the strategic motive related to international trade. The paper shows that the surprisingly foreign competition can be welfare improving but at the same time requiring a higher optimal domestic R&D subsidy.

The basic setup is a version of Impullitti (2006) with only one country, the leader, active in R&D subsidies. In this paper I introduce an empirical index of the dimension of international competition described above. Precisely, I build a measure of international R&D competition using OECD STAN data on geographical distribution of R&D investment in 2-digit manufacturing industries. Those sectors where the US investments in research are well above the aggregate R&D investment from the rest of the world are going to be considered non-competitive, while those sectors where US and the other countries are more “neck-to-neck” will be the competitive. The share of neck-to-neck sectors will be my measure of international competition for innovation. The baseline version shows an increase from 35 percent of competitive sectors in 1973 to 70 percent in 1990. Robustness checks with more standard measures of geographical R&D concentration confirm the results.

\textsuperscript{4}The measure of the set of competitive industries is exogenously given. It might depend on previous structural government policies, or on cultural and institutional characteristics.
In a calibrated version of the model described above the paper evaluates the quantitative effects of this increase in competition on US welfare. Moreover, using estimates of the R&D subsidy implicit in the R&E Tax Credit introduced in the US in 1981, it evaluates the optimality of this policy response to the observed increases in competition in the period 1973-90.\textsuperscript{5}

**Related literature.** The paper is related to the empirical literature on strategic trade and industrial policy. Most of existing works have focused on case studies of specific sectorial policies (i.e. tariffs, quotas, export and production subsidies) and have compared the welfare gains or losses of trade versus industrial policies.\textsuperscript{6} Dixit (1988) represents the first attempt at evaluating the welfare effects of a U.S. trade policy for the automobile sector in a general equilibrium model. Dixit’s paper also differs from the previous and subsequent empirical works on these issues for explicitly studying the welfare losses related to the gap between the observed and the optimal policies. The current paper follows a similar strategy with three original departures: first, it focuses neither on trade policy nor on what is commonly defined industrial policy, but studies the welfare gains of optimal strategic R&D subsidies to all industries in the economy. I am not aware of any similar attempts in the literature. Second, it evaluates the impact of changes in international R&D competition on the welfare gains from optimal subsidies. Finally, here as in the companion paper Impullitti (2006), strategic policy is studied within an endogenous growth model, thus adding long-run growth effects to the existing static frameworks.

In the last decade substantial effort has been dedicated to studying the relation between competition, innovation and growth (see e.g. Peretto 2003, De Niccolò and Zanchettin 2006, Marimon and Quadrini 2005, and the papers surveyed in Aghion and Griffith 2005). The existing works focus on changes in product market competition (PMC) - domestic or foreign entry - and mainly restrict the analysis to the effects of competition on growth without considering the overall impact on national welfare. Some papers extend the analysis to welfare effects of raising competition but policy implications are not formally derived (see for instance, Klundert and Smulders 1997, Tang and Waelde 2001).

This paper switches to a dimension of competition different from PMC, and it expressly studies the effects of foreign competition on optimal innovation subsidies. The measure of

\textsuperscript{5}I include the entire period along which we observe increases in competition, even though R&D subsidies are introduced only in 1981; since I perform an exercise in normative economic analysis, the extended period allows me to study the effects of the lack of government response to competition in the period 1973-80.

\textsuperscript{6}See Feenstra (1995) for a survey. Most of the existing literature is based on calibrated general equilibrium models. See Berry, Levinshon, and Pakes (1999) for a pioneering econometric analysis of a strategic trade policy.
competition is pinned down by the international distribution of R&D efforts and does not involve any changes in entry or market structure - neither in the product markets nor in R&D sectors. The idea is that even in a world where national and international barriers to entry have been completely removed, if the international distribution of research investments is skewed in some sectors firms will not be actively challenged by foreign competitors. As a consequence, this new measure of competition complements the existing ones in the process of understanding the nature and mechanisms of global competition in the market place. The main contribution of this paper is to provide an empirical index of this new dimension of competition and to study its quantitative implications in a calibrated general equilibrium model with endogenous growth and strategic innovation policy.

The rest of the paper is organized as follows. Section 2 presents the data, discusses several versions of the competition index, and compare it more standard measures. In section 3 sets up the model, derive the steady state equilibrium conditions, and calibrate it for the U.S. economy. Section 4 explores the basic theoretical mechanism, the business-stealing and growth effects of competition and their role in determining the optimal subsidy. The main results are presented in section 5 where the competition index and the model are used to compute the welfare loss associated with the observed US subsidy response to competition with respect to the optimal response. Section 6 concludes.

2 Features of the data

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

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7See OECD ANBERD Rev.2, 2005.
data on R&D investment for two and three-digit manufacturing industries.

