Innovation policy in a Global Economy: a European Perspective

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Abstract

This paper studies the welfare effects of international competition in the market for innovations, and analyzes the costs and benefits of cooperative and non-cooperative R&D subsidies within the context of the European Union and its heterogeneous member states. We set up a two-country quality ladder growth model where the leader, the old member (West), has R&D firms innovating in all sectors of the economy, and the follower, the new member country (East), shows innovating activity only in a subset of industries in which there has been a previous entry of the leader's subsidiary firms and technology transfer has occured. The economies are open and we focus particularly on the interactions between trade, FDI and the innovation policy.

Both governments engage in a strategic R&D subsidy game and respond optimally to changes in other country's subsidy. For a given level of subsidies, increases in foreign competition raise the quality of goods available (growth effect) and lowers domestic profits (business-stealing effect); the overall effect of competition on domestic welfare depends on the relative strength of these two counteracting forces. When governments play a strategic subsidy game, increases in foreign competition trigger a defensive innovation policy mechanism that raises the optimal domestic R&D subsidy. Cooperation in subsidies is beneficial for the EU economy at the medium levels of cooperation, while it is welfare reducing at very low or very high levels of cooperation. The medium levels of cooperation, however, can not be implemented without transfers to the economy of the West which experiences welfare losses.

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1 Introduction

In the decades following World War II, U.S. firms were undisputedly the global leaders in the production and provision of innovation-intensive goods and services. In the 1970s and early 1980s, however, Japanese and European firms began to challenge American technological leadership in high-tech industries such as electronics, aircraft, scientific instruments, and medical equipment.

Within the European Union, there is a similar development in the context of the old and new member countries. Previous innovation dominance of the traditional EU countries has been challenged by the new member countries in several hi-tech industries. The European Techno-Economic Policy Support Network studies document rapid market entry and increased innovation activity in two sectors (pharmaceuticals and car industry) in several Eastern European countries which had a tradition of an active R&D sector in the post-WWII decades. However, most revival in the R&D activities in the post-transition period is preceded by the inflows of the old members FDI and the establishment of the multinational corporations' subsidiaries in the new member markets.

These developments have fueled debates on the welfare effects of an increasing foreign competition in the innovation-intensive industries, and have led academics and policy makers to discuss the virtues and dangers of different policy responses to competition[1]. In the EU context, these issues become particularly interesting for the prospect of growth revival and optimal welfare policies in the EU region as a whole.

In this paper we study the effects of the international competition on welfare and on the double role of the R&D subsidies in stimulating innovation and protecting national interests. While trade policies such as tariffs and export subsidies are restricted by the

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

WTO and other international institutions, generalized subsidies to R&D are left to the discretion of single governments. While there is virtually no trade restrictions within the European market and various aspects of industrial policy have been regulated, the R&D policies are hardly synchronized. Hence the policy makers can use this dimension of the fiscal policy to promote the competitiveness of national firms in the intra-EU market, as well as in the global economy. Moreover, the strategic nature of the R&D subsidies leads us naturally to consider possible national and supra-national gains from policy cooperation. Therefore, we study the effects of international competition in innovation on welfare and the associated cooperative and non-cooperative R&D policy within the EU.

We set up a non-scale, fully-endogenous, Schumpeterian growth model (Dinopoulos and Thompson, 1998, Howitt, 1999, Young, 1998, Peretto, 1998), with two countries, West and East (old and new member states within the EU context), having the same population and preferences, but different distributions of research efforts across industries, autonomously choosing their innovation subsidy. Trade is free and multinational corporations are active in a subset of sectors of the economy. Newly accessed countries, with relatively high human capital and low wages present attractive destinations for the old members' subsidiary establishments. In the search for a lower production cost, the old members transfer their production to the new member regions, which brings along the technology transfer and the activation of the local R&D sector for the purpose of adaptive R&D. This triggers the innovation of the local entrants (potentially contracting the research institutions previously revived by subsidiaries' demand for the adaptive R&D) who start competing for both regions' market share. This environment growth is driven by R&D investment of profit-maximizing firms competing to develop higher-quality products and obtain leadership in the market. However, the FDI activity as the main vehicle of technological transfer to the East is endogenous. It is driven by the trade-off between the production outsourcing to the cheeper location and an increaded probability of the Eastern leapfrogging due to higher technological spillovers.

Economists have explored the welfare effects of competition focusing on changes in product market competition produced by the foreign entry. We propose a different, and complementary, measure that focuses on competition in the innovation activity, originating in the Western (old member) economy, and subsequently triggered in a subset of Eastern (new member) industries with the entry of subsidiary companies.

As a consequence, increases in international competition are unidirectional in that they represent the penetration of foreign researchers into industries where previously only domestic innovators had been active.

