Losers, Winners and Prisoner Dilemmas in International Subsidy Wars

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Abstract

Two central results in the strategic trade literature are that governments shall support winners and that there is a policy prisoner dilemma in international subsidy wars (i.e.: countries have incentives to support local firms but they would be better off by cooperating to not intervene). We show that exactly the contrary holds when asymmetries between firms are endogenous. Specifically, the incentives to support are bigger for loser firms given that intervention can aim at making them winners (competitiveness shifting effects). As a result the countries that host less competitive firms always prefer intervention. We illustrate this with the Airbus-Boeing case.

Keywords: R&D Investment, R&D subsidies, Asymmetric Firms.
JEL Classification: F13, H52, L13, L52, O31.

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1 Introduction

Government intervention through the support of industries raises a lot of polemic and disagreement, and this is especially true amongst political circles. From the side of economic theory, though, the consensus is for long time inclined for the non intervention case. In fact, the international trade policy theory under perfect competition advocates that free trade is in general optimal (Bhagwati, 1988).

During the 80's and the 90's, however, the so-called strategic trade literature of Brander and Spencer (1985) challenged a little this vision by giving an economic rational for government intervention: imperfect competition[1]. The strategic trade policy argument follows from the fact that imperfect competitive sectors generate excess returns that firms want to fight for. In this sense governments may have incentives to support local firms through subsidies in order to promote *profit shifting effects* from foreign firms to national ones.

Given the extraordinary attention that the strategic trade reasoning received amongst policy makers (see the Clinton administration) the following problem emerged: should governments target *winners* or *losers* firms? Some like de Meza (1986) and Neary (1994) looked at this by modeling exogenous asymmetric firms. The answer given by both was that *winner* firms are preferable for support once they provide larger *profit shifting effects.* Accordingly, since subsides can only do *profit shifting effects* but not *competitiveness shifting effects* (i.e.: *losers* becoming *winners*), when a firm is a *loser* there is no point in supporting her because nothing can turn her into a *winner.*

Unfortunately, it is very hard to access if industrial policies of different countries follow mainly the advise of economists by picking *winners.* However we know that *loser* firms are very often chosen for support[2]. In fact, the helping *losers* cases are many times commented in the media and as such call a great deal of public attention. The classic example is the European aircraft firm Airbus[3]. It is sometimes argued that without the subsidies given by the European Union (EU), the (initially) *loser* Airbus would have been very easily knocked out by the *winner* Boeing and would never become a *winner* as it is today. The second part of this argument, however, cannot

[1] Because of that, "in the church of economics, this theory is something of a heresy" (*The Economist*, February 3 1996, pp. 68).

[2] See Baldwin and Robert-Nicoud (2006) for evidence on the lobby success of *losers.*

[3] For academic reference see Dixit and Kyle (1985) or Irwin and Pavcnik (2004). For more general commentators see *The Economist*, June 25 2005, pp. 14 and pp. 90.

be easily reconciled in the strategic trade literature given that, as mentioned above, this theory does not encompass *competitiveness shifting effects*.

This issue becomes even more problematic since Brander and Spencer (1985) defense of intervention goes under some qualification when more than one country follows a subsidy policy. Specifically, with two governments the same incentives for intervention arise as with just one government, but the two countries would be better off by cooperating to not intervene. In other words there is a policy *prisoner dilemma* in international subsidy wars. This result obviously puts into question the applicability of subsidy policies. In fact, what is the point of subsidizing local firms if in case foreign countries do the same there is nothing to gain?

Moreover, in the Airbus-Boeing case this policy *prisoner dilemma* predicts that if the US retaliates by also supporting Boeing, the Airbus subsidy advantage would simply vanish. In reality however Airbus did not loose the lead even after the US also started to subsidize Boeing. Actually, nowadays Airbus and Boeing compete "nose to nose"[4].

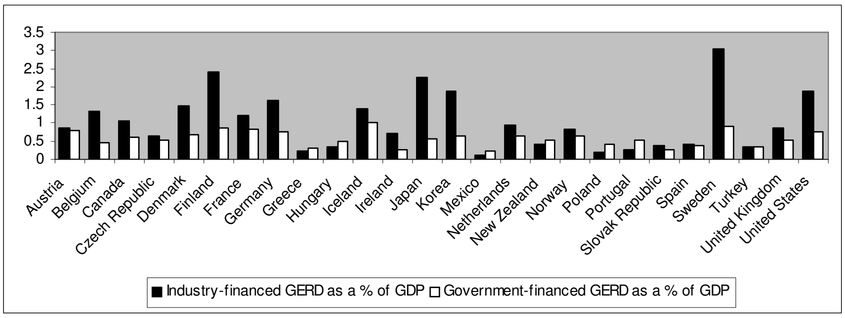
This paper then tries to tackle these two central results in the strategic trade literature: that governments shall support *winners* and that there is a *prisoner dilemma* in international subsidy wars. Specifically, as in Dixit and Kyle (1985) we keep in the background the Airbus *versus* Boeing case. However, obviously the example should not be taken literally.

We then develop a two country (US and EU), two firms (Boeing and Airbus), third market model (like in Brander and Spencer, 1985) where firms invest in process R&D (as in Leahy and Neary, 1997) and governments can choose to subsidize or not R&D. Therefore, similar to most of the strategic trade literature, we model governments in a very simplistic way, since they can only use one policy instrument: R&D subsidies. However, unlike what is standard in this literature we do not confine governments to intervention: governments must choose if they wish to support the local firm[5].

In addition, we differ from Leahy and Neary (1997) in the sense that firms are modeled as having different levels of *commitment* power in R&D (in the spirit of Stackelberg, 1934). *Commitment* power in R&D refers to a firm ability to influence rivals strategic choices through first mover advantages in R&D. In game terms this means that some firms choose R&D before others.

[4] *The Economist*, June 25 2005, pp. 90

[5] Cooper and Riezman (1989) instead endogenizes the government decision on alternative policy instruments (quantity controls *versus* export subsidies). Hwang and Schulman (1993) besides this choice also allows governments to decide to not intervene.



