# Cooperative and Non-cooperative R&D Policy in an Economic Union

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**Abstract**

Should R&D policies be coordinated within an economic union? Given the potential impact of R&D policies on firms' competitiveness, why do R&D policies remain national, while e.g. trade and industrial policies are strongly regulated or coordinated within economic unions? To address such questions, we construct a simple model with horizontally differentiated consumer goods, where each firm may invest in R&D to improve the quality of its product. Assuming that the goods are produced in different countries within an economic union, we compare uncoordinated and coordinated R&D policies. We show that uncoordinated R&D policies imply too small R&D subsidies for horizontally differentiated goods and too high subsidies for goods that are close substitutes. Furthermore, small, net exporting countries of R&D intensive goods have less incentives to subsidize R&D than large countries, resulting in an unwarranted vertical product differentiation between goods produced in different countries. Coordination of R&D policies at the union level helps overcome some of these problems. However, if only a subset of countries coordinate their R&D policies, the union welfare may be lower than if there is no R&D coordination at all.

# 1 Introduction

Should industrial R&D policies within the EU be centralized or decentralized? Should national R&D policies towards firms and industries be regulated within an economic union like the EU? When other policy measures – such as trade and industrial policies – are subject to EU regulations, harmonization or centralization, why does not the same apply for R&D policies? These are some of the questions that we address in this paper.

Research and development (R&D) play an important role in many industries. R&D and policies to stimulate R&D may benefit both firms and consumers by improving the quality or reducing the cost of products. Such policies may also affect the competitiveness of firms in international markets. Hence, in many countries R&D policies are considered to be of vital importance for the industrial development. To mention only one example, the National Technology Agency of Finland (TEKES) states that "Tekes´ primary objective in to promote the technological competitiveness in Finnish industry and the service sector ....(and) increase production and exports." Similar objectives found the basis for public funding of industrial R&D in many countries.

There are a number of reasons why R&D policies receive so much attention. First, of course, it is simply due to the fact that R&D is potentially very important for economic development and growth, and thus an area in which policies may have a great impact. Secondly, there are typical characteristics of R&D – such as spillovers and externalities, public-goods aspect of the activity and so on – that may render a market solution inefficient from a national point of view. Thirdly, R&D investments may be used strategically in the multi-stage, multi-period game between firms, and we know that there may be a role to play for the government in affecting the outcome of such games. And finally, and not the least, while other types or trade and industrial policies are now more and more regulated internationally, R&D policies still remain a national responsibility and concern, with little or no supranational regulation or coordination.

Even within economic unions, like the EU, R&D policies seem to belong to the domestic domain. However, given the potentially strong strategic impact of such policies, as well as important welfare implications, there may be good reason to consider the need for international coordination or regulation of R&D policies in similar ways as we see for many other policy areas. Yet, to the best of our knowledge, the question of international coordination of R&D policies has received little attention in the literature. While there is a solid and growing literature on the need for and effects of R&D policies to correct for various market inefficiencies, and also a literature on how R&D cooperation between firms may be beneficial even from a national point of view, there seems to be much less focus on the need for international policy coordination. This paper is a first attempt at throwing light on why international policy coordination may be called for, and how such coordination may affect the outcome.

From the literature on R&D policies in oligopolistic markets (see next section for a short and selective review) there are basically three reasons for active policies towards the firms' R&D investments: Spillovers, strategic behaviour, and consumer surplus considerations. The former (spillovers) and the latter (consumer surplus) typically imply a need for policies to stimulate to more R&D than a market solution would give, while strategic behaviour by firms may work in both directions, depending on the exact market conditions. In an international setting, the literature shows that there may be close similarities between R&D policies and strategic trade policies. In particular, if export policies are prohibited (e.g. by international agreements) policies to stimulate R&D may be used as a second-best option to capture the strategic-trade-policy benefits. In fact, some studies show that R&D subsidies may be a more robust recommendation than export policies, in the sense that the effects are less sensitive to the exact type of competition in the markets (Cournot versus Bertrand) and also to the type of R&D (cost reducing versus quality improving). However, most of the "strategic trade policy effects" of both export and R&D policies are sensitive to the assumption that only one country use active policies. Once several countries are active on the policy arena, the outcome may well be a policy competition of the prisoners' dilemma type, with no net benefits for any of the countries. This is particularly true if the basis for active policies in the first place is solely of the strategic type. If, on the other hand, policies are there to correct for externalities or to take care of consumer surplus effects, the outcome may be a different one. In either case, however, we find it interesting to see how international policy coordination may affect the market and the overall welfare of R&D as well as R&D policies. In particularly, we think it is of great relevance to focus on coordination of R&D policies within economic unions, since such unions typically have coordinated or common policies for a number of related policy areas, like trade and industrial policies.

To study R&D policies within an economic union, we construct a simple model with horizontally differentiated consumer goods, where each firm may invest in R&D to improve the quality of and hence the demand for its product. We assume that the goods are produced in different countries within an economic union, and analyze the implications of uncoordinated and coordinated R&D policies across the countries. To simplify, we assume that there is only one firm in each country (in the industry in question), and there are no spillovers. In the model, there are thus two channels through which R&D subsidies may affect the country's welfare: By increasing consumer surplus through enhancing the overall quality of products, and by improving the competitive position of the domestic firm in the international markets. While the former may be a good reason for R&D subsidies both at the national level and for the economic union as a whole, the latter is a "profit shifting" argument leading to policy competition between national governments with no net welfare benefits for the union. In this setting we compare uncoordinated and coordinated R&D policies within the union.

We focus on different cases, depending on the size and net export position of the countries. Small, net-exporting countries may choose different policies from large countries, where domestic consumption is also important. And policy coordination may hence have quite different effects, depending on the pattern of consumption and production between countries. We show that uncoordinated R&D policies tend to give rise to too small subsidies for horizontally differentiated goods and too high subsidies for goods that are close substitutes.

Furthermore, net exporters of R&D intensive goods have incentives to give small

R&D subsidies relative to countries that also have a significant domestic consumption of the goods, resulting in an unwarranted vertical product differentiation between goods produced in different countries. Such problems may partly be solved if R&D policies are coordinated at a union level. However, if R&D policies are coordinated only between a subset of countries, then union welfare may be lower than if there is no R&D coordination at all.

## 1.1 Related literature

R&D policies in imperfectly competitive markets have been studies in a number of important contributions, focussing on various aspects of R&D. D'Aspremont and Jacquemin (1987) show that with spillovers between firms, it may be welfare enhancing to allow oligopolistic firms to cooperate at the R&D stage of production, while being competitors in the output markets. The reason is simply that with positive externalities between firms, a competitive solution implies too little R&D as the individual firm does not take into account the positive effect on other firms. In a cooperative solution, R&D levels in the firms will be set to maximize industry profits rather than the profits of the individual firms.

Neary and Leahy (1997) give a more comprehensive analysis of R&D policies and R&D cooperation between firms in oligopolistic markets. They show how the role and type of policies depend on the interaction between a number of factors: the degree of spillovers between firms, the strategic behaviour of firms, and the ability to commit to future actions for firms as well as for governments. If firms can commit fully to future actions, there is no room for strategic behaviour; and if firms in addition are allowed to cooperate on R&D, there is no need for coordinating R&D policies, even if there are strong spillovers. If, on the other hand, firms cannot commit fully to future actions, first-period R&D investments may be used in a strategic way to affect the future market game. In such cases, Neary and Leahy show that whether strategic behaviour leads to more or less R&D and output, depends on the how strong spillovers there are, whether firms cooperate or nor, and whether the firms' action in the market game are strategic substitutes or complements. If firms' actions are strategic substitutes, spillovers are low, and firms do not cooperate, strategic behaviour leads to too much R&D and output. In other cases strategic behaviour typically leads to less R&D and output. In either case, policies may be used to correct for the strategic behaviour, thus enhancing welfare.