The second component of the model is the introduction of a strategic R&D subsidy game in the endogenous growth framework. Each government sets subsidies autonomously in order to maximize national welfare, thereby responding optimally both to the changes in the other country's subsidy and in the international competition. There are two basic motivations for the R&D subsidies in this economy: the presence of knowledge spillovers, typical of R&D-driven growth models, leads to a non-efficient market allocation of the research effort, so creating the scope for policy intervention. Second, for the old members, the presence of foreign firms in innovation races produces a strategic motive for subsidies: R&D subsidies can be used to support national firms in the competition for the global leadership. On the other hand, for the new members, R&D subsidies provide a higher incentive for the production transfer by the old memebers, and the activation of domestic R&D activitiy in the first place.

Models of trade and growth turn out to be difficult to solve when countries are asymmetric in their economic structure and in their policy, thus we calibrate the model to the EU economy and explore its qualitative properties numerically.[2] In the benchmark simulation, we focus on three specific issues: i) the effects of each region's subsidy on innovation and welfare, holding the other region's subsidy at 0% level ii) the outcomes of a non-cooperative subsidy game iii) the effect of cooperation between the West and the East in setting the R&D subsidies.

The main results are as follows. Increases in innovation competition have two opposite effects on welfare: a *growth effect* (henceforth GRE) and a *business-stealing effect* (henceforth BSE).

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

As is common in quality-ladder models, growth increases welfare through the effect of quality improvements on consumer surplus. This is the GRE of competition, which benefits consumers in both countries.Entry of the Eastern R&D workers into new sectors also implies that, with a probability proportional to their research effort, monopoly rents shift from the Western to the Eastern firms. "Home bias" in asset ownership documented in the literature implies that profit-shifting has a negative impact on the Western income and welfare - this is BSE.[3] It follows that the effect of competition on welfare in the West depends on the relative strength of the GRE and the BSE: if the GRE is stronger (weaker) than the BSE, competition raises (reduces) Western welfare. On the other hand, Western subsidies promote innovation in the West and create positive GRE effect, but also result in a higher transfer and a reduction in the Eastern wages and profits.

When both countries play a strategic subsidy game and respond optimally to the changes in other region's subsidies and, thus, the competition in innovation, we find that increases in competition raise the *scale* of foreign business-stealing, thereby increasing the scope for strategic subsidies in the home country. Hence, competition increases the role of subsidies as a rent-protecting device and triggers a sort of *defensive innovation policy* mechanism.

Finally, we show that medium levels of subsidy cooperation are beneficial for the EU economy. However, the West experiences welfare losses due to a reduced multinationals' production transfer and higher competition threat from the East, compared to the no- or full-cooperation scenarios. This implies that policy cooperation will not be implemented without certain transfer mechanisms.

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

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

1996, Neary and Leahy, 2000, and Leahy and Neary, 1999, and 2001). This literature has not devoted much attention to the effects of international competition and trade liberalization on strategic R&D subsidies.

Furthermore, they are confined to static models where the dynamic effects of innovation are not taken into account.

The second strand of related works is the one exploring the welfare effects of competition in endogenous growth frameworks (i.e. Kludert and Smulders,1997, and Tang and Waelde, 2001), as well as that studying the links between competition, national and/or international, and growth (i.e., Aghion et. al., 2006, Boldrin and Levine, 2005, Gustafsson and Segerstrom, 2007, Melitz, 2003, Navas and Licandro, 2006, Peretto, 2003).

The growth effect of international competition in the present paper is, though, substantially different from those in the existing literature for the following reasons: first, the effect is produced by foreign entry in R&D and not by product market competition; second, the growth mechanism does not operate through the productivity gap between entrant and exiting firms - firms are homogenous in production - but through welfare improving labor reallocation and the innovation activity revival in the East. Gustafsson and Segerstrom (2011) study a similar model (multinational companies transfer production and trigger foreign *imitative* R&D), but are not interested in R&d subsidy game. They study the effects of IPR protection for which that set-up is suitable.

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

2 The model

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

2.1 Households

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

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

subject to

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

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

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

where N_0 is the initial population and n is its constant growth rate, ρ is the common rate of time preference - with $\rho > n$ - and $r(t)$ is the market interest rate on a risk-free bond available in both countries. $q(j, \omega, t)$ is the per-member flow of good ω, of quality $j \in \{0, 1, 2, ...\}$, purchased by a household at time $t \geq 0$. $p(j, \omega, t)$ is the price of good ω of quality j at time t, $c(t)$ is nominal expenditure, and $W(0)$ and $Z(0)$ are human and non-human wealth levels. A new vintage of a good ω yields a quality equal to λ times the quality of the previous vintage, with $\lambda > 1$. Different vintages of the same good ω are regarded by consumers as perfect substitutes after adjusting for their quality ratios, and $j^{\max}(\omega, t)$ denotes the maximum quality in which the good ω is available at time t. As is common in quality ladders models we 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 the static utility by spreading their expenditures $c(t)$ evenly across the product lines and by purchasing in each line only the product with the lowest price per unit of quality, that is the product of quality $j = j^{\max}(\omega, t)$. Hence, the household's demand of each product is:

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

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

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

2.2 Product market

In each country, firms can hire workers to produce any consumption good $\omega \in [0, 1]$ using a linear technology. Unit labor requirement for any good production is a^k, where $k = W, E, M$ is the producer indicator, West (W, old member), East (E, new member) and multinational or domestic firm subsidiary (M). The wage rate is w^K, $K = W, E$, with $w^W > w^E$. 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. Technology is mobile, in the sense that a firm that owns the technology can use it everywhere.