My original index is a measure of the overlapping research support that appears in the model. I take the U.S. as my domestic, leading country, and Japan and the Europe, as the foreign, follower countries. The basic criterion is the following: for each year, in the period 1973-90, we consider a sector competitive if the U.S. share of total R&D investment in that sector is smaller than 50%. My set of sectors is composed of 21 two and three-digits manufacturing sectors, and the competitive subset, \( \omega \), is the number of sectors with U.S. share of R&D below 50% divided by the total number of sectors.\(^8\)

[FIGURE 1 ABOUT HERE]

Figure 1 shows that my measure of international competition in manufacturing has a clear increasing trend in the period considered. Competitive sectors are 35 percent of the total in 1973, rising to 70 percent in 1990. When we focus only on high-tech and medium high-tech sectors, the share of competitive sectors reaches its highest value of 70 percent in 1980. This suggests that in technology-intensive sectors, the foreign challenge to U.S. leadership has grown faster than in the rest of the economy. I also computed the index weighting the sectors with their size (value added) and the trend in competition does not change very much.\(^9\)

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

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

\(^8\)ANBERD data do not consider only four 2-digits manufacturing sectors for measurement problems.

\(^9\)The data and the results with different specification of the index are available upon request.
The erosion of U.S. leadership led policy makers to introduce new measures to reduce the private cost of innovation. Fiscal incentives to R&D, like the Research and Experimentation Tax Credit of 1981, were introduced. The strengthening of intellectual protection, which began with 1982 legislation which established the Court of Appeals for the Federal Circuit, improved the protection granted to patents holders. The Bayh-Dole Patent and Trademark Amendments Act of 1980 and the Federal Technology Transfer Act of 1986, were both aimed to transform federal laboratories into sources of innovation for U.S. firms. The former allowed agencies to issue patents to small business and universities for inventions made with agency funds. The latter promoted incentives for collaboration in research between federal laboratories and firms. Another important initiative was the National Cooperative Research Act in 1984, which reduced antitrust persecutions of joint ventures for pre-commercial research. Mowery (1998) describes this set of policies as a "structural change in the US national innovation system": the post-1980 shift in technology policy direction, started during the Reagan and Bush administrations and continued as a trademark of Clinton’s economic policy, was directly aimed at stimulating civilian innovation, by strengthening the appropriability of innovations and by facilitating private firms’ access to the gigantic pool of public technologies produced during the Cold War years.10 A common characteristic of these policies is that they all aim at stimulating innovation by reducing the cost of R&D.

In our exercise we consider only one measure of this broad package of policies, the Research and Experimentation Tax Credit introduced in 1981 as a temporary measure and renewed yearly until recently when it was made permanent. The R&E tax credit is neither the most

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relevant nor the most effective R&D cost-reducing policy introduced in the 1980s, but it is the only one for which there are aggregate data that can be easily used in a stylized macro model.\footnote{11The intellectual property rights the technology transfer policies mentioned above are relevant in terms of magnitude and impact on private innovation. For example, Link (1999) shows that in terms of government expenditures five technology transfer program, the Small Business Innovation Research Program (SBIR), the CRADAS, the Advanced Technology Program (ATP), SEMATECH, and the Dual-Use Technology Program, amounted to about 3.5 billions on average in the period 1993-96. To put this public direct funding to private research in a policy perspective, in the same period it has been estimated that the total government spending implicit in the R&E tax credit is around 1.6 billions. Hence, these five programs sum up to government outlays that are double the costs of the R&E tax credit. Notice that, other important public/private cooperation programs, like the research joint ventures under the NCRA, are not included here because of lack of data on their cost.}

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

Figure 1 shows Hall (1992) estimates of the average across firms of the effective R&D subsidy rate related to the Research and Experimentation Tax Credit.\footnote{12We can illustrate the point with a simple example from Mammoneas and Nadiri (1996). If the official credit rate is 25 per cent, the cost to the firm of $1 of incremental R&D would be reduced by $0.25. However, the $1 increase in R&D decreases the tax credit for the next three years by $0.33x0.25 = $0.083 for each year. With a discount rate if 10 per cent the effective tax reduction of a $1 increase of R&D spending is $0.25 − \left(\sum_{t=1}^{3} \frac{0.083}{(1 = 0.1)^t}\right) = $0.045. Thus, the official tax credit rate of 25 per cent becomes an effective rate of 4.5 per cent.} As shown in the figure, the effective tax credit estimated by Hall, computing the reduction in the tax price of R&D produced by the tax credit, fluctuates around 3 and 5 percent of the cost of R&D in the period considered. Although the legislation set the official credit rate around 20 per cent, the effective credit rate has been on average around 4 per cent. This gap is due to the incremental design of the credit: by increasing the current R&D investment a firm will increase its current total tax credit but it will also raise the base level of R&D above which the credit is granted for the following three years.\footnote{13The average is weighted with R&D spending by each firm. See Hall (1992) for details on the estimation method.}

Even though the incremental feature of the tax credit reduced its effective rate there is extensive evidence showing that it did have an impact on private innovation. Hall (1992)
working on firm-level data finds that private innovation responds to reductions in the after-tax cost of R&D - often called the tax price of R&D. In her estimates the tax price elasticity of R&D is larger than one, which means that a 5 per cent effective R&D tax credit leads to a 5 percent increase in R&D at the firm level on average. This findings are confirmed by those in Hines (1993) that uses different econometric methods, and by those in Baily and Lawrence (1992) based on macro data. Bloom, Griffith and Van Reenen (2000) find an elasticity around unity for a panel of countries including the U.S. in the period 1981-99.