Note: Data available at www.oecd.org. GERD: gross domestic expenditure in R&D.

Figure 1: Government versus Industry financed R&D as % of GDP (2001)

In particular, we assume that the *leader* Boeing has a first mover advantage in R&D against the *follower* Airbus. The result is that without government intervention, the higher *commitment* firm (Boeing) is a *winner*, while the one that lacks this capability (Airbus) is a *loser*.

As such we concentrate our analysis in the strategic nature of R&D, in the sense that it can help firms to win over the competition. For that reason, R&D subsidies can be a very powerful weapon since they can affect the innovative behavior of firms, and in this way also influence the competitiveness battle against rivals.

This is apparently recognized by the OECD governments given the great amount of public funds that they attribute to subsidize innovation (figure 1). In fact, not only government financed R&D has a great weight in these economies, but it is also in some cases comparable to industry financed R&D.

This paper aims to study some of the incentives involved in subsidizing R&D, specially because they are so widespread but at same time theory tell us that they are innocuous for loser firms and for multi governments intervention cases. In particular, using the set-up described above we will show that contrary to the general belief, the incentives to support *losers* can be higher than those to support *winners* and that the country that hosts the *loser* firm can be better off by intervening (i.e.: there is no policy *prisoner dilemma*). This is so because the EU government R&D support to the *loser* Airbus can help her to become a *winner*, i.e.: our model has *competitiveness shifting effects*. We therefore present a special case where a country does not lose by intervention even if the rival country retaliates.

Notably, R&D investment is the sole culprit for these outcomes through the endogenous effects that it has on the competitiveness of firms. In fact, results in this paper cannot be reproduced if either the leader advantages can only affect outputs but not efficiency (as in Stackelberg, 1934) or firms are exogenously asymmetric (like in Neary, 1994). What this tells us is that if firm competitiveness is endogenous the effects of government intervention can have strong de-stabilizing effects not previously unveiled.

2 The Model

The world economy consists of two producer countries: the EU and the US (where US variables are indicated by an asterisk) and two firms that produce an homogeneous aircraft product: Airbus (from the EU) and Boeing (from the US). Firm behavior is modeled as a simple Nash-Cournot duopoly where firms compete in the final product market and process R&D investment. It is assumed that firms sell their output only in a third market that is not involved in production and Boeing has a first mover advantage in R&D. In addition, national governments can choose to subsidize R&D or not.

2.1 Demand and Firms

Following Brander and Spencer (1981), Airbus and Boeing face linear demands in the third country:

$$P = a - b\left(q + q^{*}\right) \tag{1}$$

where q are the sales of Airbus (and similarly q^{*} for Boeing), a is the intercept of the demand function and b is an inverse measure of market size.

Airbus profits can be defined as:

$$\Pi = \left(P - C - t\right) q - \Gamma + sk \tag{2}$$

where C are the marginal costs, Γ are the fixed costs, k is the R&D investment and s is the R&D subsidy given by the EU government. An analogous expression holds for Boeing, with C^{*}, Γ^{*}, k^{*} and s^{*}. Instead both Airbus and Boeing bear the same trade costs, i.e.: $t = t^{*}$.

2.2 Technology

R&D investment enters through marginal costs and fixed costs. In particular as in Leahy and Neary (1997) we consider process R&D investment that reduces marginal costs but increases fixed costs. Specifically for Airbus:

$$\begin{aligned} C &= c - \theta k \\ \Gamma &= \gamma \tfrac{k^2}{2} \end{aligned} \tag{3}$$

where θ is the cost-reducing effect of R&D, γ is the cost of R&D and c is the initial marginal cost (i.e.: without R&D). Boeing has a similar cost structure to Airbus with $c = c^*$, $\theta = \theta^*$ and $\gamma = \gamma^*$, i.e.: Boeing and Airbus have equal marginal costs without R&D and the same level of access to technology. This symmetry is assumed so that competitiveness asymmetries between Airbus and Boeing can only arise endogenously.

Throughout the paper it will prove useful, like in Leahy and Neary (1997), to define a parameter η that relates the market size and the R&D variables:

$$\eta = \tfrac{\theta^2}{\gamma b} \tag{4}$$

Accordingly, a high η represents a large return on innovative activities, since the cost-reducing effect of R&D (θ) weighted by market size ($1/b$) is large relatively to its cost (γ). The reverse interpretation holds for low η. Then η can be thought as an indicator of the "relative return to R&D".

2.3 Commitment Power in R&D

The idea of *commitment* power was introduced by von Stackelberg (1934) to refer to the ability of some players to influence rivals strategic choices through first mover advantages. Bagwell (1995), in turn, defines precisely the assumptions behind *commitment* power. First, moves in the game are sequential with some players committing to actions before other players select their respective actions. Second, late moving players perfectly observe actions selected by first movers. We adopt Bagwell (1995) definition in here.

In view of that, a firm has *commitment* power in R&D if she can commit to the output stage, i.e.: R&D levels are chosen in a previous stage to outputs. The contrary happens when a firm has *no-commitment* power: the firm sets outputs and R&D levels simultaneously. Thus, when a firm has *commitment* power, she can use R&D with two objectives: to improve her own productive efficiency and to affect the rivals' strategic decisions. When a firm does not have *commitment* power in R&D, instead, only the former holds[6].

In the light of the Airbus-Boeing example we then assume that Boeing has a first mover advantage in R&D against Airbus[7].

2.4 R&D subsidies

In what concerns R&D subsidies (s and s^*), governments can either decide to give an R&D subsidy to the local firm or to abstain from that support[8].

It is then considered four R&D subsidy cases: the *benchmark no government active*, where both countries do not subsidize (i.e.: $s = s^* = 0$); the *EU active*, where only the EU government subsidizes, i.e.: $s \neq 0$ and $s^* = 0$; the *US active*, where only the US government subsidizes (i.e.: $s^* \neq 0$ and $s = 0$); and the *two governments active*, with subsidization by both the EU and the US (i.e.: $s \neq 0$ and $s^* \neq 0$). When deemed necessary, expressions for the *benchmark*, *EU active*, *US active* and the *two governments active* will be indicated respectively by a upper-script B, EU, US and $EU + US$. These four cases are shown in matrix format in figure 2.