As is usual in Schumpeterian models with vertical innovation (e.g. Grossman and Helpman, 1991 and Aghion and Howitt, 1992), the next best vintage of a good is invented by means of the R&D performed by the 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. We assume that the patent becomes obsolete when further innovation occurs in the industry. The unit elastic demand structure encourages the monopolist to set the highest possible price to maximize profits, while the existence of a competitive fringe sets a ceiling equal to the world's lowest unit cost of the previous quality product. This allows us to conclude that the price $p\left(j^{\max}(\omega,t),\omega,t\right)$ of every top quality good is:

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

As long as the incumbent's production cost are such that it can drive the previous incumbent out of the market and reentry is costly, he can charge the price up to the λ times marginal cost of the competitive fringe, i.e. potential entrants who could produce the previous vintage. However, we assume that entry is costless only for the local competitive fringe (firms in the market of the current leader) and thus the maximum price a leader can charge is λ times the local marginal cost of production.

From the static consumer demand (**??**), the demand for each product ω is:

$$\frac{(c^{W}(t)+c^{E}(t))N(t)}{\lambda a^{k}w^{K}(t)}=q\left(\omega,t\right), \tag{5}$$

where $c^{W}(t)$ and $c^{E}(t)$ are the domestic and foreign expenditures at time t. The above equation implies that, in equilibrium, the supply and demand of every consumption good coincides. It follows that the monopoly profits accruing to global quality leaders from country $K=W,E$ in sector ω will be equal to

$$\pi^{K}(\omega,t)=q\left(\omega,t\right)a^{k}w^{K}(t)\left(\lambda-1\right)=(c^{W}(t)+c^{E}(t))N(t)\left(1-\frac{1}{\lambda}\right). \tag{6}$$

For domestic subsidiary firms that produce in foreign country, the profits are given by

$$\pi^{MNE}(\omega,t)=q\left(\omega,t\right)\left(\lambda a^{W}w^{W}(t)-a^{M}w^{E}(t)\right)=(c^{W}(t)+c^{E}(t))N(t)\left(1-\frac{a^{M}w^{E}(t)}{a^{W}w^{W}(t)\lambda}\right). \tag{7}$$

2.3 R&D races

In each industry, leaders are challenged by the R&D firms that employ workers and produce a probability intensity of inventing the next version of their products. Before the establishment of subsidiary firms in foreign country, only Western firms are capable of performing R&D and challenging Western leaders across industries. However, once a subsidiary adaptive R&D has been conducted in the East, technology transfer makes possible for the R&D in the East as well. The arrival rate of innovation in industry ω at time t is $I(\omega, t)$, which is the aggregate of the Poisson arrival rate of innovation produced by all R&D firms targeting product ω. Each R&D firm can produce a Poisson arrival rate of innovation according to the following technology:

$$I_i^K(\omega, t) = \frac{A^k l_i^K(\omega, t)}{X(\omega, t)}, \tag{8}$$

where $X(\omega, t) > 0$ measures the degree of complexity in the invention of the next quality product in industry ω, $L^K(\omega, t) = \sum_i l_i^K(\omega, t)$ is the total labor used by R&D firms and $I^K(\omega, t) = \sum_i I_i^K(\omega, t)$ is the total investment in R&D (total arrival rate) in country K, sector ω. A^k is the R&D productivity parameter where A^M is the productivity of adaptive R&D, while A^W and A^E are the R&D productivities in the West and the East, respectively.

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

$$X(\omega, t) = 2\kappa N(t), \tag{9}$$

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

Governments subsidize R&D expenditures at the rate s^K. Each R&D firm chooses l_i^K in order to maximize its expected discounted profits. Free entry into the R&D races drives the expected profits to zero, generating the following equilibrium condition:

$$v^K(\omega, t)\frac{A^k}{X(\omega, t)} = (1 - s^K)w^K. \tag{10}$$

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

$$v^K(\omega, t) = \frac{\pi^K(\omega, t)}{r(t) + I(\omega, t) - \frac{\dot{v}(\omega,t)}{v(\omega,t)}}, \tag{11}$$

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

$$\frac{\pi^K(\omega, t)}{r(t) + I(\omega, t) - \frac{\dot{v}(\omega,t)}{v(\omega,t)}} = \frac{(1 - s^K)w^K X(\omega, t)}{A^k}, \tag{12}$$

This condition, together with the Euler equation summarizes the utility maximizing household choice of consumption and savings, and the profit maximizing choice of the manufacturing and the R&D firms.