Finally, it is worth noticing that the R&E tax credit is only a part of the R&D tax policy in the US, the other important parts are the general expensing rules for R&D and the foreign source income allocation rules for R&D. In brief, the first of these components is very relevant: from 1956 R&D expenditures can be expensed for tax purposes and this implies a 100 per cent write-off of expenses on a type of investment that do not generate income immediately. This is already a tax subsidy on R&D expenditures whose rate is equal to the corporate tax rate. The other component it is relative to tax treatment of expenses of multinational corporation.14

This paper focuses only on the R&E tax credit because it represents the major change in R&D tax policy in the 1980s.15

A final remark on the way I model the R&E tax credit is needed. If the corporate tax rate does not change the expensing of R&D cost for tax purposes does not influence the decision to invest in research and development: the corporate tax rate is applied to total revenues net of all costs, including R&D costs. Thus, our stylized economy with no corporate tax rate is similar to one where the corporate tax rate is constant over time. As a consequence, the R&E tax credit can be modeled as a subsidy to research and development additional to the tax subsidy implicit in the expensing of R&D; and, since we do not study the effects of changes in the corporate tax credit, it is possible to model the research tax credit as a simple R&D subsidy.16

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

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

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

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

3.1 Households

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

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

subject to

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

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

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

where $N_0$ is the initial population and $n$ is its constant growth rate, $\rho$ is the common rate of time preference - with $\rho > n$ - and $r(t)$ is the market interest rate on a risk-free bond available in both countries. $q(j,\omega,t)$ is the per-member flow of good $\omega$, 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 $\omega$ of quality $j$ at time $t$, $c(t)$ is nominal expenditure, and $W(0)$ and $Z(0)$ are human and non-human wealth levels. A new vintage of a good $\omega$ yields a quality equal to $\lambda$ times the quality of the previous vintage, with $\lambda > 1$. Different versions of the same good $\omega$ 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 $\omega$ is available at time $t$. As is common in quality ladders models I will assume price competition at all dates, which implies that in equilibrium only the top quality product is produced and consumed in positive amounts. $T$ is a per-capita lump-sum tax.
The instantaneous utility function has unitary elasticity of substitution between every pair of product lines. Thus, households maximize static utility by spreading their expenditures \( c(t) \) evenly across the product line and by purchasing in each line only the product with the lowest price per unit of quality, that is the product of quality \( j = j^{\text{max}}(\omega, t) \). Hence, the household’s demand of each product is:

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

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

\[
\dot{c} = r(t) - \rho
\]

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 (CRS) technology with one worker producing one unit of product. The wage rate is \( w^K \), where \( K = D, F \) is the country indicator, domestic (\( D \)) and foreign (\( F \)). However in each industry the top quality product can be manufactured only by the firm that has discovered it, whose rights are protected by a perfectly enforceable world-wide patent law. I assume that technology is mobile, firms own the technology but can use it everywhere. It follows that multinational companies are free to establish subsidiaries in low wage countries to carry out the manufacturing of their products, so in equilibrium labor prices will equalize. I choose the wage as the numeraire, that is: \( w^D = w^F = 1 \).

As usual in Schumpeterian models with vertical innovation (e.g. Grossman and Helpman, 1991 and Aghion and Howitt, 1998) the next best vintage of a good is invented by means of the R&D performed by challenger firms in order to earn monopoly profits that will be destroyed by the next innovator. During each temporary monopoly, the patent holder can sell the product at prices higher than the unit cost. I assume, as standard in the literature, that the patent expires when further innovation occurs in the industry.

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

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

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

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

where \( c^D(t) \) and \( c^F(t) \) are domestic and foreign expenditures at time \( t \). The above equation says that, in equilibrium, supply and demand of every consumption good coincides. It follows that the stream of monopoly profits accruing to the monopolist which produces a state-of-the-art quality product in country \( k = D, F \) will be equal to

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

Hence a firm that produces good \( \omega \) in country \( K = D, F \) has market value

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

where \( I(\omega, t) \) denotes the worldwide Poisson arrival rate of an innovation that will destroy the monopolist’s profits in industry \( \omega \). This is a no-arbitrage condition which states that the expected rate of return of a stock issued by an R&D firm is equal to the riskless rate of return \( r(t) \). This follows from the assumption that there are efficient financial markets channelling savings into R&D firms.