In an international setting, there are close links between R&D policies and strategic trade policies. In a two-period model with R&D investments in the first period, and a "standard strategic trade policy model" with Cournot duopoly and exports to third market in the second period, Spencer and Brander (1983) focus on the strategic effects of R&D investments and the potential role of various types of policies. If the government can tax or subsidize both R&D and exports, the optimal policy would be to tax R&D to counteract the strategic investments by firms, while subsidizing exports in the "standard" strategic trade policy way. However, if exports subsidies cannot be used, Spencer and Brander show that it is optimal to subsidize R&D. Leahy and Neary (2000) – in a more general framework – emphasize that the R&D subsidy result is a second best one, given that export policies cannot be used. However, they argue that it may be a particularly relevant second-best case, since international institutions and agreements, like the WTO, limit the use of export subsidies, while R&D policies are still allowed. Bagwell and Staiger (1994) and Brander (1995) conjecture that R&D subsidies may in fact be a more robust result than export subsidies, in the sense that R&D subsidies may be optimal both with Cournot and Bertrand competition in the second period. Leahy and Neary (2001) focus directly on the robustness result, and confirm the conjecture from Brander (1995) that (when export policies are not available) subsidizing R&D investments remains an optimal policy for a number of different cases; it is robust for various types of competition and for cost-reducing as well as for demand-raising R&D.

Most of these contributions, however, limit the analysis to unilateral policies. Several of them emphasize that if two or more countries use active policies, the policy competition that follows will typically give too high subsidies and hence too high R&D investments (see e.g. Spencer and Brander, 1983, Brander, 1995 and Leahy and Neary, 2001).

In our model, we do not include all the dimensions stressed in previous contribution. Our focus is on the need for and effects of cooperation between governments when it comes to R&D polices. For that purpose we choose one particular framework in which active R&D policies would typically be the outcome in a non-cooperative solution. Like Spencer and Brander (1983) (and a number of related papers, as discussed above), we focus on the international dimension, with one firm in each country, and we stick to the case where exports policies are not available. Hence, governments may find it beneficial to subsidize R&D for strategic trade policy reasons. However, contrary to many of these contributions, we do not make the simplifying assumption of just looking at exports to third markets; we explicitly include consumption and the effects on consumer surplus. Furthermore, we allow for active policies in all countries, as our main concern is about the interaction and coordination of such policies between countries within an economic union. Hence, R&D policies – whether they are uncoordinated or coordinated – may partly be in use for strategic reasons, and partly to due to consumer-surplus considerations.

To simplify, we ignore spillovers. Furthermore, the model does not allow for strategic behaviour by firms, as we have a two-stage game where the governments choose R&D policies in the first stage, and the firms choose both their R&D and their output levels in the second stage. Hence, to the extent that R&D have strategic effects in our model, it is because the governments can commit to R&D policies prior to the firms' decisions in the model. In the concluding section we discuss alternative timing structures, and find that these assumptions are not crucial for the main results of the paper.

## 2 The Model

*Demand side*

There are two identical groups of consumers, located in country $i = 1, 2$. The population size in each group is equal to 1. The consumers demand two possibly differentiated goods, $A$ and $B$, and have a quadratic utility function given by

$$U_i = \alpha_A q_{Ai} + \alpha_B q_{Bi} - \frac{1}{1+b}\left(\frac{q_{Ai}^2}{2} + \frac{q_{Bi}^2}{2} + b q_{Ai} q_{Bi}\right), \quad (1)$$

where $q_{Ai}$ and $q_{Bi}$ are the quantity of good $A$ and $B$, respectively. The first subscript thus indicates the good number, and the second subscript the location of the consumer. The parameter $b \in [0, 1]$ measures the degree of horizontal differentiation between the goods; the goods are completely independent if $b = 0$, while there is no horizontal differentiation between them if $b = 1$. More generally, the two goods are closer horizontal substitutes from the consumers' point of view the higher is $b$.[1]

The variable $\alpha_j > 0$ ($j = A, B$) is a measure of the objective quality of good $j$; the higher the value of $\alpha_j$ the better do the consumers perceive the good to be. The goods are thus vertically differentiated if $\alpha_A \neq \alpha_B$.

Letting $p_{ji}$ denote the price of good $j$ in country $i$, we may express consumer surplus as $CS_i = U_i - p_{Ai}q_{Ai} - p_{Bi}q_{Bi}$. Optimal consumer behavior implies that $\partial CS_i/\partial p_{Ai} = \partial CS_i/\partial p_{Bi} = 0$, from which we find that the inverse demand curve in country $i = 1, 2$ equals

$$p_{ji} = \alpha_j - \frac{q_{ji} + bq_{ki}}{1 + b} \qquad (j, k = A, B, ; j \neq k). \tag{2}$$

*Supply side*

The goods are produced by two independent profit maximizing firms. Each firm may invest in R&D in order to improve the quality of the good it offers, leading to a positive shift in the demand curve. Specifically, we assume that

$$\alpha_j = \alpha + x_j \tag{3}$$

where $\alpha > 0$ is a positive constant and $x_j \geq 0$ is an objective quality measure. The R&D product function is given by $x_j = f(y_j)$, where $y_j$ is input of R&D resources and $f'(y) > 0$. We will make the realistic assumption that a marginal quality improvement is more expensive the higher the initial quality of the good, which

[1] A more general formulation of the utility function would be $U_i = \alpha_A q_{Ai} + \alpha_B q_{Bi} - \frac{1+\beta}{1+b}\left(\frac{q_{Ai}^2}{2} + \frac{q_{Bi}^2}{2} + bq_{Ai}q_{Bi}\right)$. If $\beta = b$, we have a standard quadratic utility function where an increase in $b$ both implies that the goods become less differentiated and that the total size of the market decreases. With $\beta = 0$, on the other hand, the total size of the market is independent of $b$. Thereby the parameter $b$ becomes a one-dimensional measure of product differentiation. Since the focus of this paper is on how horizontal product differentiation as such affects R&D incentives, we have assumed that $\beta = 0$.

means that $f''(y) < 0$.[2] In order to obtain closed form solutions we let $x_j = \sqrt{y_j/\phi}$, or $y_j = \phi x_j^2$, where $\phi > 0$ is a positive constant. We normalize such that the unit price of $y_j$ is equal to 1.

Suppose that firm $j$ receives a subsidy equal to $s_j$ for each unit $x_j$ of R&D. Assuming that the marginal production costs of the final good is equal to $c$, we can then write the profit function of firm $j$ as

$$\pi_j = (p_{j1} - c)q_{j1} + (p_{j2} - c)q_{j2} - \phi x_j^2 + s_j x_j, \tag{4}$$

The two first terms on the r.h.s. of equation (4) are equal to the operating profit of selling good $j$ in country 1 and 2, respectively, the third term is R&D costs, and the fourth term R&D subsidies.

## 2.1 Social optimum

Assume that the consumers and producers are all located within an economic union, where welfare is given by

$$W = CS_1 + CS_2 + \pi_A + \pi_B - s_A x_A - s_B x_B.$$

In social optimum the price of each good will be equal to marginal production costs; $p_{ji} = c$. To find the optimal R&D investment level we further note that the aggregate consumer benefit of a marginal quality improvement is equal to 1 per unit they consume of a given good ($\partial (U_1 + U_2) / \partial x_j = q_{j1} + q_{j2}$), while the marginal cost of a quality improvement is equal to $2\phi x_j$. This indicates that $q_{j1} + q_{j2} = 2\phi x_j$. The first-order conditions for social optimum, which technically is found by setting $\partial W/\partial x_j = \partial W/\partial q_{ji} = 0$, thus equal

$$p_{ji} = c \text{ and } q_{j1} + q_{j2} = 2\phi x_j \qquad (j = A, B). \tag{5}$$

Equation (5) characterizes the social optimum, provided that the second-order conditions hold. However, the second-order conditions will not hold for sufficiently high

[2] If $f''(y) \geq 0$ the firms will either not invest in quality improvement at all or they will make an infinitely high investment.

values of $b$. To see why, assume that $b = 1$. Then there is no horizontal differentiation between the goods, and it obviously cannot be socially optimal to invest in quality improvements of both of them. Thus, there will potentially exist one high-quality good and one low-quality good. However, the low-quality good will not be produced, since marginal production costs are assumed to be independent of the quality level (and $p_{ji} = c$ in social optimum).

The higher is $\phi$, the larger is the value of $b$ above which it is optimal to invest in quality improvement of only one good (see proof of Proposition 1 in the Appendix). To see the intuition for this, assume that $\phi$ - and thus the marginal quality improvement costs ($2\phi x_j$) - is "high". Then welfare may be higher by satisfying the consumers' demand for horizontally differentiated goods by producing two relatively close substitutes with a "low" quality than by producing only one "high-quality" good. If $\phi$ is "small", on the other hand, the social planner may sacrifice horizontal differentiation and instead invest more in quality improvement of the remaining good.