2.4 Balanced growth

In this section we derive the steady state properties, where per-capita endogenous variables are stationary. To close the model we need to introduce the labor market clearing conditions and the national resource constraints. From the free entry condition (**??**) and the steady state stationarity of the R&D labor allocation, it follows that $\dot{v}^K(t)/v^K(t) = \dot{X}(t)/X(t) = n$, for $K = W, E$. Finally, from the Euler equation for consumption we get the steady state value of the interest rate, $r(t) = \rho$.

The arbitrage conditions specified in the previous section lead to the following steady state expressions for equilibrium conditions (**??**):

$$\begin{aligned}
\frac{2\kappa N}{A^W}(1-s^W)w^W &= \frac{\pi^W}{\rho+I^W-n}, \\
\frac{2\kappa N}{A^M}(1-s^E)w^E &= \frac{\pi^{MNE}}{\rho+I^W+I^E-n}-\frac{\pi^W}{\rho+I^W-n}, \\
\frac{2\kappa N}{A^E}(1-s^E)w^E &= \frac{\pi^E}{\rho+I^W+I^E-n},
\end{aligned} \tag{13}$$

where the second line presents the equilibrium condition for establishing Western subsidiary firms in the East. The adaptive R&D cost is equal to the benefit of these establishments accruing to the Western headquater. i.e. the value of the new subsidiary minus the value of the transferred business from the Western economy (only the surplus created).

2.4.1 Industry composition

There are three types of industries in the global economy - a set of industries with the Western quality leaders and production in the West, the industries with Western quality leaders but outsourced production to the subsidiary firms in the East, and finally the set of industry with the production in the East by the Eastern quality leaders. We denote the shares of each of these types by ω^W, ω^M and ω^E, respectively, with $\omega^W+\omega^M+\omega^E=1$. In a steady state equilibrium, the shares of industries need to be constant implying that the outflows and the inflows into each type have to be the same. Formally, in the West

$$\omega^W I^M = (\omega^M+\omega^E)I^W \tag{14}$$

which gives the share of Western industries as a function of the innovation and transfer rates

$$\omega^W = \frac{I^W}{I^M+I^W} \tag{15}$$

In the East, the condition for the industries with the Eastern quality leaders is given by

$$\omega^E I^W = \omega^M I^E \tag{16}$$

which, using the expression for the share of Western industries, gives

$$\omega^E = \frac{I^M}{I^M + I^W} \frac{I^E}{I^E + I^W} \tag{17}$$

Finaly, using $\omega^W + \omega^M + \omega^E = 1$, the share of industries with the production by multinationals, is derived as

$$\omega^M = \frac{I^M}{I^M + I^W} \frac{I^W}{I^E + I^W} \tag{18}$$

2.4.2 Labor markets

The total manufacturing labor is given by the total labor supply minus the labor used in the R&D.

$$\frac{(c^W + c^E)}{\lambda w^W}(1 - \bar{\omega}) = L^W - 2\kappa \left(\frac{I^W}{A^W} \right), \tag{19}$$

$$\frac{(c^W + c^E)}{\lambda w^E} \frac{\bar{\omega} I^E}{I^W + I^E} + \frac{(c^W + c^E) a^M}{\lambda a^W w^D} \frac{\bar{\omega} I^D}{I^D + I^F} = L^E - 2\kappa \left[\frac{I^{MNE}}{A^M} + \bar{\omega} \frac{I^E}{A^E} \right], \tag{20}$$

where $\bar{\omega}$ presents the share of sectors in which production is conducted in the East, either by a subsidiary firm (multinational, MNE) or by a local Eastern firm.

2.4.3 Expenditures

In each country, the total expenditures plus savings (investment in R&D) must equal the national income, wages plus profits (or interest income on assets).[4]

$$c^W + 2\kappa \frac{I^W}{A^W} w^W + 2\kappa \frac{I^{MNE}}{A^M} w^E = w^W + (c^W + c^E) \left[(1 - \frac{1}{\lambda})(1 - \bar{\omega}) + (1 - \frac{a^M w^E}{\lambda a^W w^W}) \bar{\omega} \frac{I^W}{I^W + I^E} \right], \tag{21}$$

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

$$c^E + 2\kappa \frac{I^E}{A^E} w^E \bar{\omega} = w^E + (c^W + c^E)(1 - \frac{1}{\lambda})\bar{\omega} \frac{I^E}{I^W + I^E}. \tag{22}$$

2.4.4 Welfare

We complete the description of the model by showing the expressions for welfare. Substituting the steady state instantaneous utility of the household problem (**??**) into the discounted utility, discounted welfare indicator for both countries is

$$W^K \equiv \ln \frac{c^K}{P} + \frac{g}{\rho - n} \tag{23}$$

where $g = \left[I^W + \bar{\omega} I^E \right] \ln \lambda$ is the global growth rate that, which in our economy with perfect international knowledge spillovers increases consumer surplus in both countries. P represents the price index. In the present framework with quality improving goods, "growth" is interpreted as the increase of the representative consumers' utility level over time .