### 3.3 R&D races

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

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

\[
I^K_t(\omega, t) = \frac{AI^K_t(\omega, t) \left( \frac{X^K(\omega, t)}{X(\omega, t)} \right)^{-\alpha}}{X(\omega, t)},
\] (8)
where \( X(\omega, t) > 0 \) measures the degree of complexity in the invention of the next quality product in industry \( \omega \), \( \alpha > 0 \) represents a negative externality, \( L^K(\omega, t) = \sum_i l^K_i(\omega, t) \) is the total labor used by R&D firms and \( I^K(\omega, t) = \sum_i l^K_i(\omega, t) \) is the total investment in R&D (total arrival rate) in country \( K \). This technology implies that each firm’s instantaneous probability of success is a decreasing function of the total domestic R&D investment in the industry. A possible interpretation of this property is that when firms increase R&D in a sector, the probability of duplicative research effort also increases, thereby reducing the probability that any single firm will discover the next vintage of goods and appropriate the profit rent associated with it. Therefore, the sector-specific negative externality in research technology produces decreasing returns to scale (DRS) in R&D at the industry level. Moreover, I assume that this negative externality is country-specific. The country-specific nature of DRS in R&D could be motivated by the presence of some fixed costs such as lab equipment.\(^{17}\)

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

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

with positive \( \kappa \), thereby formalizing the idea that it is more difficult to introduce a new product in a more crowded market. The PEG rules out implausible “scale effects”. This formulation, in particular, allows for sustained per-capita growth without population growth and leads to a class of models also know as fully-endogenous growth frameworks (Aghion and Howitt 2005).\(^{18}\)

Governments subsidize R&D expenditures at the rate \( s^K \). Each R&D firm chooses \( l^K_i \) in

\(^{17}\)Hall et. al. (1988), Pakes and Griliches (1984), and Kortum (1993) provide empirical evidence on the existence of DRS in R&D due to duplicative research and fixed costs. A typical microfundation for this is attainable by relating the DRS in R&D at the country level to heterogeneous ability of workers (Eaton and Kortum 1999). As investment in research increases in a country, workers of lower ability will be used and R&D productivity will decline. In my model the presence of global labor markets does not allow this type of microfundation.

\(^{18}\)Acronym “PEG” refers to the “permanent effects on growth” of policy measures such as R&D subsidies and tariffs; they can alter the steady state growth rate. A different specification of the difficulty index, proposed by Segerstrom (1998), is \( X(\omega, s) = \mu I(\omega, s) \), which formalizes the idea that early discovery fish out the easier inventions first, leaving the most difficult ones for the future. This specification is called (TEG), and it refers to the fact that it implies only “temporary effects on growth” of policy measures. That is the reason why models that use this specification are also known as semi-endogenous growth models (see also, among others, Kortum 1997 and Jones 1995).
order to maximize its expected discounted profits.\textsuperscript{19} Free entry into R&D races drives the expected profits to zero, generating the following equilibrium condition:

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

The usual Arrow or replacement effect (Aghion and Howitt 1992) implies that the monopolist does not find it profitable to undertake any R&D at the equilibrium wages. Substituting for the value of the firm from (7) into (9) we get:

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

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

\subsection*{3.4 Modeling international competition: the overlapping research support.}

Before closing the model I provide some details on my definition of international competition. I model competition as the measure of the set of sectors where research from both countries overlaps. Let \( \xi_c \) be the set of industries where domestic and foreign researchers compete to discover the next vintage of products. I choose \( \bar{\omega} \in (0, 1) \) to be the measure of the subset of industries \( \xi_c \). Therefore the composition of worldwide investment in innovation will be the following:

\[ I(\omega, t) = I^D(\omega, t) + I^F(\omega, t) = I^D_c(t) + I^F(t), \quad \omega \in \xi_c \]
\[ I(\omega, t) = I^D_m(\omega, t) = I^D_m(t), \quad \omega \in 1 - \xi_c \]
\[ X(\omega, t) = 2\kappa N(t) \quad \text{for all } \omega, \]

\textsuperscript{19}The discounted profits equals

\[ v(\omega, t)A h^K \left( \frac{L^K(\omega, t)}{X(\omega, t)} \right)^{-\alpha} \frac{1}{X(\omega, t)} - l^K(1 - s^K) \]

where \( s^K \) is the R&D subsidy.
where \( \kappa > 0 \), \( I^D_c(\omega,t) \) and \( I^D_m(\omega,t) \) are country D’s investment in R&D in the competitive and in the non-competitive sectors respectively, and \( I^F(\omega,t) \) is the research investment of country F. The symmetric structure of the model leads us to study only symmetric allocations of R&D investment, \( I^D_c(\omega,t) = I^D_c(t), \ I^D_m(\omega,t) = I^D_m(t), \ I^D(\omega,t) = I^D(t) \) for all \( \omega \in (0,1) \).