It can be shown that also the market economy will provide only one good (with a relatively high quality) if $\phi$ is small and the goods are sufficiently close horizontal substitutes, while both goods will be produced even if they are only slightly horizontally differentiated if $\phi \geq 4$. Since we are not concerned about the question of whether the market economy produces too many or too few varieties, we will in the following for simplicity assume that $\phi = 4$. Moreover, for the questions that we are interested in, it is illustrative to impose the restriction that both goods are produced in positive quantities for all values of $b$ also in social optimum. Given this restriction, we can use equations (2), (3) and (5) to find (see also Appendix):

**Proposition 1:** *Given the restriction that* $q_{ji} > 0$ *for all* $b \in [0, 1]$*, social optimum is characterized by* $x_j = (1/3)(\alpha - c)$ , $q_{ji} = (4/3)(\alpha - c)$ *and* $W = (8/3)(\alpha - c)^2$.

The important insight from Proposition 1 is that quantities, quality levels and welfare are independent of the degree of horizontal differentiation in social optimum.

# 3 Market equilibrium

Below, we shall consider a two-stage game where R&D subsidies are set at stage 1, and the firms decide on investments in R&D and compete in quantities at stage 2 (Cournot competition). Other timing structures will be discussed in Section 4.

## 3.1 Stage 2: R&D and output decisions

We solve the game through backward induction, and thus start with stage 2 where the first-order conditions are given by $\partial \pi_j / \partial q_{ji} = \partial \pi_j / \partial x_j = 0$. It is now instructive to analyze the maximization problem with respect to quantities and qualities separately. First, solving $\partial \pi_j / \partial q_{ji} = 0$ for $j = A, B$ and $i = 1, 2$ we find

$$q_{ji} = \frac{1+b}{2+b}(\alpha - c) + \frac{1+b}{4-b^2}(2x_j - bx_k) \quad (j \neq k) \tag{6}$$

The first term in equation (6) is increasing in $b$. This reflects the fact that the competitive pressure increases as the goods become less (horizontally) differentiated, resulting in a lower price and higher quantity. We further see that $\partial q_{ji} / \partial x_j > 0$ and $\partial^2 q_{ji} / (\partial x_j \partial b) > 0$. This means that a higher quality of good $j$ increases output of the same good, and more so the larger is $b$. The reason for the latter is that the smaller the horizontal differentiation between the goods, the more prone are the consumers to shift to good $j$ if the quality of that good increases. Conversely, an increased quality of good $k$ has a larger negative quantity effect on good $j$ the closer horizontal substitutes the goods are.

As explained above, a marginal increase in the quality level of a good increases the consumers' willingness to pay for that good by one unit for each unit they consume. Since the cost of a marginal quality improvement for firm $j$ is equal to $2\phi x_j$ minus R&D subsidies $s_j$, we thus have $\partial \pi_j / \partial x_j = q_{j1} + q_{j2} - 2\phi x_j + s_j = 0$. Setting $\phi = 4$ (in which case the second-order conditions are satisfied) we consequently find

$$x_j = \frac{q_{j1} + q_{j2} + s_j}{8} \tag{7}$$

Since quantity is increasing in $b$, it follows from equation (7) that also quality investments are increasing in $b$, other things equal.

By combining equations (6) and (7) we can now write the outcome of stage 2 as

$$x_j = \frac{1+b}{7+3b}(\alpha - c) + \frac{2(7-b-2b^2)s_j - b(1+b)s_k}{2(7+3b)(7-5b)} \tag{8}$$

and

$$q_{ji} = 4\frac{1+b}{7+3b}(\alpha - c) + (1+b)\frac{(7-b)s_j - 4bs_k}{2(7+3b)(7-5b)} \tag{9}$$

The more firm $j$ receives in R&D subsidy, the more it will invest in quality improvement ($\partial x_j/\partial s_j > 0$) and the higher will its output be ($\partial q_{ji}/\partial s_j > 0$). This in turn implies that a unilateral increase in R&D subsidies for one firm makes the rival less competitive ($\partial q_{ji}/\partial s_k < 0$), reducing the incentives for that firm to invest in quality improvement. Thereby we have $\partial x_j/\partial s_k < 0$.

From equations (8) and (9) we further find that

$$\frac{\partial^2 q_{ji}}{\partial b \partial s_j} = 4\frac{\partial^2 x_j}{\partial b \partial s_j} = 4\frac{49 + 14b + 13b^2}{(7+3b)^2(7-5b)^2} > 0, \tag{10}$$

which means that an increased subsidy for firm $j$ has a larger effect on that firm's output and R&D investments the higher is $b$. This reflects the fact an R&D subsidy reduces the marginal costs of quality improvements, and that a larger share of this cost reduction accrues to the consumers the higher the competitive pressure between the firms.

To sum up, we have:

**Proposition 2:** *Other things equal, output and R&D investments are higher the less horizontally differentiated the consumer goods ($\partial q_{ji}/\partial b > 0$ and $\partial x_j/\partial b > 0$). Each firm will invest more in R&D and produce a higher quantity the more it receives in R&D subsidies and the less the rival receives in R&D subsidies. The absolute effect of higher R&D subsidies on quantities and qualities are increasing in $b$.*

In the market economy we thus see that both quantities and R&D expenditures are increasing in $b$, reflecting that a higher (horizontal) substitutability between the goods increases the competitive pressure. This is in contrast to social optimum, where the quality level as well as output of each good are independent of $b$. However, it is easily confirmed that both R&D expenditures and output are too low from a social point of view in the market economy. This indicates that union welfare will increase if the firms are granted R&D subsidies.

For the sake of later references, it is useful to note that we can use equations (4) and (9) to write the profit level of firm $j$ as

$$\pi_j = \frac{q_{j1}^2}{1+b} + \frac{q_{j2}^2}{1+b} - 4x_j^2 + s_j x_j \tag{11}$$

## 3.2 Stage 1: R&D policies

In this section we will look at optimum R&D policies in countries within an economic union, and see how supranational coordination of such policies may affect the market. As the motivation for as well as the effects of R&D policies may vary depending on the size and the net export position of the countries, we have to study various cases. We start with a case in which all production takes place in two small countries where domestic consumption is of little or no importance. In such a setting only export markets matter for the policy decision. We then proceed to look at large countries, where domestic consumption as well as international competitive conditions matter for the optimal policies.

### 3.2.1 Two small countries

R&D intensive industries typically require large markets. Thus, countries with a small home market are often dependent on exports to make R&D investments profitable. In this section we will investigate the equilibrium R&D subsidy policy in two small countries, $A$ and $B$, that produce goods $A$ and $B$, respectively. In order to highlight the forces at work, we shall assume that all output is exported to consumers in country 1 and country 2.[3]

Welfare in country $j = A, B$ is equal to the profit level of the domestic firm net

[3] Alternatively, we could have assumed that all consumers are located in one country, which would spare us one country subscript for the consumer countries. However, in order to simplify comparisons with the other scenarios we consider, we will assume that the consumers are located in two different countries.

of R&D subsidies:

$$W_j = \pi_j - s_j x_j \tag{12}$$

At stage 1 the government in each of the two producer countries simultaneously set the R&D subsidy level for its home firm in such a manner that it maximizes domestic welfare. The first-order conditions are thus $\partial W_j / \partial s_j = 0$ for $j = A, B$. From Proposition 2 we know that a partial increase in the subsidy level to firm $j$ makes that firm invest more in R&D and produce a higher output, while the other firm will invest less in R&D and reduce its output. This suggests that the government in country $j$ will take two different effects into account when it sets the subsidy level. The *direct effect* of an increased subsidy $s_j$ is that firm $j$ will invest more in quality improvement, thus increasing the consumers' willingness to pay for the good. The second effect, which we label the *business stealing effect*, is that a higher quality of good $j$ reduces the competitiveness of good $k$. Other things equal, the business stealing effect leads to a higher price and larger demand for good $j$. In the Appendix we show that we may write the first-order condition for the subsidy level in country $j$ as

$$\frac{\partial W_j}{\partial s_j} = \underbrace{\frac{1}{7-b}\left(q_j - 8x_j\right)}_{\text{Direct effect}} + \underbrace{\frac{4b}{7-b}\left(\frac{1}{1+b}q_j - x_j\right)\left(-\frac{\partial q_k}{\partial s_j}\right)}_{\text{Business stealing effect}} = 0, \tag{13}$$

where $q_j = q_{j1} + q_{j2}$ and $q_k = q_{k1} + q_{k2}$. From equation (7) we know that the first-order condition for firm $j$ is to invest in quality improvement until $x_j = (q_j + s_j)/8$, which means that $(q_j - 8x_j) = -s_j$. We thus see that the direct effect of a marginal increase in $s_j$, expressed by the first term in (13), is equal to $-s_j/(7-b)$. The direct effect of a positive subsidy level is thus negative and decreasing both in $b$ and $s_j$. This indicates that an R&D subsidy $s_j > 0$ has a negative welfare effect for country $j$, and more so the less horizontally differentiated the goods are.