Two-country endogenous growth models become complicated when either structural or public policy differences affect the endogenous variables. We explore the implications of the model numerically.[5] We focus on three specific issues: i) the effects of Western (Eastern) subsidy on both economies for a given level of Eastern (Western) R&D subsidies; ii) the effects of optimal subsidies, when countries play a non-cooperative subsidy game. iii) the incentives to set R&D subsidies cooperatively. Calibration details are given in the appendix.

3 Benchmark numerical results

In this section we present the results of the first numerical exercise. We keep the Western (Eastern) R&D subsidies constant at 0% and describe the two basic effects of

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

an increases in the Eastern (Western) subsidies on the two economies. We summarize the main findings:

Result 1. *Higher Eastern R&D subsidy produces the following effects on the Western economy (Figure 1):*

i. *Reduces Western profits and income - this is the BSE.*

ii. *It reduces total R&D spending and innovation, as well as the rate of production transfer to the East through subsidiary firms as long as the Eastern subsidy is not too high. For high levels of Eastern subsidy, the transfer rate starts increasing due to the positive effect of subsidy on investment in adaptive R&D and reduction in I^E which compensates for the increase in the labor cost in the East.*

iii. *As long as the increase in Eastern innovation is strong enough, it increases the growth rate of the global economy - this is the GRE.*

iv. *The effect on Western welfare depends on the relative strength of the GRE* and BSE.

Result 2. *Higher Western R&D subsidy produces the following effects on the Eastern economy (Figure 2):*

i. *Reduces Eastern profits and income - this is the BSE.*

ii. *It reduces total R&D spending and innovation, but increases the presence of foreign subsidiary firms. Profits shift to the West and the Eastern relative wage falls.*

iii. *As long as the increase in the Western innovation is strong enough, it increases the growth rate of the global economy - this is the GRE.*

iv. *The effect on Eastern welfare depends on the relative strength of the GRE* and BSE.

Next, we compute the optimal strategic R&D subsidy for both countries. A two-stage policy game between the two countries is set up: at stage 1, governments set their

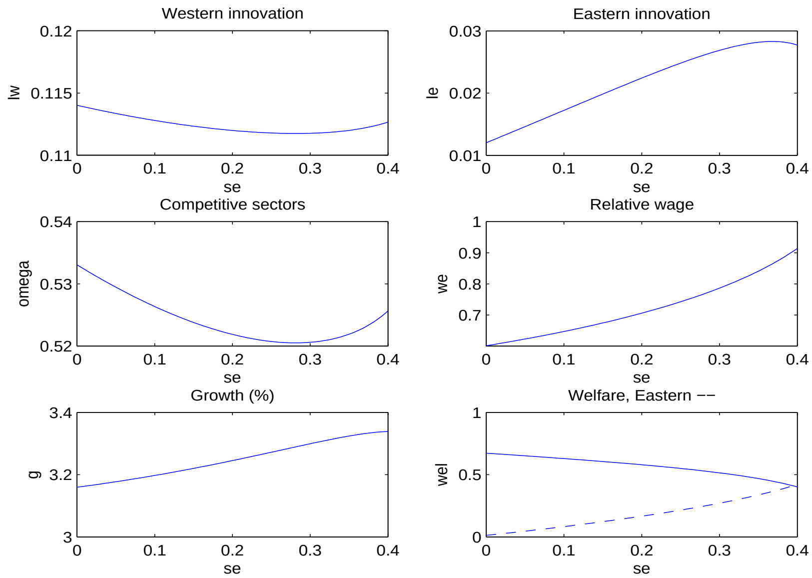

Figure 1. Increase in foreign subsidy

subsidies; at stage 2, the R&D and manufacturing firms choose their profit-maximizing level of activity, and households choose their utility-maximizing consumption bundles and asset holdings. For each level of the other country's subsidy, policy makers set their subsidy according to the following best-response functions

$$s_n^W(s_n^E) = \arg\max \left\{ W^W(s_n^W, s_n^E) \right\}, \tag{24}$$

$$s_n^E(s_n^W) = \arg\max \left\{ W^E(s_n^W, s_n^E) \right\}. \tag{25}$$

This policy game yields a Nash equilibrium pair of subsidies, s_n^{*W} and s_n^{*E}.[6]

Result 3. *Increases in other country's R&D subsidy trigger a defensive R&D subsidy response: higher levels of foreign subsidy lead to higher optimal strategic subsidy in the home country* $s_n^{*W}(s_n^{*E})$ *and v.v.*

[6]The subscript n stands for non-cooperative subsidies.