### 3.5 Balanced growth

In this section I derive the steady state properties of the model, where per-capita endogenous variables are stationary. To close the model I need to introduce the labor market clearing condition and the national resource constraints. From the free entry condition (9) we get \( v^D(t)/n^D(t) = (1-\alpha)\dot{X}(t)/X(t) + \alpha \dot{L}^{K}\(t)/L^K(t) \). Using the R&D technology (8) research labor can be expressed as a function of the innovation arrival rate.\(^{20}\) It follows that \( L^{K}(t)/L^K(t) = [1/(1-\alpha)] I^F/I^F + \dot{X}(t)/X(t) \) and \( \dot{L}^{K}(t)/L^D(t) = [1/(1-\alpha)] (I^D_m/I^m + I^D_c/I^c) + \dot{X}(t)/X(t) \); since in steady state the allocation of R&D labor is stationary, it means that \( L^{K}(t)/L^K(t) = \dot{X}(t)/X(t) \). Furthermore, using the specification of the R&D difficulty index (PEG) we obtain \( v^K(t)/v^K(t) = \dot{X}(t)/X(t) = n \), for \( K = D, F \). Finally, from the Euler equation for consumption we get the steady state value of the interest rate, \( r(t) = \rho \).

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

\[
\frac{(c^D + c^F)}{\lambda} = 2 - 2\kappa \left[ \varpi \left( \frac{I^D_c}{A} \right)^{\frac{1}{1-n}} + (1-\varpi) \left( \frac{I^D_m}{A} \right)^{\frac{1}{1-n}} + \varpi \left( \frac{I^F}{A} \right)^{\frac{1}{1-n}} \right]. \tag{11}
\]

The LHS represents the total demand for goods (labor), while the RHS is the total supply, given by total labor resources minus labor used in research. To close the model I need to consider the resource constraint of the two countries. In each country total expenditures plus savings (investment in R&D) must equal the national income, wages plus profits (or interest income on assets).\(^{21}\)

\(^{20}\)Using (8) we can express labor allocated to research as \( L^D(t) = \varpi X(t) (I^D_c(t)/A)^{\frac{1}{1-n}} + (1-\varpi) X(t) (I^D_m(t)/A)^{\frac{1}{1-n}} \) for the domestic country and \( L^F(t) = \varpi X(t) (I^F(t)/A)^{\frac{1}{1-n}} \) for the foreign country respectively. From now on I will use these expressions in the place of the labor allocated to research.

\(^{21}\)In a similar two-country quality-ladders model Segerstrom and Lundborg (2002) do not treat R&D expen-
\[2\kappa \left[ \varpi \left( \frac{I^D}{A} \right)^{\frac{1}{1-\alpha}} + (1 - \varpi) \left( \frac{I^m}{A} \right)^{\frac{1}{1-\alpha}} \right] + c^D = 1 + (c^D + c^F) \left( \frac{\lambda - 1}{\lambda} \right) \left[ 1 - \varpi + \varpi \frac{I^D}{I^D + I^F} \right] \] (12)

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

Notice that R&D investment is simply the wage bill of R&D workers and that each country appropriates the monopoly rent in the subset of industries where that country is the world leader. It is also worth noticing that we are assuming complete “home-bias” in asset ownership, in the sense that domestic firms are completely owned domestically and foreign firms are completely foreign-owned.\(^{22}\)

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

\[\frac{2\kappa}{A} (1 - s^F) = \frac{(c^D + c^F) \left( \frac{\lambda - 1}{\lambda} \right) \left( I^F \right)^{-\alpha}}{\rho + I^D + I^F - n} \left( \frac{I^D}{A} \right)^{1-\alpha}, \ \omega \in \xi_c \]
\[\frac{2\kappa}{A} (1 - s^D) = \frac{(c^D + c^F) \left( \frac{\lambda - 1}{\lambda} \right) \left( I^D \right)^{-\alpha}}{\rho + I^D + I^F - n} \left( \frac{I^D}{A} \right)^{1-\alpha}, \ \omega \in \xi_c \] (14)

\[\frac{2\kappa}{A} (1 - s^D) = \frac{(c^D + c^F) \left( \frac{\lambda - 1}{\lambda} \right) \left( I^m \right)^{-\alpha}}{\rho + I^D - n} \left( \frac{I^m}{A} \right)^{1-\alpha}, \ \omega \in 1 - \xi_c, \]

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

Before solving the equilibrium systems and deriving the main conclusions I will complete the description of the model by showing the expressions for welfare. Substituting the steady d\(\)itudes as investment. They acknowledge that R&D should be treated as investment in national accounts but in reality, they claim, this is not done. We instead include R&D investment in the national budget constraint: one implication of this is that taxes levied to fund R&D subsidy cancel out in the constraint with the reduction in R&D costs due to subsidies. Considering R&D as current expenditures does not change our qualitative results.

\(^{22}\)This assumption is supported by empirical evidence on home-bias in asset ownership. French and Poterba (1991) and Tesar and Werner (1995) estimated the percentage of aggregate stock market wealth invested in domestic equities at the beginning of the 1990s to be well above 90% in the U.S. and Japan and around 80% in the UK and Germany.
state instantaneous utility of the household problem (1) into the discounted utility, I obtain
discounted welfare indicators for both countries,

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

where \( g = [\bar{\omega}(I^D + I^F) + (1 - \bar{\omega}) I^D_m] \ln \lambda \) is the growth rate that, in our symmetric free trade
economy, is common for both countries. In the present framework with quality improving
goods, “growth” is interpreted as the increase over time of the representative consumer utility
level.