2.5 Timing of the Game

It is now possible to define the timing of the game (see figure 3). In the first stage governments decide on whatever to subsidize or not. In the second stage governments (depending on the option of the first stage) select the amount of R&D subsidy to be awarded to the local firm. In the third stage

[6] *Commitment* power in R&D therefore gives *leader* advantages to a firm that competes with another one that lacks such capability. As a result, and as it will be seen bellow, firms with different *commitment* capabilities can become endogenously asymmetric because their R&D choices internalize the differences that they have at this level.

[7] The difficulty with this *leader-follower* set-up is to substantiate the first mover advantage. According to Hamilton and Slutsky (1990), however, when the first mover advantage is not made endogenous (as in here), this can still be justified by exogenous factors as incumbent-entrant relations that makes one firm a *leader*. In our opinion, this undoubtedly applies to the Boeing-Airbus case, since Boeing was an indisputable leader of the market prior to Airbus entry.

[8] We do not look at the role of international institutions (such as WTO) in fostering international cooperation. On this literature see the review by Staiger (1995).

EU \ US	Not-Subsidize ($s^*=0$)	Subsidize ($s^*\neq 0$)
Not-Subsidize (s=0)	B	US
Subsidize (s≠0)	EU	EU+US

Figure 2: Subsidy Cases

Stage \ Game	B	EU	US	EU+US
Stage 1	**Subsidize *versus* not-Subsidize**			
Stage 2	**n.a.**	**s**	**s***	**s,s***
Stage 3	**k***			
Stage 4	**Airbus: Entry versus non-entry**			
Stage 5	**k,q,q***			

(n.a.: not applies)

Figure 3: Timing of the Game

Boeing sets k^*. In the fourth stage Airbus makes the entry decision. In the fifth stage Boeing decides on q^* and Airbus (in case she had decided to enter) chooses q and k simultaneously.

3 Production and Entry

The model is solved in the usual fashion by backward induction. However, in spite of considering alternative R&D subsidy games that differ in the order of the moves of the players (B, EU, US and $EU+US$), all of them can be solved in a similar fashion in what concerns the production variables (R&D and outputs). As such the strategy followed in this section is to find the general R&D and output expressions common to all R&D subsidy cases.

To calculate outputs use the first-order conditions (FOC) in relation to q and q^*. At this stage computation output expressions are still independent of differences in *commitment* power in R&D between firms and of the type of the subsidy game being played. As such outputs are just equal to:

$$\begin{aligned} q &= \tfrac{D-t+2\theta k-\theta k^{*}}{3b} \\ q^{*} &= \tfrac{D-t+2\theta k^{*}-\theta k}{3b} \text{ for } \forall \text{ subsidy cases} \end{aligned} \qquad (5)$$

where $D = (a - c)$ is a measure of a firm "initial cost competitiveness" (i.e.: without R&D investment). The parameter space is restricted to $D > t$ so that trade costs are not prohibitive.

To find R&D levels compute the FOCs in relation to k and k^{*}. Note however that now, contrary to outputs, it is necessary to take into consideration whatever firms can commit or not to R&D. We start first with Boeing. Since Boeing has *commitment* power in R&D, her FOC in relation to k^{*} is:

$$\tfrac{d\Pi^{*}}{dk^{*}} = \tfrac{\partial\Pi^{*}}{\partial k^{*}} + \tfrac{\partial\Pi^{*}}{\partial q}\tfrac{dq}{dk^{*}} \qquad (6)$$

The first and second terms on the right hand side of equation 6 are usually called respectively the non-strategic motive and the strategic motive for R&D[9]. Accordingly, R&D is strategic when the second term is non-zero. This is the case if a firm chooses R&D in a previous stage to outputs, i.e.: when a firm has *commitment* power in R&D (as Boeing). On the contrary, R&D is non-strategic if the second term is zero. This happens for example if a firm chooses R&D and outputs simultaneously, i.e.: when a firm has *no-commitment* power in R&D (as Airbus). Therefore, since Airbus cannot commit to R&D, her FOC in relation to k is simply:

$$\tfrac{d\Pi}{dk} = \tfrac{\partial\Pi}{\partial k} \qquad (7)$$

As a result, R&D expressions for Airbus and Boeing under the *two governments active* case are:

$$\gamma\left(k\right)^{EU+US} = \theta\left(q\right)^{EU+US} + \left(s\right)^{EU+US} \qquad (8)$$

$$\gamma\left(k^{*}\right)^{EU+US} = \tfrac{4\theta}{3}\left(q^{*}\right)^{EU+US} + \left(s^{*}\right)^{EU+US} \qquad (9)$$

In the other subsidy cases equations 8 and 9 are just modified accordingly: in the *benchmark* case by setting $s = s^{*} = 0$, in the *EU active* case by setting $s^{*} = 0$ and in the *US active* case by making $s = 0$.

[9] Note that the whole foreign firm FOC in relation to R&D is: $\frac{d\Pi^{*}}{dk^{*}} = \frac{\partial\Pi^{*}}{\partial k^{*}} + \frac{\partial\Pi^{*}}{\partial q^{*}}\frac{dq^{*}}{dk^{*}} + \frac{\partial\Pi^{*}}{\partial q}\frac{dq}{dk^{*}}$, but from the envelop theorem $\partial\Pi^{*}/\partial q^{*} = 0$.

From equations 8 and 9 we can see that Boeing and Airbus differences at level of *commitment* power in R&D create endogenous competitiveness asymmetries between the two firms[10]. Specifically, Boeing (the firm with *commitment* power) over invests by a proportion of 4/3 relatively to Airbus (the firm with no *commitment* power). As in Fudenberg and Tirole (1984) over investment by Boeing aims at discouraging entry by Airbus[11]. The consequence of this over investment by Boeing is that if Airbus decides to enter the market she will be less competitive than Boeing. In other words the firm with *no-commitment* power in R&D is a *loser* and firm with *commitment* power in R&D is a *winner*. We will prove this assertion bellow.