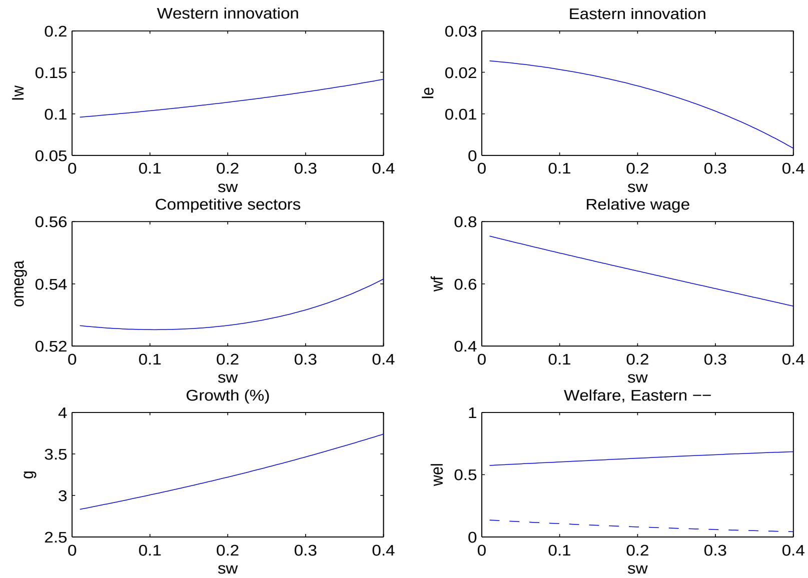

Figure 2. Increase in domestic subsidy

The first step in understanding this result is to explain that the best-response functions obtained in the simulation confirm the presence of strategic policy complementarity. To show 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 the optimal subsidy. We do this by expressing the welfare equation in a form that facilitates intuition, and by decomposing the marginal effects of subsidies on national welfare. The present value of national welfare (**??**) in both countries can be written as

$$W^K \equiv (\rho - n)U = \ln \frac{c^K}{P} + \frac{g^K}{\rho - n} = G + Y^K - R^K, \text{ for } K = D, F, \tag{26}$$

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

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

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

Thirdly, in sectors with Eastern incumbents successful Western innovation drives Eastern firms out of business and shifts monopolistic profits toward the West, thereby increasing domestic income and welfare. This is the $IBSE$, which in our utility metric (**??**) works on Π^W. Since home R&D firms do not take this effect into account when innovating, a bias toward underinvestment is produced.

Finally, the R&D investment by a national firm increases the sectorial level of research. This is the RCE and has the following components: first, more resources must be allocated to R&D in order to maintain the steady state level of innovation, this makes fewer resources available for consumption. Second, as consumption is reduced, incumbent firms profits in all sectors will also be reduced, resulting in even lower consumption. Since R&D firms do not take this effect into account, this produces another bias toward overinvestment. However, higher $DBSE$ increases the incentive for production transfer through subsidiaries which increases domestic profits and provide more labor resources for R&D. This mitigates the negative RCE. These components affect welfare through the resource constraint: in the metric of our utility function in (**??**) they affect R^W, total labor resources allocated to R&D, and the total profit Π^W respectively.[7] Using (**??**) we can express the different marginal effects of the R&D subsidy on the Western welfare as follows:

$$\frac{\partial W^W}{\partial s^W} = \underbrace{\frac{\partial (R^W, \Pi^W)}{\partial s^W}}_{\substack{RCE \\ (-)}} + \underbrace{\frac{\partial G}{\partial s^W}}_{\substack{GRE \\ (+)}} + \underbrace{\frac{\partial \Pi^W}{\partial s^W}}_{\substack{IBSE \\ (+)}} + \underbrace{\frac{\partial \Pi^W}{\partial s^W}}_{\substack{DBSE \\ (-)}} \,, \tag{27}$$

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

In the East, the effects of R&D subsidy are similar - positive GRE and $IBSE$, and negative $DBSE$ and RCE. However, Eastern subsidies decrease the production transfer rate as the relative wage rises. For higher level of subsidies, the increase in innovation rate falls, GRE and $IBSE$ are reduced, while the transfer rate starts returning to higher levels.

The main force driving strategic policy complementarity is the strategic motive for subsidy: higher Eastern subsidies produce a higher *intensity* of foreign business stealing, thereby strengthening the role of Western subsidies in protecting domestic rents -this is indicated by $IBSE$ in (**??**). It follows that an increase in s^E improves the marginal effects of s^W on welfare, thus raising the optimal Western subsidy. Although the optimal subsidy increases primarily for the strategic reasons that we have just discussed, Eastern competition also improves both the GRE and the RCE of the Western subsidies.