Two-country endogenous growth models become complicated when either structural or
policy differences affect endogenous variables. Structural differences, in the form of asym-
matic research supports and policy differences, in the form of national R&D subsidies, are
crucial in my exploration of the effect of international competition on national welfare and
optimal policy. In the following sections I explore the implications of the model numerically.

3.6 Calibration

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

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

See for instance Lundborg and Segerstrom (2002).

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.
to be between 0.1 and 0.6 (Kortum 1993), so as a benchmark I take an intermediate value and set the R&D externality coefficient $\alpha$ at 0.4.

Parameters calibrated “internally”- I simultaneously choose $A$ and $\kappa$ so that the numerical steady state solution of the model matches the following stylized facts: an average growth rate for the US economy of 2.3% in the period 1951-2000 (Penn World Table). An average R&D investment, as a share of GDP, of 2.5% in the period 1951-2000 (NSF S&E Indicators 2004); a consumption, as a share of GDP, of 0.67, in the period 1951-2004 (BEA NIPA tables). I also use an initial value for the subsidy of both countries of 0.044, which is the average effective R&D tax credit for the period 1981-90 estimated in Hall (1992). Table I below summarizes the benchmark parameters calibration.25

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
<th>moment to match</th>
<th>source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>0.07</td>
<td>interest rate</td>
<td>Mehra and Prescott (1985)</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>1.2</td>
<td>markup</td>
<td>Basu (1996)</td>
</tr>
<tr>
<td>$n$</td>
<td>0.014</td>
<td>population growth rate</td>
<td>Jones and Williams (2000)</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.4</td>
<td>returns to R&amp;D</td>
<td>Kortum (1993)</td>
</tr>
<tr>
<td>$A$</td>
<td>0.4</td>
<td>internal</td>
<td>NSF, BEA, PWT</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>0.65</td>
<td>internal</td>
<td>NSF, BEA, PWT</td>
</tr>
</tbody>
</table>

It is worth noting that by calibrating the model on U.S. data, I am implicitly assuming that the stylized facts presented above are similar in the two economies. Since I am studying competition for innovation among similar countries this does not appear to be a problematic assumption. If we consider OECD countries we find many similarities in the long-run facts described above.26

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

In this section I keep R&D subsidies in both countries constant and describe the two basic effects of increases in international competition - increases in $\overline{\omega}$ - on domestic welfare. First, the presence of foreign R&D firms in a larger number of sectors leads to a better international division of research labor, thereby increasing the global innovation rate and benefiting

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

26 The results presented in the following sections are based on this benchmark calibration of the model. In the appendix I perform a detailed sensitivity analysis showing that the qualitative results are not affected by changes in the benchmark parameters.
consumers worldwide. This ‘growth effect’ (GE) of competition increases both domestic and foreign welfare by improving the quality of the goods consumed. Second, foreign firms replace domestic leaders in some of the newly competitive sectors and, as a consequence, monopolistic rents shift abroad and domestic aggregate profits, income, and welfare decline - this is the ‘business-stealing’ effect (BSE) of foreign competition.

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

<table>
<thead>
<tr>
<th>( \omega )</th>
<th>0</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income D</td>
<td>1.346</td>
<td>1.311</td>
<td>1.276</td>
<td>1.241</td>
<td>1.206</td>
<td>1.171</td>
</tr>
<tr>
<td>Income F</td>
<td>1.000</td>
<td>1.034</td>
<td>1.069</td>
<td>1.103</td>
<td>1.137</td>
<td>1.171</td>
</tr>
<tr>
<td>( I^D )</td>
<td>0.154</td>
<td>0.154</td>
<td>0.154</td>
<td>0.153</td>
<td>0.153</td>
<td>0.153</td>
</tr>
<tr>
<td>( I^F )</td>
<td>0.106</td>
<td>0.106</td>
<td>0.106</td>
<td>0.106</td>
<td>0.106</td>
<td>0.105</td>
</tr>
<tr>
<td>( I^C )</td>
<td>0.106</td>
<td>0.106</td>
<td>0.106</td>
<td>0.106</td>
<td>0.106</td>
<td>0.105</td>
</tr>
<tr>
<td>R&amp;D Spending D</td>
<td>0.266</td>
<td>0.241</td>
<td>0.216</td>
<td>0.191</td>
<td>0.166</td>
<td>0.142</td>
</tr>
<tr>
<td>R&amp;D Spending F</td>
<td>0</td>
<td>0.028</td>
<td>0.057</td>
<td>0.085</td>
<td>0.113</td>
<td>0.142</td>
</tr>
<tr>
<td>Growth rate</td>
<td>0.028</td>
<td>0.030</td>
<td>0.032</td>
<td>0.034</td>
<td>0.036</td>
<td>0.038</td>
</tr>
<tr>
<td>Welfare D</td>
<td>0.398</td>
<td>0.426</td>
<td>0.454</td>
<td>0.481</td>
<td>0.509</td>
<td>0.536</td>
</tr>
<tr>
<td>Welfare F</td>
<td>0.320</td>
<td>0.364</td>
<td>0.407</td>
<td>0.450</td>
<td>0.493</td>
<td>0.536</td>
</tr>
</tbody>
</table>