From equation (13) we further see that the business stealing effect vanishes if $b = 0$; in that case the two goods are completely unrelated, and a change in the quality of one good does not affect demand for the other good. However, the less horizontally differentiated the goods are, the more prone are consumers to change from a low-quality to a high-quality good. Thus, in order to steal business from firm

$k$ the government in country $j$ has stronger incentives to pay subsidies the higher is $b$ (see Appendix for a formal proof).

Inserting for (8) and (9) into (13) and solving for the two countries we find that (for $j = A, B$) :

$$s_j = b^2 \frac{16(1+b)}{49 + 14b - 19b^2 - 8b^3} (\alpha - c); \ \frac{\partial s_j}{\partial b} > 0 \tag{14}$$

We thus see that the equilibrium subsidy level is equal to zero if $b = 0$, because there is no business stealing effect in this case. For higher values of $b$, however, the subsidy level is positive and strictly increasing in $b$. This reflects the fact that the business stealing effect is more dominating the less horizontally differentiated the goods are. Using equations (8) and (9) we further find that equilibrium quantities and quality levels are given by

$$q_{ji} = \frac{4(1+b)(7-b-2b^2)}{49 + 14b - 19b^2 - 8b^3} (\alpha - c) \text{ and } x_j = \frac{(1+b)(7-b)}{49 + 14b - 19b^2 - 8b^3} (\alpha - c),$$

which are both increasing in $b$. This is true both because profit maximizing output and R&D investments are increasing in $b$ and because the subsidies are increasing in $b$.

Since the countries provide R&D subsidies only in order to allow their respective domestic firms to steal profit from each other, welfare in the two producer countries is lower with subsidies than without subsidies (see Appendix). We thus have the following result:

**Proposition 3:** *Suppose that consumer goods A and B are produced by firms located in the two small countries A and B, respectively. With a non-cooperative R&D policy, the governments in the two producer countries will then subsidize R&D undertaken by its home firm unless the goods are completely unrelated (* $s_j = 0$ *for* $b = 0$ *and* $s_j > 0$ *for all* $b > 0$*). R&D investments and subsidy levels are higher the closer horizontal substitutes the goods are (* $\partial x_j / \partial b > 0$ *and* $\partial s_j / \partial b > 0$*). Welfare in the producer countries is lower if they provide R&D subsidies than if they do not provide subsidies.*

The subsidy game analyzed above results in a prisoners' dilemma, where the producer countries end up providing R&D subsidies even though this reduces their welfare. Suppose now that the two countries cooperate in their subsidy policy. In this case the countries will maximize the sum of profit minus R&D subsidies. Solving $\partial(W_A + W_B)/\partial s_A = \partial(W_A + W_B)/\partial s_B = 0$ we find

$$s_j = -b\frac{4(1+b)}{7+7b+2b^2}(\alpha - c); \quad \frac{\partial s_j}{\partial b} < 0. \tag{15}$$

As shown above, the direct effect for the producer countries of granting R&D subsidies is negative (c.f., equation (13)). The producer countries will therefore optimally levy a tax on R&D if they coordinate their policies at stage 1 and internalize the business stealing effect. This is why $s_j < 0$ for all $b > 0$ in equation (15). Indeed, in the cooperative equilibrium the governments in the producer countries have incentives to reduce the product market competition between the firms. Since the competitive pressure is increasing in $b$, the governments will therefore set a higher R&D tax the closer substitutes the consumer goods are. This is why $\partial s_j/\partial b < 0$.

The output and R&D investments in this case equal

$$x_j = \frac{1+b}{7+7b+2b^2}(\alpha - c); \quad \frac{\partial x_j}{\partial b} < 0 \tag{16}$$

and

$$q_{ji} = \frac{2(1+b)(b+2)}{7+7b+2b^2}(\alpha - c); \quad \frac{\partial q_{ji}}{\partial b} > 0 \tag{17}$$

The governments in $A$ and $B$ cannot prevent the firms from competing, and therefore output is increasing in $b$. However, the R&D taxes imply that R&D investments are lower the closer substitutes the two firms produce.

Even though it may be difficult to implement a policy where R&D is taxed, welfare in the producer countries is unambiguously highest if that is possible. Otherwise, the next best solution is to set the subsidy level equal to zero. We now have:

**Proposition 4:** *Suppose that consumer goods $A$ and $B$ are produced by firms located in the two small countries $A$ and $B$, respectively. With a cooperative R&D policy, the governments in the two producer countries will optimally tax R&D undertaken by the two firms unless the goods are completely unrelated ($s_j = 0$ for $b = 0$*

*and $s_j < 0$ for all $b > 0$). R&D taxes are higher and R&D investments lower the closer horizontal substitutes the goods are ($\partial x_j / \partial b < 0$ and $\partial s_j / \partial b < 0$).*

Figure 1 plots the subsidy levels given by equations (14) and (15)[4]. The equilibrium subsidy level at $b = 0$ is zero whether the countries cooperate or not. Otherwise the optimal policy behaves quite differently in the two regimes. Larger values of $b$ means that the competitive pressure between the firms increases, and this gives the countries an incentive to grant larger subsidies if the countries do not cooperate. However, if the countries cooperate, they will instead tax R&D in order to reduce the (from these two countries' point of view) destructive competition between the firms.

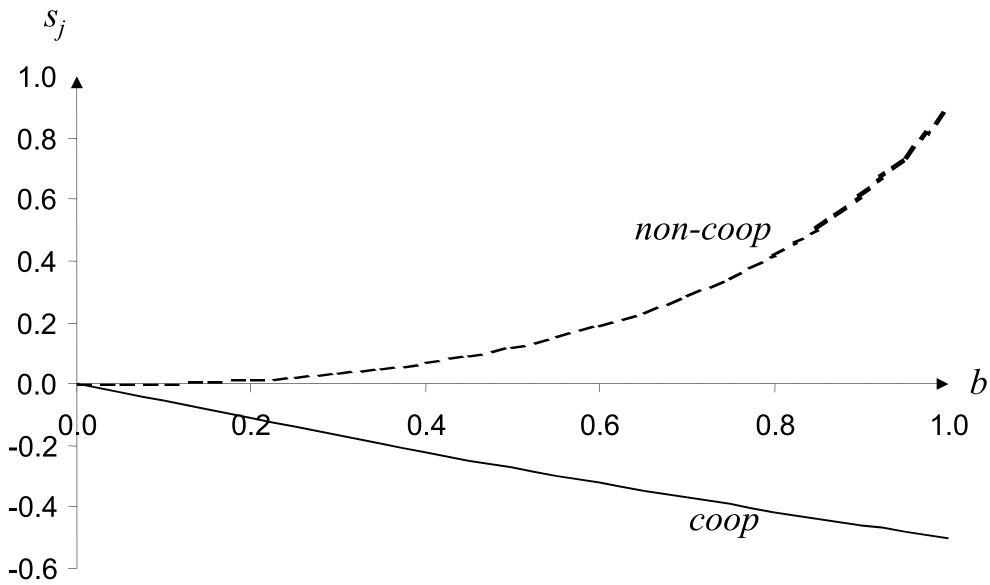


**Figure 1:** *Cooperative and non-cooperative R&D subsidies for two small countries.*

### 3.2.2 Two large countries

Next, assume that firm $A$ is located in country 1 and firm $B$ in country 2 (in this case *countries* $A$ and $B$ play no role in the analysis). Welfare in the two countries

[4]The actual subsidy levels are $(\alpha - c)$ times the values shown in the figure.

is given by

$$W_1 = CS_1 + \pi_1 - s_1 x_1 \text{ and } W_2 = CS_2 + \pi_2 - s_2 x_2, \tag{18}$$

where we have chosen to use subscript 1 for the good produced in country 1 (good $A$) and subscript 2 for the good produced in country 2 (good $B$).