A final remark on the sign of the optimal R&D subsidy is necessary. In quality-ladder growth models whether the optimal R&D subsidy is positive or negative depends on the relative strength of the several externalities involved. Similarly to Grossman and Helpman (1991) and Segerstrom (1998), in this model the sign of the optimal subsidies depends on parameter specifications.

[7] This effect is sometimes called in the literature 'intertemporal R&D spillovers effect' because it depends on the impact of current innovation on future R&D productivity.

4 The gains from policy cooperation

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

In this section, we introduce an R&D policy coordination that internalizes the business-stealing effect and takes into account the growth effect of subsidies in both countries. We consider a form of cooperation where the subsidies are set separately by the governments in order to maximize the welfare function that is a linear combination of national and world welfare.

$$s_{co}^W(s_{co}^E;\overline{\omega},\beta) = \arg\max\left\{T^W(s_{co}^W, s_{co}^E;\overline{\omega},\beta)\right\},$$

$$s_{co}^E(s_{co}^W;\overline{\omega},\beta) = \arg\max\left\{T^E(s_{co}^W, s_{co}^E;\overline{\omega},\beta)\right\},$$

where

$$T^K = (1-\beta)W^K + \beta W^{EU}, \text{ for } K = W, E \tag{28}$$

is the the objective function of policy maker K and

$$W^{EU} = W^W + W^E = 2G + (Y^W + Y^E) - (R^W + R^E) \tag{29}$$

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

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

The basic result can be summarized as follows:

Result 4. *For the East facing increases in the Western subsidies, the incentives to cooperate increase and the gains are positive, as well as for the EU up until a certain medium level of cooperation. Higher levels reduce the subsidies further, production transfer increases and both the Eastern and the EU welfare fall. On the other hand, the Western welfare decreases with cooperation for low to medium levels and increases for medium to high degrees of cooperation. Overall, a medium level of policy cooperation increases the EU welfare, but, in the absence of a compensation scheme, it will not be implemented. (Table 1. and Figure 3.)*

β	s^W	s^E	W^W	W^E	W^{total}	$growth$
0.00	0.36	0.4	0.489	0.319	0.808	3.80
0.25	0.32	0.4	0.475	0.337	0.812	3.69
0.50	0.28	0.4	0.457	0.358	0.815	3.58
0.75	0.24	0.38	0.460	0.352	0.812	3.46
1.00	0.08	0.23	0.524	0.239	0.763	3.03

Table 1. The effect of cooperation

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

$$\frac{\partial T^W}{\partial s^W} = \underbrace{\frac{\partial R^W}{\partial s^W}}_{\substack{RCE \\ (-)}} + \underbrace{(1+\beta)\frac{\partial G}{\partial s^W}}_{\substack{GRE \\ (+)}} + \underbrace{\frac{\partial \Pi^W}{\partial s^W}}_{\substack{IBSE \\ (+)}} + \underbrace{\beta\frac{\partial \Pi^E}{\partial s^W}}_{\substack{IBSE \\ (-)}} . \qquad (30)$$

Comparing (**??**) with (**??**) we can observe that two additional effects appear in the case with cooperation.[8] First, we see the internalization of the negative $IBSE$ of the Western subsidies on the Easternn profits: a fraction β of the damage inflicted upon the East by subsidy-led profit-stealing is internalized. Second, Western subsidies have an additional growth effect, βGRE, because policy cooperation takes into account the positive innovation effect of home R&D subsidies on foreign welfare.

Low levels of cooperation imply high subsidies, strong FDI and weak threat from the Eastern innovation which does not bring enough incentives for the cooperation from the West, while the East and the total EU welfare would benefit from cooperation and lower subsidies. Intermediate levels of cooperation impose reduction in the s^W, less FDI, increase in the Eastern innovation, and a reduction in Western innovation and profits. The Western welfare is at the lowest point while the East benefits due to higher profits and labor income. Finally, with high cooperation, both subsidies are reduced, FDI is stronger, and the Eastern threat is again low. Basically, these are the levels of subsidies that imply that the East is mostly used as a production hub for the Western economy. Hence, when cooperative subsidies are low (high degree of cooperation), the West benefits less from internalizing the international business-stealing, while the opposite happens in the East. Lower promotion of innovation reduces the growth rate of both regions. Medium levels of cooperation are, thus, optimal for the EU as a whole but not implementable due to the negative effect on the Western welfare.

The intuition for the positive global gains from cooperation is straightforward: on the one hand, in setting subsidies non-cooperatively neither government takes into account the GRE of its subsidies on the other country's welfare, thereby producing an incentive to free ride on innovation subsidies; on the other hand, competitive subsidies do not take into account the negative $IBSE$ on the other country, thus creating a beggar-thy-neighbor effect. Finally, there is a trade-off for the East in terms of labor allocation between subsidiary firms and own R&D sector, which is optimal at the intermediate levels of cooperation. These three external effects produce a prisoner-dilemma type of outcome that leads to lower levels of global welfare.