Before that, we can still study the entry decision of Airbus. To be precise, Airbus will only enter the market if she can make positive profits. To check this, substitute into Airbus' profit expression (equation 2) for Airbus' R&D levels (equation 8). Ignoring upper scripts for the different R&D subsidy cases, the profit expression for Airbus simplifies to:

$$\Pi = q\frac{q\gamma b(2-\eta)-\theta s}{2\gamma} + s\frac{\theta q+s}{2\gamma} \tag{10}$$

As long as Airbus has positive outputs and the second order condition (SOC) holds (see Appendix A), the sign of Airbus profits depend only on the R&D subsidy given by the EU. To be precise, if $s = 0$ (US and B cases), Airbus profits are unambiguously positive, i.e.: Airbus enters the market. If instead $s \neq 0$ (EU and $EU + US$ cases) the sign of equation 10 depends on whatever s is a subsidy or a tax. If s is a subsidy, Airbus profits are always positive (even with $q = 0$) and therefore she always enters the market. If instead s is a tax, Airbus' profits can either be positive or negative depending on output levels, q. Since s is endogenous to the model, however, we have to proceed to the study of the optimal R&D subsidy before making a final statement on Airbus' entry decision.

[10]Due to this from now on we call the game in this paper endogenous asymmetry subsidy game in order to differentiate it from the exogenous asymmetry subsidy games of Neary (1994) and de Meza (1986).

[11]This happens to be so, because in Cournot competition, outputs are strategic substitutes (see Bulow et al. 1985), i.e.: if q increases, q^* decreases (and in consequence also Boeing profits). But since when k^* increases, q decreases, then $\frac{\partial \Pi^*}{\partial q}\frac{dq}{dk^*} = \frac{\theta}{3}q^* > 0$, i.e.: the strategic effect on R&D for Boeing is positive.

4 R&D Subsidies and Production

This section computes the second stage of the model: R&D subsidies. As in the strategic trade literature (Brander and Spencer, 1985), the third-market assumption implies abstraction from domestic consumption. Then, when for example the EU government decides to not subsidize, the EU welfare is just equal to Airbus' profits (i.e.: $W = \Pi$ for B and US cases). Instead, when the EU government gives R&D subsidies, the EU welfare is defined as a function of Airbus' profits minus the amount of R&D subsidy paid:

$$W = \Pi - sk \text{ for } EU \text{ and } EU + US \text{ cases} \tag{11}$$

The same happens for the US government welfare function.

As a result and as shown in appendix the EU government subsidy under the EU case is:

$$(s)^{EU} = \frac{\theta}{(3-2\eta)} (q)^{EU} \tag{12}$$

Instead, in the $EU + US$ case, $(s)^{EU+US}$ is as in equation 12 with $(q)^{EU}$ substituted for $(q)^{EU+US}$.

In turn the US government subsidy in the US case equals:

$$(s^*)^{US} = \frac{\theta\eta}{3(2-\eta)} (q^*)^{US} \tag{13}$$

For the $EU + US$ case, instead, $(s^*)^{EU+US}$ is similar to equation 13 but $(q^*)^{US}$ is substituted for $(q^*)^{EU+US}$. Note that the difference between equation 12 and equation 13 is due to the fact that Boeing has a higher *commitment* power in R&D than Airbus. In other words, governments incentives to intervene depend on the R&D capability of the local firm. The following sections analyze the consequences of this.

Before that, we can use equations 5, 8, 9, 12 and 13 to solve simultaneously for q, q^*, k, k^*, s and s^* under the different R&D subsidy cases:

$$\begin{aligned}
(q)^B &= \frac{(3-4\eta)(D-t)}{b(9-2\eta(7-2\eta))} \\
(q^*)^B &= \frac{3(1-\eta)(D-t)}{b(9-2\eta(7-2\eta))} \\
(k)^B &= \frac{\theta(3-4\eta)(D-t)}{\gamma b(9-2\eta(7-2\eta))} \\
(k^*)^B &= \frac{4\theta(1-\eta)(D-t)}{\gamma b(9-2\eta(7-2\eta))}
\end{aligned} \tag{14}$$

$$
\begin{aligned}
(s)^{EU} &= \frac{\theta(D-t)(3-4\eta)}{b(3-2\eta)(9-4\eta(4-\eta))} \\
(q)^{EU} &= \frac{(D-t)(3-4\eta)}{b(9-4\eta(4-\eta))} \\
(q^*)^{EU} &= \frac{3(D-t)(3-2\eta(3-\eta))}{b(3-2\eta)(9-4\eta(4-\eta))} \\
(k)^{EU} &= \frac{2\theta(D-t)(6-\eta(11-4\eta))}{\gamma b(3-2\eta)(9-4\eta(4-\eta))} \\
(k^*)^{EU} &= \frac{4\theta(D-t)(3-2\eta(3-\eta))}{\gamma b(3-2\eta)(9-4\eta(4-\eta))} \qquad (15)
\end{aligned}
$$

$$
\begin{aligned}
(s^*)^{US} &= \frac{\theta^3(D-t)(1-\eta)}{b^2\gamma(9-\eta(14-3\eta))(2-\eta)} \\
(q)^{US} &= \frac{(D-t)(6-\eta(11-3\eta))}{b(9-\eta(14-3\eta))(2-\eta)} \\
(q^*)^{US} &= \frac{3(D-t)(1-\eta)}{b(9-\eta(14-3\eta))} \\
(k)^{US} &= \frac{\theta(D-t)(6-\eta(11-3\eta))}{b\gamma(9-\eta(14-3\eta))(2-\eta)} \\
(k^*)^{US} &= \frac{\theta(D-t)(8-\eta(11-3\eta))}{b\gamma(9-\eta(14-3\eta))(2-\eta)} \qquad (16)
\end{aligned}
$$