At stage 1 the governments in each country simultaneously maximize the sum of domestic consumer surplus and profit net of R&D subsidies. This yields the first-order condition

$$\frac{\partial W_i}{\partial s_i} = \underbrace{\frac{1}{7-b}\left(q_i - 8x_i\right)}_{\text{Direct effect for firm } i} + \underbrace{\frac{4b}{7-b}\left(\frac{1}{1+b}q_i - x_i\right)\left(-\frac{\partial q_k}{\partial s_i}\right)}_{\text{Business stealing from firm } k} + \frac{\partial CS_i}{\partial s_i} = 0. \tag{19}$$

The first two terms in (19) are the same as those that characterized the first-order condition for the subsidy game between two small countries, where we showed how the business stealing effect implied that the optimal subsidy level for each country was positive and increasing in $b$. The third term is the change in consumer surplus in country $i$ subsequent to an increase in $s_i$. Other things equal, also this term is positive and increasing in $b$, since larger R&D subsidies lead to improved product quality.

Solving (19) simultaneously for $i = 1, 2$ we find

$$s_i = \frac{8\left(1+b\right)\left(3b^2 + 2b + 7\right)}{189 + 47b - 73b^2 - 27b^3}\left(\alpha - c\right) > 0, \quad \frac{\partial s_i}{\partial b} > 0. \tag{20}$$

The subsidy level is thus increasing in $b$, as was the case when the we analyzed the subsidy game between two non-cooperating small countries. However, the inclusion of domestic consumer surplus gives the countries an extra incentive to provide subsidies. In particular, this means that the subsidy level is positive also at $b = 0$.

Combining (8) and (20) we further find

$$x_i = \frac{\left(1+b\right)\left(35 - 2b - 5b^2\right)}{189 + 47b - 73b^2 - 27b^3}\left(\alpha - c\right), \quad \frac{\partial x_i}{\partial b} > 0. \tag{21}$$

In the previous section we found that two small countries observed a welfare loss by providing R&D subsidies. However, the same is not necessarily true in the present case where we consider two large countries (so that consumer surplus is included). On the contrary, welfare is higher with subsidies than with zero subsidies if $b < b^* \approx 0.91$ (see proof of Proposition 5 in the Appendix). The reason for this is that the firms will have relatively small investments in R&D for low values of $b$, which is bad for the consumers. This the governments can correct for by granting R&D subsidies. However, since the business stealing effect becomes increasingly stronger as $b$ increases, the countries overprovide R&D subsidies when $b$ is large.[5]

We now have:

**Proposition 5:** *Suppose that consumer goods A and B are produced by firms located in the two large countries* 1 *and* 2*, respectively. With a non-cooperative R&D policy, the governments will then always subsidize R&D undertaken by its home firm* ($s_i > 0$ for all $b \geq 0$). *R&D investments and subsidy levels are higher the closer horizontal substitutes the goods are* ($\partial x_i/\partial b > 0$ and $\partial s_i/\partial b > 0$). *Welfare is higher (lower) with subsidies than without subsidies if* $b < b^* \approx 0.91$ ($b > b^*$).

It is straight forward to prove that due to higher competition, the profit level of the firms are decreasing in $b$ if they do not receive any R&D subsidies. However, zero subsidies are not an equilibrium; equation (20) makes it clear that the subsidy levels are positive. Indeed, inserting for (20) it can be shown that the subsidy levels increase so fast in $b$ that the equilibrium profit levels of the firms are actually higher the closer substitutes they produce. This is illustrated in Figure 2, which in particular shows that the firms make a lower profit as monopolies ($b = 0$) than as duopolists producing perfect substitutes ($b = 1$).

In this paper we treat the degree of horizontal differentiation as exogenous. However, the result that the governments have stronger incentives to provide R&D subsidies to their domestic firms the higher is the product market competition, indicates that R&D subsidy games between governments may give firms excessive incentives to produce close substitutes.

[5] This does not mean that R&D investments and product quality are too high *per se*. On the contrary, comparing $x_i$ in equation (21) with the socially optimal quality level given by Proposition 1, we find that the quality level is higher in social optimum. However, *given the relatively low output* in the market economy, the R&D subsidies are so large that the firms invest too much in R&D if $b > b^*$.

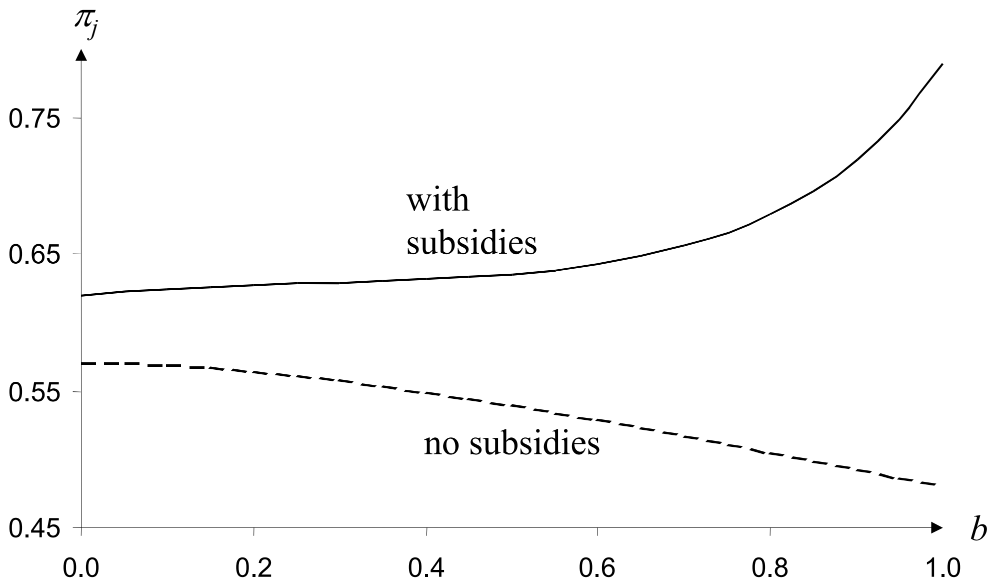


**Figure 2:** *Two large countries. Profit levels with and without subsidy levels in an R&D subsidy game.*

Suppose now that the two countries coordinate their R&D policies, and choose subsidy levels that maximize aggregate welfare, $W = W_1 + W_2$, in the two countries. We then have

$$W = CS_1 + CS_2 + \pi_1 + \pi_2 - s_1 x_1 - s_2 x_2. \tag{22}$$

Solving $\partial W / \partial s_i = 0$ for $i = 1, 2$ we find a unique equilibrium, with a subsidy rate given by

$$s_i = \frac{8\,(1+b)}{13 + 12b + 3b^2}\,(\alpha - c)\,. \tag{23}$$

Differentiating $s_i$ with respect to $b$ we further see that

$$\frac{\partial s_i}{\partial b} > 0 \text{ if } b < b' \text{ and } \frac{\partial s_i}{\partial b} < 0 \text{ if } b > b',$$

where $b' = \frac{2}{3}\sqrt{3} - 1 \approx 0.15$. To see the intuition for this result, note first that in social optimum an improved product quality will result in higher output, while the consumer price will be unchanged. The reason for the latter is that the socially optimal price is equal to marginal production costs $c$, which in particular is independent of R&D investments. In the market economy, on the other hand, a quality improvement leads partly to a higher quantity and partly to a higher price (higher mark-up). The higher mark-up represents a deadweight-loss for the society, which reduces the social gains from the quality improvement. Other things equal, the price increase is smaller the less market power the firms have. In our context the market power of the firms is decreasing in $b$. This in turn implies that the private gains (measured as the sum of increased consumer surplus and profit) of an R&D subsidy is increasing in $b$. More precisely, in the Appendix we prove that

$$\frac{\partial \Lambda}{\partial s} > 0 \text{ and } \frac{\partial^2 \Lambda}{\partial b \partial s} > 0, \tag{24}$$

where $\Lambda \equiv CS_1 + CS_2 + \pi_1 + \pi_2$ and $s$ is a common subsidy level. The equation thus indicates that the firms should be granted higher subsidies the larger is $b$, and this explains why $\partial s_i / \partial b > 0$ for $b < b'$. However, from Proposition 2 we know that the firms invest more in quality improvement and responds more to an increase in the subsidy level the higher is $b$. Since the marginal R&D costs ($2\phi x_i$) of quality improvement is increasing in the quality level, the R&D subsidies thus impose higher resource costs for the society the closer substitutes the goods are. This effect, which indicates that R&D subsidies should decrease in $b$, dominates for $b > b'$.[6]

Inserting for $s_i$ from (23) into (8) we find that

$$x_i = \frac{(3+b)(1+b)}{13+12b+3b^2}; \quad \frac{\partial x_i}{\partial b} > 0.$$

The quality level is thus monotonically increasing in $b$, even though the same is not true for the subsidy level. It can further be shown that the profit level of the firms are now decreasing in $b$, unlike the case where the countries do not coordinate the R&D policies.