The innovation or GE of competition depends entirely on the presence of local decreasing returns in R&D. Intuitively, the negative country-specific R&D externality \( \alpha \) in (8) implies that research labor is more productive when spread more evenly around the globe than when concentrated in one country. More precisely, the decision to invest in innovation is determined by two margins: the allocation of labor between production of goods and R&D, and the allocation of R&D between competitive and non-competitive sectors. The first margin is not affected by competition because, as we can see in eq.(9) the cost of research is fixed by the constant wage rate.\(^{27}\) Consider now the marginal benefits of investing in research - marginal

\(^{27}\)In fact, as we can see rows 3 to 5 of table II, innovation per-sector does not change with competition. The little changes reported are the result of computation errors in the numerical solution.
productivity of R&D times the present value of the monopolistic firm - in a competitive and a non-competitive sector. In equilibrium the no-arbitrage condition between investing in a R&D firm in a competitive industry and in a non-competitive industry requires the two marginal benefits to be equal:

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

Since the productivity of R&D is higher in the competitive industries - due to the country-specific DRS in R&D - the value of the firm $v^K(\omega, t)$ in equilibrium must be lower in these industries. As the value of the firm is given by profits - which are the same in both industries - discounted by the interest rate and the arrival rate of innovation, it follows that innovation in the competitive sectors must be higher than in non-competitive sectors. Hence, from (16) we conclude that in equilibrium we have $I^D_c + I^F > I^D_m$. As showed in table II innovation per sector does not change with competition, that is \( \partial I^D_c / \partial \omega = \partial I^F / \partial \omega = \partial I^D_m / \partial \omega = 0 \). Thus, competition simply increases the share of industries with an higher arrival rate of innovation, thereby producing a positive effect on the aggregate growth rate of the economy - \( \partial g / \partial \omega = \left[ (I^D_c + I^F) - I^D_m \right] \log \lambda > 0 \) for all \( \alpha > 0 \).

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

5 Foreign competition and optimal non-cooperative subsidies

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

\[ s_n^D(s_n^F; \omega) = \{ \arg \max W^D(s_n^D, s_n^F; \omega) \}, \quad (17) \]

\[ s_n^F(s_n^D; \omega) = \{ \arg \max W^D(s_n^D, s_n^F; \omega) \}. \quad (18) \]

Below I show that if there is strategic policy complementarity this policy game yields a Nash equilibrium pair of subsidies, \( s_n^*^D(s_n^*^F; \omega) \) and \( s_n^*^F(s_n^*^D; \omega) \), as a function of the level of competition.\(^{28}\) Figures 3 to 5 show the Nash equilibrium for different levels of competition.

[FIGURES 1–3 ABOUT HERE]

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

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

where the growth effect (GE) equals the present value of the common growth rate, \( GE = GE^D = GE^F = g/(\rho - n) \). Any time an innovation arrives, consumers can buy goods of a higher quality for the same price. These benefits last indefinitely because future innovations build on past innovations. \( \Pi^K \) are the logs of the per-capita aggregate real profits for the two countries\(^{29}\). The standard resource constraint effect of innovation is represented by the

\(^{28}\)The subscript \( n \) stands for non-cooperative subsidies.

\(^{29}\)The logarithm of the per-capita consumption aggregate profits are

\[ \Pi_i^D = \ln \left( (c_i^D + c_i^F) \left[ \left( \frac{\lambda - 1}{\lambda} \right) \right] [1 - \omega + \bar{\omega} t_i^D / (t_i^D + t_i^F)] / \lambda \right) \]

and

\[ \Pi_i^F = \ln \left( (c_i^D + c_i^F) \left[ \left( \frac{\lambda - 1}{\lambda} \right) \right] [\omega t_i^F / (t_i^D + t_i^F)] / \lambda \right) \]

for the domestic and the foreign country respectively.
log of total real investment in research, \( R^K = \ln(L^K/\lambda) \), that reduces resources available for consumption. Finally, labor income \( w \) is \( \ln(1/\lambda) \). Using (20) we can express the different marginal effects of the R&D subsidy on domestic welfare as follows:

\[
\frac{\partial W^D}{\partial s^D} = \frac{\partial R^D}{\partial s^D} + \frac{\partial GE}{\partial s^D} + \frac{\partial \Pi^D}{\partial s^D}
\]

Here I discuss the effect of an increase in foreign subsidies on the marginal welfare effect of domestic subsidies, and later I explain the effect of increasing foreign competition on the optimal domestic subsidy. The main force driving strategic policy complementarity is the BSE of foreign subsidies. Higher foreign subsidies produce a higher intensity of foreign business-stealing, and so the role of subsidies in protecting domestic rents increases. An increase \( s^F \) improves the marginal effects of \( s^D \) on welfare, thus producing a positive effect on the optimal domestic subsidy.\(^{30}\) The explanation for the best response of the foreign country is analogous and we can omit it.\(^{31}\)

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

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

---

\(^{30}\)Even though the BSE is the key force for this result, two other effects operates in the same direction. First, since DRS in R&D are country-specific, increases in the intensity of foreign research, triggered by higher R&D subsidies, do not affect the productivity of domestic R&D, and thus do not change the marginal impact of domestic subsidies on innovation. Second, the entry of foreign researchers increases the obsolescence of innovation in competitive sectors, thus reducing domestic research in those sectors. It follows that the marginal productivity of domestic R&D increases, so that, at the margin, the innovation effect of domestic subsidies is stronger while the resource constraint is weaker.