Finally, there is another result worthy of mention: optimal subsidies are lower under

[8] We have omitted the $DBSE$ because it is not key for explaining the intuition.

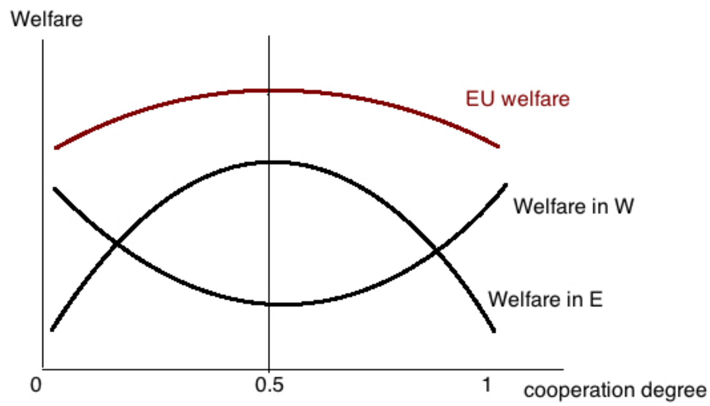

Figure 3. Welfare effect of cooperation

cooperation. Internalizing the negative $IBSE$ on foreign income reduces the strategic motive for subsidies, thus reducing $s_{co}^{W*}(s_{co}^{E};\overline{\omega},\beta)$; whereas the positive GRE on foreign welfare increases the growth motive, thus increasing $s_{co}^{W*}(s_{co}^{E};\overline{\omega},\beta)$. Depending on the relative strength of these two effects the optimal cooperative subsidy can be higher or lower than the non-cooperative one.

5 Conclusion

In this paper we have analyzed the interaction between the international technological competition and the optimal competitive and cooperative R&D subsidies in two asymmetric growing economies. The dimension of competition that we explore is based on a leader-follower representation of the EU economy where the leading country innovates in a broader set of industries than the follower. The innovation in the follower occurs only within the sector where the leader has established subsidiary firms and has thus transferred technology and has activated the R&D activities of the follower.

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

Increases in competition trigger a *defensive R&D subsidies* mechanism: the optimal subsidy increases with the number of sectors where domestic and foreign firms compete in innovation. As competition increases, the role of subsidies in protecting domestic rents becomes more relevant. Furthermore, the strategic motive for subsidies suggests the importance of evaluating the gains from cooperation in the R&D policy. Implementing the cooperative solution and comparing it to the non-cooperative outcome, we find that when cooperative subsidies are low (high degree of cooperation) or high (low degree of cooperation), the West benefits less from internalizing the international business-stealing, while the opposite happens in the East. High cooperation that reduces subsidies also reduces the growth rate of both regions. Medium levels of cooperation are optimal for the EU as a whole but not implementable due to the negative effect on the Western welfare. Hence, the presence of innovation asymmetries among countries and the specific role of the FDI as a technology transfer vehicle can create obstacles to the implementation of cooperative R&D subsidies that benefit the EU welfare.

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6 Appendix: Calibration

In this section we calibrate the parameters of the model to match long-run empirical regularities of the EU economy. We calibrate 8 parameters. Three of them, ρ, λ, n, are calibrated using benchmarks from the growth and business cycle literatures, $a^W$is set to 1, while the others, A^W, A^M, A^E, a^M and κ, are calibrated internally in order for the model's steady state to match facts of the EU economy.[9] This calibration exercise is exclusively targeted at understanding the qualitative properties of the model.[10]

Some parameters of the model have close counterparts in real economies so that their calibration is straightforward. We set ρ, which in the steady state is equal to the interest rate r, to 0.07 to match the average real return on the stock market for the past

[9]Notice that, by calibrating the model on EU data we are implicitly assuming that the stylized facts presented above are similar in the two economies.

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

century of 0.07.[11] We set λ to 1.2, to match an average markup over the marginal cost of 20 per cent. This is consistent with the range $10-40$ percent reported in Basu (1996) estimates of average sectorial mark-up. We calibrate n to match the population growth rate of 1.14%, which is the average business sector labor force growth rate.

We simultaneously choose A^W, A^E, A^M, a^M and κ so that the numerical steady state solution of the model matches the following stylized facts: an average growth rate for the EU economy of 2.3%; an average R&D investment, as a share of GDP, of 2.5%; consumption, as a share of GDP, of 0.67 and the Eastern relative wage of 0.6. We also use an initial value for the subsidy of both countries of 0%. The parameters' values obtained minimizing the quadratic distance between the model steady state and the statistics listed above are $A^M = 0.24$, $A^F = 0.32$, $a^M = 0.9$, $A^W = 0.4$ and $\kappa = 0.65$.

[11] 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.