We can now state:

**Proposition 6:** *Suppose that consumer goods A and B are produced by firms located in the two large countries* 1 *and* 2, *respectively. If the countries coordinate their R&D policies, the subsidy level is higher (lower) the closer substitutes the goods are if* $b < b'$ $(b > b')$. *The quality levels of the goods are increasing in* $b$.

[6] Put differently, this effect implies that the *need* to subsidies R&D decreases in $b$.

Figure 3 compares the subsidy levels with non-cooperative and cooperative R&D policies in a context with two large countries. The subsidy levels are then given by equations (20) and (23), respectively. The figure makes it clear that we cannot in general be sure whether the subsidy levels are higher with or without policy cooperation. In the non-cooperative equilibrium each government will subsidize its home firm taking into account the positive effect that a subsidy has on domestic consumer surplus, but will disregard the effect on the foreign consumer surplus. In the cooperative equilibrium, on the other hand, the governments will set subsidy levels that maximize aggregate welfare. In particular, this means that they will take into account the positive consumer surplus effect of an R&D subsidy in both countries for each good. This is the reason why the subsidy level is higher in the cooperative equilibrium for $b < b''$ in figure 3. The reason why the subsidy levels are lower in the cooperative than in the non-cooperative equilibrium for $b > b''$, is the fact that the governments will internalize the business stealing effect when they maximize aggregate welfare. This effect is stronger the closer substitutes the goods are, and will therefore dominate when $b$ is relatively high.

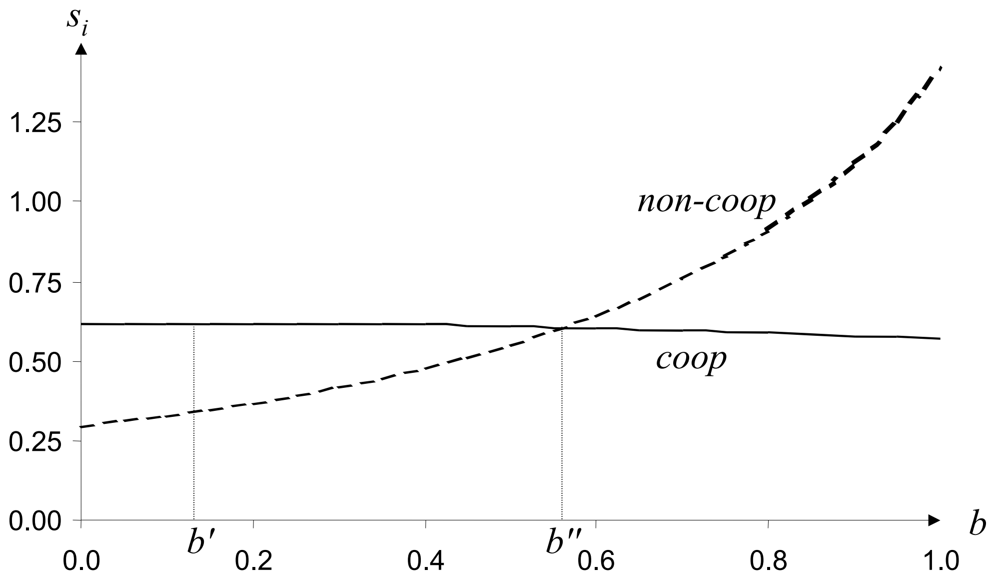


**Figure 3:** *Cooperative and non-cooperative R&D subsidies for two large countries.*

#### 3.2.3 One small and one large country

Finally, we will consider the case with one small and one large country. We then assume that firm $A$ is located in country $A$, and that this firm exports all its output to country 1, where firm 1 and all the consumers are located. Welfare in the two countries is then equal to

$$W_A = \pi_A - s_A x_A \text{ and } W_1 = CS_1 + CS_2 + \pi_1 - s_1 x_1, \tag{25}$$

where we use subscript 1 for the good produced in country 1 (good $B$).

The equations in this case are quite complex, and are given in the appendix. However, it is straight forward to show that the government in country $A$ has no incentives to grant subsidies to its home firm if $b = 0$ (in which case the firms are monopolists), while country 1 will subsidize its home firm in order to increase consumer surplus. This is what we should expect from the previous analysis. The business stealing effect further indicates that both countries have incentives to subsidize their home firms if $b > 0$. However, we should expect that the incentives to pay R&D subsidies to improve the product quality increase faster in $b$ for country 1 than for country $A$. To see why, recall that a quality improvement partly results in a higher quantity and partly in a higher price (which in isolation represents a deadwight-loss), but that the price increase is smaller the larger is the competitive pressure between the firms. The fact that a given quality improvement has a relatively small price effect for high values of $b$ is bad for country $A$, which cares only about producer surplus (net of subsidies), but goods for country 1, which also cares about consumer surplus. This in turn implies that R&D investments will be higher in country 1 than in country $A$, and more so the higher is $b$. We thus have:

**Proposition 7:** *Suppose that good $A$ is produced in the small country $A$, while good $B$ is produced in country 1, where all the consumers are located. The countries will then produce vertically differentiated goods. Country 1 will provide larger R&D subsidies than country $A$, and produce goods of a higher quality. The difference in product quality is increasing in $b$.*

Proposition 4 is illustrated in Figure 4, which measures the difference $x_1$ between

$x_A$ on the vertical axis and the extent of horizontal differentiation on the horizontal axis. The figure shows that the closer horizontal substitutes the firms produce, the larger will the vertical product differentiation be.

It should be noted that the vertical product differentiation is not due to differences in, e.g., consumer preferences or other factors that could make it socially beneficial to produce both high-quality and low-quality goods. Rather, the quality differentiation is due to the fact that the each country sets R&D subsidy levels that maximize domestic welfare instead of aggregate welfare for the union, and that the small country has 'insufficient' incentives to provide R&D subsidies. Indeed, union welfare is maximized when the firms are granted subsidies as given by equation (23), where we analyzed cooperative R&D policy between two large countries.