$$
\begin{aligned}
(s)^{EU+US} &= \frac{\theta(D-t)(6-\eta(11-3\eta))}{b(54-\eta(159-2\eta(74-\eta(26-3\eta))))} \\
(s^*)^{EU+US} &= \frac{\theta^3(D-t)(3-2\eta(3-\eta))}{b^2\gamma(54-\eta(159-2\eta(74-\eta(26-3\eta))))} \\
(q)^{EU+US} &= \frac{(D-t)(18-\eta(45-\eta(31-6\eta)))}{b(54-\eta(159-2\eta(74-\eta(26-3\eta))))} \\
(q^*)^{EU+US} &= \frac{(D-t)(18-\eta(45-6\eta(5-\eta)))}{b(54-\eta(159-2\eta(74-\eta(26-3\eta))))} \\
(k)^{EU+US} &= \frac{2\theta(D-t)(12-\eta(28-\eta(17-3\eta)))}{b\gamma(54-\eta(159-2\eta(74-\eta(26-3\eta))))} \\
(k^*)^{EU+US} &= \frac{\theta(D-t)(24-\eta(57-2\eta(17-3\eta)))}{b\gamma(54-\eta(159-2\eta(74-\eta(26-3\eta))))} \qquad (17)
\end{aligned}
$$

We restrict the parameter space in the model such that in all R&D subsidy cases at least Boeing has always non-negative outputs and R&D levels. Conversely, we do not want that in any event the *leader* exits the market. As shown in Appendix A this is so as long as:

$$
0 < \eta < \frac{3-\sqrt{3}}{2} \qquad (18)
$$

Furthermore, equation 18 is also sufficient to guarantee that for the alternative subsidy cases, Airbus outputs and R&D levels as well as the EU and the US R&D subsidies are always positive[12]. Then in the context of this model it is never optimal to tax R&D.

It is now possible to give a final statement on the entry decision of Airbus. Given that $q > 0$ due to equation 18, then also as shown in the end of the previous section, if the EU government does not intervene (B and US cases) Airbus enters the market. We can now also check what happens if the EU government intervenes by simply substituting in equation 10 for the optimal EU subsidy (equation 12) to obtain:

$$\Pi = \frac{b(9-2\eta(8-\eta(5-\eta)))}{(3-2\eta)^2}q^2 > 0 \tag{19}$$

Then, as long as the SOC holds Airbus profits are always positive. This means that neither the higher commitment power of Boeing neither the R&D subsidy by the US or by the EU government can deter Airbus entry[13].

5 Winners and Losers: Pick Who?

In order to access if governments shall help *winners* or *losers* it is necessary first to know who are the *winners* and who are the *losers.* This can only be investigated in the *benchmark* case, since in the subsidy cases (EU, US and $EU+US$) this question is already internalized through the R&D subsidy given by national governments. It comes out that the relation between Airbus and Boeing in the *benchmark* case is (see Appendix A for proof):

$$\begin{array}{rcl} (q)^B & < & (q^*)^B \\ (k)^B & < & (k^*)^B \end{array} \tag{20}$$

[12] Also, as it will be seen bellow, if equation 18 does not hold the comparative statics of the model do not make much economic sense.

[13] The case for entry deterrence in this model is weak because fixed costs are endogenous to the R&D choices of the firm (see equation 3). Then when a firm chooses R&D levels she does so such that it does not prevent her to enter the market. If instead a part of Airbus fixed costs are exogenous (for example $\Gamma = f + \gamma k^2/2$), then like in Dixit (1980) and Spence (1977), Airbus would face a threshold level of exogenous fixed costs (f) between enter and non-entering. Obviously, this would not change our analysis for fixed costs bellow this threshold. In addition, if the EU support also covers Airbus' exogenous fixed costs, that would make these costs irrelevant for Airbus entry decision. We believe that this has happened in the Airbus case.

With no surprise, the firm with higher *commitment* power in R&D (Boeing) is the *winner*, while the firm with lower *commitment* power (Airbus) is the *loser*. Obviously this is due to the first mover advantage in R&D that Boeing has relatively to Airbus.

Now that we have identified the *winners* and the *losers*, we must ask what type of firms shall the subsidy policy target: the *winners* or the *losers*? As already said before, the literature on the field defends that governments should help *winners*. For example in de Meza (1986) and Neary (1994) the less cost competitive is the domestic firm, the lower should be the subsidy given to her (see Appendix C). This is so because (exogenous) more competitive firms make larger *profit shifting effects* than less competitive firms.

Note however that there are some differences between the models by de Meza (1986) and Neary (1994) and the one in here. The most important one is that in de Meza (1986) and in Neary (1994) the competitiveness asymmetries between firms are exogenous while in here they are endogenous[14].

This endogenous *versus* exogenous competitiveness difference however is important given that it allows us to make some qualifications to some results from the strategic trade literature. The first consequence of the endogenous asymmetry property of our model comes through the relation between the EU and the US subsidy (see Appendix A):

$$\begin{aligned} (s)^{EU} &> (s^*)^{US} \\ (s)^{EU+US} &> (s^*)^{EU+US} \end{aligned} \tag{21}$$

In opposition to the strategic trade policy, then, in here the incentives to support *losers* (Airbus) are larger than those to support *winners* (Boeing).

The second consequence falls out from the pattern of intervention in equation 21 that complete alters the competitiveness relation between Airbus and Boeing. This is so not only when solely the EU intervenes but also when both governments are active (see Appendix A):

$$\begin{aligned} q &> q^* \\ k &> k^* \text{ for } EU \text{ and } EU+US \text{ cases} \end{aligned} \tag{22}$$

[14] Other difference is that in de Meza (1986) and Neary (1994) firms compete solely in outputs and so the only policy instrument available for governments is an export subsidy.

The EU therefore uses the R&D subsidy not only to recover Airbus' competitive disadvantage but also to make her to leapfrog Boeing. In other words the EU subsidy provokes *competitiveness shifting effects*: it helps the initial *loser* Airbus to become a *winner* and it makes the initial *winner* Boeing a *loser*.