\(^{31}\)It is worth noticing that when research supports are asymmetric (\( \bar{\omega} < 1 \)) the Nash equilibrium strategy shows high subsidy in the foreign and low subsidy in the domestic country. This implies that the smaller is the set of sectors where national firms innovate the higher the optimal subsidy is. Intuitively, in a model with country and sector specific DRS in R&D, both the creative and the destructive effects of innovation occur locally and at the industry level. It follows that with fewer innovative sectors research will be concentrated in those sectors, innovation will have high obsolescence rate and R&D will be less productive. As a consequence, the market solution will show more underinvestment in R&D than in those economies with a bigger set of innovative sectors.
are challenged by foreigners is larger. It follows that the role of domestic subsidies as a rent-
protecting devise rises. Moreover, the same force makes the domestic best response steeper, which
implies that the sensitivity of the optimal $s^D$ to changes in $s^F$ rises.\footnote{This result does not rely on the fact that the optimal subsidy is positive. The sensitivity analysis in the appendix shows that when the model is also solved for parameters specifications that give negative optimal subsidies and result 1 still holds qualitatively. More precisely, with those specifications an increase in international competition reduces the optimal domestic R&D tax.} Intuitively, as the scale of foreign competition grows each dollar of foreign subsidies represents a more serious threat to the domestic leadership.\footnote{In this paper I am interested in studying the domestic country, the former leader that experiences increasing competition from the foreign follower. Thus, I comment only briefly on the latter. The smaller change in foreign optimal subsidies is the result of a general equilibrium effect. On the one hand, an increase in $\varpi$ rises both foreign innovation and its national aggregate profits, so for each $s^D$ the level of $s^F$ that maximizes $W^F$ should be lower; indeed, the foreign best-response function shifts left - as we see in the figures. On the other hand, the fact that the domestic best-response function shifts upward, as $\varpi$ increases, triggers strategic complementarity: the foreign policy maker reacts by rising its subsidy - this is a movement along the foreign country’s best-response function. The relatively minor effect of competition on foreign subsidies is the general equilibrium result of these two counteracting forces.}

Finally, even though the optimal subsidy increases primarily for the strategic reasons that I just discussed, foreign competition, by increasing the productivity of domestic R&D, improves also the balance between the resource constraint and the GE. In fact, the presence of the country-specific R&D externality in (8) implies that research efficiency is higher in competitive sectors. Hence, an increase in the number of competitive sectors raises the aggregate productivity of domestic research labor thereby improving the marginal effect of subsidies on aggregate innovation. Since subsidies stimulate innovation, and the latter is produced more efficiently, it follows that competition increases subsidies also through its impact on the growth rate.

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

The scope of our quantitative experiment is to evaluate the optimality of the R&E Tax Credit in the U.S. as a response to the increase in technological competition in the 1970s and 1980s. I compute the U.S. welfare with the observed levels of competition, using the index for the measure of the overlapping research support $\varpi$, and the subsidy rate, shown in figure 1; then I compare this to the welfare under the same competition levels but using the optimal subsidy rates. I consider the following measure of the welfare loss
\[ \tilde{W}^D = \int_0^\infty e^{-(\rho-n)t} \left[ \int_0^1 \ln\left( \frac{\lambda^D}{\lambda} \right) (1+\beta) d\omega \right] dt = \]
\[ \ln \frac{\lambda^D}{\lambda} + \left[ \bar{\omega}(I_c^D + I_F) + (1 - \bar{\omega}) I_m^D \right] \ln \frac{\lambda}{\rho - n} + \ln(1 + \beta) \]

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

### TABLE V

<table>
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<tr>
<th>Welfare loss related to observed US R&amp;D Subsidy</th>
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<tr>
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<tr>
<td>( \omega )</td>
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<tr>
<td>optimal subsidy</td>
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<td>observed subsidy</td>
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<td>welfare Loss in %</td>
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The U.S. R&E Tax Credit estimated in Hall (1992) does not seem to be responding optimally to changes in competition. Even though the scope of this exercise is not to explain the actual U.S. policy response to competition I will make a few remarks on how future research could tackle a positive analysis of the facts.

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

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

7 Extension: local labor markets and the wage-stealing effect of competition

Coming soon.....

8 Conclusion

Coming soon.....

References


9 Appendix: sensitivity analysis
Figure 1. Non-cooperative subsidies with 30% of competitive sectors

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

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