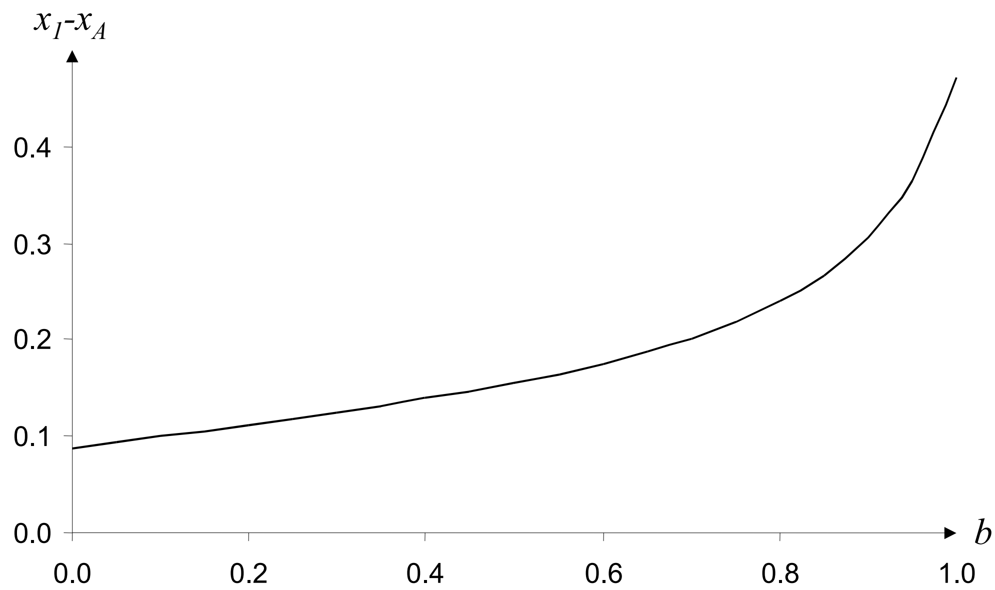


**Figure 4:** *Vertical product differentiation.*

# 4 Concluding remarks

Though this paper has focused on implications of coordinated and uncoordinated R&D policies in economic unions in general, we believe that the analysis is of particular relevance for the EU. One reason for this is that we in the EU find R&D intensive industries located in countries with relatively small home markets as well as in countries with large home markets. Firms located in countries with large home markets typically sell a significant share of their output domestically, while high innovation costs often imply that export profitability plays a crucial role for firms located in countries with small home markets. A prime example of this is the Finnish mobile telephone company Nokia and its Swedish competitor Ericsson; they both have far too small home markets to cover their large R&D investments through domestic sales.

A second reason why we think our analysis is of particular relevance for the EU, is that this union to a larger extent than for instance NAFTA and ASEAN has an institutional framework that potentially provides it with means to coordinate R&D policies. The union has a common policy on a wide range of areas, including trade policy, regulation policy and competition policy. Moreover, The European Commission has the authority to prevent national governments from implementing industrial policies that may distort competition in a smaller or larger part of the union. Thus, the Commission may for instance overrule national governments and prohibit mergers between domestic firms, and it may prohibit more or less hidden production subsidies. However, the Commission's attitude seems to be more laissez-faire when it comes to national R&D policies. This is a bit surprising, since it is clear that countries may use R&D policies to improve the competitiveness of domestic firms. An illustrative example of this, which we mentioned in the Introduction, is the National Technology Agency of Finland (Tekes). Each year Tekes gives about 380 million euros in R&D subsidies to domestic firms, and on its web page it writes that its primary objective is to promote "competitiveness in Finnish industry ... and increase [Finnish] production and exports". It does not take much imagination to interpret this as partly representing (not very well hidden) distortive subsidies.

In the paper we showed that an R&D subsidy game between two producer countries does not necessarily hurt the union as a whole. However, compared to optimum for the union, R&D subsidies tend to be too small for horizontally differentiated goods and too high for goods that are close substitutes. An interesting question is therefore whether the EU should encourage producer countries to cooperate when they set R&D subsidies. Our analysis indicates that this might be a dangerous path to follow. In particular, cooperation between net exporters of R&D intensive goods may have detrimental welfare effects for union, even though it may be favourable for the producer countries. The optimum R&D policy for the union as a whole must be one that corrects for the "consumer surplus" effects of R&D in imperfectly competitive markets, whereas the "profit shifting" effects are eliminated. To achieve such an optimum, either centralized R&D policies, or a complete policy coordination between all involved parties (i.e. both producer and consumer countries) would be necessary.

In order to make the model tractable, we have made a number of simplifying assumptions. First, we have abstracted from the presence of any third countries. We do not believe this to be very serious; the tendency that competing union members pays too high R&D subsidies on close substitutes, for instance, should still hold. Second, we assumed that quantities and qualities were determined simultaneously at stage 2 of the game, and we thus abstracted from strategic competition in R&D investments by the firms. However, it can be shown that most of the results survive also if we assume that firms commit to their R&D levels before they choose quantities. The major difference is that the firms will have stronger incentives to invest in R&D. Third, we have abstracted from uncertainty and knowledge spillovers, and assumed complete information in a basically static framework. It would be interesting to relax on these assumptions, but that we will leave for future work. Fourth, we have taken the degree of horizontal differentiation between the goods as an exogenous parameter. We think it would be very interesting to make this an endogenous choice of the firms. One reason for this, is that our results indicate that governments have stronger incentives to support their domestic firms with R&D subsidies the stronger the competition from foreign firms. Indeed, we showed that with uncoordinated R&D policies the firms might therefore make higher profit if they produce close substitutes than poor substitutes. Does this, in a richer framework, imply that firms have incentives to artificially reduce the extent of product differentiation?

While there is a large strand of literature that analyses consequences of R&D

cooperation between firms, there are very few studies of likely effects of R&D policy cooperation between countries. Given the substantial amount of R&D grants given by governments in different countries, there is a need for more work on this topic. For instance, do large countries on average pay relatively higher R&D subsidies than small countries? And how important are the profit-shifting motives for national R&D policies in practice? The quote from Tekes' web page indicates that they are quite strong, which is also the impression one gets from political discussions in most countries. Still, the European Commission has only showed a moderate interest in the question of regulating or coordinating national R&D policies. Although common EU research initiatives like the framework programmes and the European research area receive a lot of attention, there is very little focus on the strategic effects of national R&D policies and the accompanying policy competition between member states.

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# 6 Appendix

*Proof of Proposition 1*

The first-order conditions for social optimum is given by $\partial W/\partial q_{ji} = \partial W/\partial x_j = 0$. Whether we solve for quantities and R&D investments simultaneously or in two stages is irrelevant, but it is most illustrative to start with $\partial W/\partial q_{ji} = 0$. For $b \neq 1$ we then find

$$q_{ji} = \frac{(\alpha - c)(1-b) + x_j - bx_k}{1-b},$$

where the second-order conditions hold for all $b < 1$. However, by inserting for $q_{ji}$ we find

$$\begin{aligned} \left(\frac{\partial^2 W}{\partial x_j^2}\right) &= -2\frac{\phi(1-b)-1}{1-b} < 0 \text{ if } \phi > 1/(1-b) \\ \left(\frac{\partial^2 W}{\partial x_1^2}\right)\left(\frac{\partial^2 W}{\partial x_2^2}\right) - \left(\frac{\partial^2 W}{\partial x_1 \partial x_2}\right)^2 &= \frac{4(\phi-1)[\phi(1-b)-(1+b)]}{1-b} > 0 \text{ if } \phi < 1 \text{ and } \phi > \frac{1+b}{1-b}, \end{aligned}$$

from which it follows that the second-order conditions do not hold for all $b \in [0,1]$ for any finite value of $\phi$. We further see that the critical value of $b$ above which the second-order conditions do not hold increases in $\phi$.

If both goods are produced, they will be sold at price equal to marginal costs. Using this it is straight forward to show that a requirement of $q_{ji} > 0$ implies that we have a unique symmetric equilibrium where the second-order conditions hold, with quantities and quality levels as stated in Proposition 1.

*Proof of equation (13)*

In order to distinguish between the direct effect and the business stealing effect of providing R&D subsidies, we calculate the first-order conditions $\partial \pi_j/\partial q_{ji} = 0$ and $\partial \pi_j/\partial x_j = 0$ separately. From this we find respectively

$$q_{ji} = \frac{(1+b)x_j + (\alpha - c)(1+b) - bq_{ki}}{2}$$

and

$$x_j = \frac{q_{j1} + q_{j2} + s_j}{8}.$$

Total differentiation of these two first-order conditions yields

$$dq_{ji} = \frac{1+b}{2} dx_j - \frac{b}{2} dq_{ki} \tag{26}$$

and

$$dx_j = \frac{1}{4} dq_{ji} + \frac{1}{8} ds_j \tag{27}$$

Combining (26) and (27) for $j = A, B$ and $i = 1, 2$ we find

$$dq_{ji} = \frac{1+b}{2(3b+7)(7-5b)} \left[ (7-b) ds_j - 4b ds_k \right] \tag{28}$$

and

$$dx_j = \frac{1}{2(3b+7)(7-5b)} \left[ 2\left(7 - b - 2b^2\right) ds_j - b(1+b) ds_k \right]. \tag{29}$$

In the non-cooperative equilibrium the countries set the subsidy levels simultaneously, which means that $ds_k/ds_j = 0$ in equilibrium. In calculating the first-order condition for the government in country $j$ we can thus combine equations (26) - (29) to find

$$\frac{dq_{ji}}{ds_j} = \frac{1+b}{2(7-b)} - \frac{8b}{2(7-b)} \frac{dq_{ki}}{ds_j} \tag{30}$$

and

$$\frac{dx_j}{ds_j} = \frac{1}{7-b} - \frac{b}{7-b} \frac{dq_{ki}}{ds_j} \tag{31}$$

The direct effects of an R&D subsidy are now given by the first term on the r.h.s. of equations (30) and (31), while the business stealing effects are given by the second term. Using that

$$\frac{dW_j}{ds_j} = \frac{2q_{j1}}{1+b} \frac{dq_{j1}}{ds_j} + \frac{2q_{j2}}{1+b} \frac{dq_{j2}}{ds_j} - 8x_j \frac{dx_j}{ds_j} \tag{32}$$

we can thus combine (30), (31) and (32) to find equation (13).