Such *competitiveness shifting effects* never occur in standard strategic trade models, like Brander and Spencer (1985), where government intervention can only provoke *profit shifting effects*. As a result, when these standard models assume exogenous asymmetric firms (as in de Meza, 1986 and in Neary, 1994), there are no incentives to support *losers*. Conversely, if firms are exogenously asymmetric, whatever national governments do, it is never possible for a subsidy policy to restrain the more competitive firms to be so.

On the contrary, if asymmetries between firms are endogenous a country with a laggard firm can try to change the competitiveness balance in favor of the local firm. In fact, remember that Boeing is just more competitive than Airbus due to the *commitment* power advantages that she possesses. From one side, this allows Boeing to strategically over-invest in R&D in order to push Airbus down into her reaction function. However from the other side, the EU government can counterbalance this *commitment* advantage of Boeing by giving a subsidy to Airbus, so that Boeing cannot use R&D strategically against Airbus. Accordingly, the EU government plays strategically against Boeing so that she cannot play strategically in R&D against Airbus.

In turn for the US the incentives to support Boeing are not so strong. This is so because the higher *commitment* power of Boeing allows her to do *profit shifting* without the help of the US subsidy. Consequently, the US government feels that Boeing does not need extra support. For that reason, in all subsidy cases the US ends up giving a lower subsidy to Boeing than the one the EU gives to Airbus (see equation 21). This has as result, that the EU intervention puts Boeing in competitive disadvantage relatively to Airbus, independently of the US government action (see equation 22)[15].

6 Subsidize or Not: a Prisoner Dilemma?

This section asks if in the context of the model in this paper governments face a policy *prisoner dilemma* when deciding on either to subsidize or not the

[15] Note that this holds even when both the US and the EU are active because both governments move simultaneously and they cannot anticipate the rival government action.

local firm. This dilemma arises if from one side governments have incentives to subsidize, but from the other side countries would be better off by cooperating to not subsidize. As we have already discussed in the introduction, the answer so far in the strategic trade literature has been on the affirmative way: countries lose when rivals retaliate (see Brander and Spencer, 1985).

In order to investigate this, we need to rank welfare under the different R&D subsidy cases (see Appendix A for proof):

$$\begin{aligned} (W)^{EU} &> (W)^{EU+US} > (W)^{B} > (W)^{US} \\ (W^{*})^{US} &> (W^{*})^{B} > (W^{*})^{EU+US} > (W^{*})^{EU} \end{aligned} \quad (23)$$

The US welfare is higher when only the US government subsidizes R&D, then when both the US and the EU governments do not subsidize, after when both governments subsidize and in the last place when only the EU government subsidizes. Instead, the EU has a different welfare ranking: the EU prefers in first place when only the EU government is active, in second place when both governments are active, in third place when no government is active, and in the last place when only the US government is active[16].

As a consequence of this welfare ranking, the non cooperative equilibrium of the endogenous asymmetry game in this paper is to have both countries subsidizing R&D (see figure 4)[17]. However, contrary to the standard result in the strategic trade policy literature, the EU does not face a policy *prisoner dilemma*. In fact the EU is always better off by intervening than by cooperating to not intervene. The opposite is the case for the US that intervenes in spite of being better off if both countries would agree to not intervene[18].

The rational for the inexistence of a policy *prisoner dilemma* in the context of this model, lies down in the strategic nature of R&D, i.e.: it is not sufficient to have asymmetric firms or *leader-follower* set-ups. Actually, if we repeat the same exercise done here in a standard Stackelberg *leader* model

[16] If instead equation 18 does not hold, the welfare ranking is $(W)^{US} > (W)^{B} > (W)^{EU} > (W)^{EU+US}$ for the EU and $(W^{*})^{EU} > (W^{*})^{B} > (W^{*})^{US} > (W^{*})^{EU+US}$ for the US, i.e.: a country prefers the rival country to intervene alone. This is a rather strange result that confirms, in our view, the choice made for the parameter space where the game is valid.

[17] Numbers in figure 4 indicated the position in the welfare rank. Accordingly, 1 for the first place and 4 for the last place.

[18] Hence if possible, the US would try to convince the EU to enter a cooperative agreement to forbid the use of R&D subsidies.

EU \ US	Not-Subsidize ($s^*=0$)	Subsidize ($s^*\neq 0$)
Not-Subsidize ($s=0$)	(3,2)	(4,1)
Subsidize ($s\neq 0$)	(1,4)	(2,3)

Figure 4: Endogenous Asymmetry Game

or in a exogenous asymmetry subsidy model (like Neary, 1994), results are not replicated totally. This is done in Appendix B for the Stackelberg *leader* model and Appendix C for the exogenous asymmetry model.

Start with the standard Stackelberg output *leader* game, where Boeing has a first mover advantage in outputs. Since firms compete only in outputs, governments can only use export subsidies (see Appendix B for details). Naturally under this set-up Boeing is still a *winner* and Airbus a *loser*. However now for both the US and the EU the optimal subsidy under all subsidy cases is zero. Thus, the policy *prisoner dilemma* does not even arise in the Stackelberg model, given that countries do not have incentives to intervene. As such to have a *leader* and a *follower* framework is not enough to justify the results in this paper. This is so because in spite of the similitudes in the *leader-follower* dichotomy, our model differs from the Stackelberg one in some other important ways.

In particular, the main difference between the two models is that in here competitiveness is endogenous, while in Stackelberg it is not. Specifically, competitiveness in our endogenous asymmetry subsidy game depends on both the R&D decisions of firms and on the policy choices of governments. As a result, the *leader* advantages of the higher *commitment* firm does not make her directly a *winner*.

In effect, as we have seen above, Boeing over invests in R&D to make the rival lower *commitment* power Airbus to reduce output levels (equation 9). However, due to R&D even Airbus (the lower *commitment* firm) can aim at increase her own competitiveness, in spite of not being able by herself to affect Boeing's competitiveness. Since through R&D subsidies, government action can affect the firms' incentives to innovate, then as said above, the EU government can play Stackelberg against Boeing so that Boeing does not play Stackelberg against Airbus[19].

On the contrary, in the Stackelberg game competitiveness is fixed (i.e.: firms always have the same marginal and fixed costs). In fact, the Stackelberg *leader* is not able to affect competitiveness, it can only influence outputs. However by influencing the rival outputs, the Stackelberg *leader* becomes a *winner* independently of governments' actions. This is so because a subsidy by the *follower* firm government is not able to control for the *leader* advantage. In other words, the country that hosts the *follower* firm sees no point in intervention since this is always ineffective. Instead, the country that hosts the *leader* firm also has no need to intervene given that the local firm is anyway an undisputable *winner*.

Take now the exogenous asymmetry subsidy model (Neary, 1994) where it is assumed that Boeing is exogenously more competitive than Airbus ($C > C^*$)[20]. Then as in our model, Boeing is a *winner* and Airbus is a *loser*. As for the Stackelberg model, governments can only use export subsidies given that firms compete just in outputs (see Appendix C for details).

With this set up we have two Nash equilibrium configurations (see also Appendix C): the first holds when Boeing's competitiveness is sufficiently large, i.e.: $(a - C^*)$ big (figure 5) and the second when this is low (figure 6).

As shown in figure 5, when Boeing is very competitive the exogenous asymmetry subsidy game of Neary (1994) has the same Nash equilibrium as the endogenous asymmetry subsidy game in this paper: intervention by both the EU and the US. However now both countries face a *prisoner dilemma* since they would be better off by cooperating to not intervene. The rational for this result is the same as for the standard symmetric firms subsidy game of Brander and Spencer (1985): individually the two countries have incentives to subsidize, and therefore they end up in a intervention equilibrium where both are worse off.

If instead Boeing is not very competitive the Nash equilibrium of the exogenous asymmetry subsidy game is also to have both countries to subsidize the local firm (see figure 6). However now the US does not face a policy *prisoner dilemma*. Then if the *winner* Boeing has only a small cost com-

[19] Accordingly, a EU subsidy by making the lower *commitment* Airbus to invest more in R&D, it also makes the higher *commitment* Boeing to reduce outputs (see equation 5 and equation 9). As such in the game of this paper when the EU government intervenes, he is aiming at the competitiveness level of the *loser* Airbus, because this can counter act Boeing's *leader* advantages.

[20] Rosen (1991) uses a similar strategy to model asymmetric firms that invest in R&D.

EU \ US	Not-Subsidize ($s^*=0$)	Subsidize ($s^*\neq 0$)
Not-Subsidize ($s=0$)	(2,2)	(4,1)
Subsidize ($s\neq 0$)	(1,4)	(3,3)

Figure 5: Exogenous Asymmetry Game (Boeing very competitive)

EU \ US	Not-Subsidize ($s^*=0$)	Subsidize ($s^*\neq 0$)
Not-Subsidize ($s=0$)	(2,3)	(4,1)
Subsidize ($s\neq 0$)	(1,4)	(3,2)

Figure 6: Exogenous Asymmetry Game (Boeing not very competitive)

petitiveness advantage it might be optimal for the US to subsidize the local firm without having to fear retaliation. In turn for the EU it continues to be better to try to reach a cooperative agreement.

The reason for this result is that when Boeing competitiveness is low, Airbus competitiveness $(a - C)$ is even lower given that by assumption $C > C^*$. Thus since governments in the exogenous asymmetry subsidy game shall support *winners* and the optimal subsidy decreases with the competitiveness disadvantage of the local firm, the EU subsidy to Airbus in this case is very small. This in turn means that the EU *profit shifting effects* are even smaller. In this sense a subsidy war with the EU is not very threatening to the US, and as a result, the US welfare under the two governments active case can be bigger than in the *benchmark* case.

Relating with our discussion of the policy *prisoner dilemma*, what the exogenous asymmetry game tell us is that to avoid this dilemma it is not enough to have asymmetric firms. However having asymmetric firms can reduce the policy *prisoner dilemma*, given that countries may also have asymmetric incentives to intervene. This always holds if asymmetries are endogenous, but is only so with exogenous asymmetries if some special conditions are satisfied.

This result highlights the importance of incorporating asymmetric firms in standard trade models, given that heterogeneities in production introduce new dimensions in international trade questions. In this sense this paper relates with recent attempts to model asymmetric firms like Melitz (2003). Nevertheless contrary to us, but similar to Neary (1994) and de Meza (1986), Melitz (2003) still holds to the asymmetric firms assumption[21]. Our paper however shows that the nature of asymmetries matters for government intervention. If asymmetries are endogenous, government intervention can have profound effects on the competitiveness equilibrium of the market. If instead asymmetries are exogenous, government intervention at most can aspire to confirm the existing competitiveness balance.

Summing up when a firm has a competitive disadvantage and this disadvantage is endogenous, government intervention in form of R&D subsidies can aim at change the competitiveness balance in favor of the local firm. The endogenous asymmetry subsidy game in this paper therefore presents a special case where countries have incentives to subsidize even when they face the threat of retaliation by rival countries. This result can redirect us to the classical article by the late Harry Johnson (1954) where he showed that under certain conditions on the elasticity of demand for imports a country may gain by imposing an optimum tariff even if other countries retaliate.

The implication of ours results are then also similar to those by Johnson (1954) given that "as in many other problems in the international economic policy, the answer depends on the circumstances of each particular cases, and that everyone who asserts that one conclusion is universally valid is making an implicit assumption about the facts which ought to be explicitly defended – if it can be".

7 Discussion

Have you heard of *Quaero* (Latin for "I seek")? *Quaero* is a state endorsed pan-European Internet search engine that looks for to challenge the Internet giant Google. In particular this European public-private consortium aims at developing technology that allows users to perform searches using pictures and sound, and not only keywords as it is now with Google and similar search engines. According to the French President Jacques Chirac the project is

[21] In particular, Melitz (2003) generates firm heterogeneity by allocating productivity levels to firms randomly accordingly to some *ex-ante* statistical distribution.

undertake "in the image of the magnificent success of Airbus" (quoted in The Economist, March 11 2006, supplement Technology Quarterly pp. 10).