*Proof that the size of the business stealing effect is increasing in b*

To show that the business stealing effect in isolation makes it optimal to pay higher subsidies the larger is $b$, we define (see equation (13))

$$\Omega_j \equiv \frac{4b}{7-b} \left( \frac{1}{(1+b)} q_j - x_j \right) \left( -\frac{\partial q_k}{\partial s_j} \right),$$

which can be rewritten as

$$\Omega_j = \frac{16b^2(1+b)}{(7-5b)(3b+7)^2}(\alpha - c) + \frac{8b^3(1+b)}{(7-5b)^2(7+3b)^2(7-b)}(bs_k + 4bs_j - 7s_k).$$

From this we find

$$\frac{\partial \Omega_j}{\partial s_j} = \frac{32b^4(1+b)}{(7-5b)^2(7+3b)^2(7-b)} > 0$$

and

$$\frac{\partial^2 \Omega_j}{\partial s_j \partial b} = \frac{128b^3(7+b)(49+42b-23b^2)}{(7-5b)^3(7+3b)^3(7-b)^2} > 0.$$

Q.E.D.

*Proof of Proposition 3*

Using equations (8), (9), (12) and (14) we find that welfare in the two producer countries equals

$$W_j^{s>0} = \frac{4(1+b)(343-147b-203b^2+31b^3+32b^4)}{(8b^3+19b^2-14b-49)^2}(\alpha - c)^2$$

if they provide equilibrium subsidies, while it is equal to

$$W_j^{s=0} = \frac{4(7-b)(1+b)}{(7+3b)^2}(\alpha - c)^2$$

if $s_A = s_B = 0$. Since

$$W_j^{s=0} - W_j^{s>0} = \frac{64b^3(1+b)^2(49+28b-5b^2-4b^3)}{(7+3b)^2(8b^3+19b^2-14b-49)^2}(\alpha - c)^2 > 0,$$

we thus see that welfare in the producer countries is higher without than with subsidies.

*Proof of Proposition 5*

Using equations (8), (9), (18) and (20) we find that welfare equals

$$W_i^{s>0} = \frac{4(1+b)(8183-637b-5594b^2-634b^3+979b^4+231b^5)}{(189+47b-73b^2-27b^3)^2}(\alpha - c)^2$$

if they provide equilibrium subsidies, while it is equal to

$$W_i^{s=0} = \frac{4(11+3b)(1+b)}{(7+3b)^2}(\alpha - c)^2$$

if $s_1 = s_2 = 0$. We thus find

$$W_i^{s>0} - W_i^{s=0} = \frac{16\left(1+b\right)^2\left(7+2b+3b^2\right)\left(287-16b-230b^2-96b^3-9b^4\right)}{\left(189+47b-73b^2-27b^3\right)^2\left(7+3b\right)^2}\left(\alpha-c\right)^2. \tag{33}$$

From (33) it is clear that $sign\left\{W_i^{s>0} - W_i^{s=0}\right\} = sign\left\{Z\right\}$, where $Z \equiv 287-16b-230b^2-96b^3-9b^4$. We immediately see that $Z$ is positive for $b=0$ and negative for $b=1$, and that $\partial Z/\partial b = -16-460b-288b^2-36b^3 < 0$ for $b \in [0,1]$. From this it follows that $Z=0$ for exactly one value of $b \in [0,1]$. Defining $b^*$ such that $Z(b^*)=0$ we find $b^* \approx 0.91$. We thus have that welfare with equilibrium subsidies is higher than with zero subsidies if $b < b^*$, while welfare with zero subsidies is higher if $b > b^*$. Q.E.D.

*Proof of equation (24)*

Maximizing welfare in equation (22) with respect to $s_1$ and $s_2$, and checking the second-order conditions, we find that we have a unique and symmetric equilibrium, with $s_1 = s_2$ (see equation (23)).

Setting $s_1 = s_2 \equiv s$ for an arbitrary common subsidy level we can use (4), (8) and (9) to find

$$\pi_i = \frac{\left(1+b\right)\left(7-b\right)\left(4\alpha-4c+s\right)\left(\alpha-c\right)}{\left(7+3b\right)^2} + \frac{7+6b+b^2}{2\left(7+3b\right)^2}s^2 \text{ and } CS_i = \frac{\left(1+b\right)^2\left(8\alpha-8c+s\right)^2}{4\left(7+3b\right)^2}. \tag{34}$$

This means that R&D subsidies increase profits, but that the increase is smaller the larger is $b$;.

$$\frac{\partial \pi_i}{\partial s} = \frac{\left(1+b\right)\left(7-b\right)\left(\alpha-c\right)}{\left(7+3b\right)^2} + s\frac{7+6b+b^2}{\left(7+3b\right)^2} > 0 \text{ and } \frac{\partial^2 \pi_i}{\partial b \partial s} = -\frac{4b\left(8\alpha-8c+s\right)}{\left(7+3b\right)^3} < 0. \tag{35}$$

From equation (34) we further find

$$\frac{\partial CS_i}{\partial s} = \frac{\left(1+b\right)^2\left(8\alpha-8c+s\right)}{2\left(7+3b\right)^2} > 0 \text{ and } \frac{\partial^2 CS_i}{\partial s \partial b} = \frac{4\left(1+b\right)\left(8\alpha-8c+s\right)}{\left(7+3b\right)^3} > 0, \tag{36}$$

so that R&D subsidies has a positive effect on consumer surplus, and more so the larger is $b$.[7]

Adding (35) and (36) we find

$$\frac{\partial \Lambda}{\partial s} = \frac{2(11+3b)(1+b)}{(7+3b)^2}(\alpha - c) + \frac{(3+b)(5+3b)}{(7+3b)^2} s \text{ and } \frac{\partial^2 \Lambda}{\partial s \partial b} = \frac{8}{(7+3b)^3}(8\alpha - 8c + s),$$

which shows that the private gains from R&D subsidies are increasing in $b$. The reason for this is that the consumer effect dominates over the profit effect, as explained in the main text. Q.E.D.

*One small and one large country: Equilibrium subsidy and quality levels.*

Solving $s_A = \arg\max W_A$ and $s_1 = \arg\max W_1$ in equation (25) simultaneously, we find

$$s_1 = \frac{8(7-2b)(1+b)(49-14b-34b^2+2b^3+5b^4)}{4459-2940b-3598b^2+1548b^3+1123b^4-200b^5-120b^6}(\alpha - c)$$

and

$$s_A = b^2 \frac{16(1+b)(91-90b-17b^2+20b^3)}{4459-2940b-3598b^2+1548b^3+1123b^4-200b^5-120b^6}(\alpha - c).$$

Inserting for these subsidy levels into (8) and (9) we find

$$x_1 = \frac{(1+b)(1029-861b-465b^2+369b^3+56b^4-40b^5)}{4459-2940b-3598b^2+1548b^3+1123b^4-200b^5-120b^6}(\alpha - c)$$

and

$$x_A = \frac{(7-b)(1+b)(91-90b-17b^2+20b^3)}{4459-2940b-3598b^2+1548b^3+1123b^4-200b^5-120b^6}(\alpha - c).$$

Figure 4 plots the difference between $x_1$ and $x_A$, which is uniquely determined except for the multiplicative term $(\alpha - c)$.

[7]Technically, the signs given in (35) and (36) could be reversed if $s$ is sufficiently negative. However, it can be show that this would imply so high taxes that investments in R&D would be negative. This does not make economic sense.