Quaero is a typical example of a strategic trade policy in action. Brander and Spencer (1985) seminal paper showed that in fact countries may gain at the expenses of others by subsidizing local firms. However, in case Google is worried about *Quaero*, the strategic trade policy solution would be for the US government also to support Google. With that *Quaero* subsidy advantage would be simply cancel out, though, in the end both countries would be worst off than in the non-intervention case: *Quaero* would not gain the competitive battle and both the US and the EU would waste tax payers money.

In addition if we consider that Google is (exogenously) more competitive than *Quaero*, then according to the strategic trade policy view the European governments are committing a big mistake in supporting *Quaero.* This is so since according to this literature *losers* should not be supported given that nothing can make them *winners* (Neary, 1994 or de Meza, 1986).

So what can explain the Airbus success? Airbus was initially in competitive disadvantage relatively to Boeing but even so, and according to some analysts, due to the European governments support she managed to become an important rival of Boeing.

This paper has tried to give some explanations for the Airbus-Boeing case. Namely we have argued that if asymmetries between firms are endogenous, government intervention can alter the competitiveness equilibrium in the market. This can be so when the *winner* firm has some sort of first mover advantages in R&D that government intervention can counter act. As a consequence of that, and contrary to what is usually held in the strategic trade literature, *losers* can also be supported to become *winners* and there is no *prisoner dilemma* in international subsidy wars.

The nature of competition in the market is therefore central. With endogenous competitiveness on R&D, governments actions can have more enduring effects on the competitive outcomes than what is usually believed in the strategic trade literature. If instead competitiveness is essentially exogenous there is little scope for government intervention (due to the policy *prisoner dilemma*) at least for targeting *loser* firms (and only in very special cases for *winner* ones).

The supporting *losers* and the no policy *prisoner dilemma* results may be thought as coming against the faith in the economic profession that "government intervention is bad, period". Government intervention has certainly dreadful effects, as we have in any case shown here: R&D subsidization can completely alter the competitiveness relations in a industry! However, only by presenting what type of effects government intervention can have, economists can argue with understanding against it.

In this sense this paper is not a defense of R&D subsidies or another kind of government intervention. As we have mentioned in the end of the last section with the help of a citation by Harry Johnson (1954), results in this paper suffer from specificity. We have just used the fact that R&D affects competition to show that anything that has an impact on the innovative behavior of firms (as government subsidization of R&D) can also subvert the competitiveness game.

Therefore, our paper also obviously does not predict the success of *Quaero*. This will depend on many factors that are outside of the analysis carried out here. Accordingly, *Quaero* and *Airbus* are two completely different cases: the nature of competition and R&D is different in aircraft and Internet industry and as such also the effects of government support may not coincide.

A Appendix: General Proofs

Second Order Condition To find the SOC, substitute in the profit expression (equation 2) for the general output expression (equation 5) and then compute the second order derivatives in order to k or k^* to obtain:

$$\frac{d^2\Pi}{dk^2} = \frac{d^2\Pi^*}{dk^{*2}} = -\frac{\gamma(9-8\eta)}{9} < 0 \tag{A1}$$

This implies that for the SOC to hold we need that:

$$0 < \eta < \frac{9}{8} \tag{A2}$$

R&D subsidy In order to find the optimum EU government R&D subsidy just begin by totally differentiating W (equation 11 in the main text)[22]:

$$dW = \frac{\partial W}{\partial q}dq + \frac{\partial W}{\partial q^*}dq^* + \frac{\partial W}{\partial k}dk \tag{A3}$$

Since from the FOC for outputs $\partial W/\partial q = \partial\Pi/\partial q = 0$, equation A3 simplifies to:

[22] This derivation is independent of the type of subsidy case being played and therefore for the moment we ignore upper-scripts for EU or $EU+US$ cases.

$$dW = -bqdq^* + (\theta q - \gamma k)\, dk \tag{A4}$$

To eliminate dq^* from equation A4 first solve $d\Pi^*/dq^* = 0$ for q^* and after totally differentiate the resulting expression to obtain: $dq^* = (\theta dk^* - bdq)/2b$. To get rid of dk^* in the previous equation proceed in a similar fashion by using $d\Pi^*/dk^* = 0$ to solve for k^* and subsequently totally differentiate the ensuing expression to get: $dk^*/b = (4\theta/3b\gamma)\, dq^*$. As such dq^* equals:

$$dq^* = -\tfrac{3}{2(3-2\eta)} dq \tag{A5}$$

Also, from $d\Pi/dk = 0$ we have that $\theta q - \gamma k = -s$. Equation A4 then boils down to:

$$dW = \tfrac{3b}{2(3-2\eta)} qdq - sdk \tag{A6}$$

Dividing equation A6 by dk we obtain the optimal EU government subsidy for the EU and the $EU + US$ cases as shown in the text (equation 12).

The derivation of the US government R&D subsidy is similar to the EU subsidy above. In fact, for the US it also holds equivalent expressions to A3 and A4. Start then from the analogous of equation A4 for the US. After solve $d\Pi/dq = 0$ for q, and totally differentiate the resulting expression to obtain: $dq = (\theta dk - bdq^*)/2b$. Next, to get rid of dk in this previous equation, make use of $d\Pi/dk = 0$. Given that Airbus has no *commitment* power and using 8 it results that $dk/b = (\theta/b\gamma)\, dq$. As such, dq can be simplified to:

$$dq = -\tfrac{1}{(2-\eta)} dq^* \tag{A7}$$

This implies that the equivalent of equation A4 for the US reduces to:

$$dW^* = \tfrac{b}{(2-\eta)} q^* dq^* + (\theta q^* - \gamma k^*)\, dk^* \tag{A8}$$

Given that from $d\Pi^*/dk^* = 0$, $\theta q^* - \gamma k^* = -(s^* + \theta q^*/3)$, it results:

$$dW^* = \tfrac{b}{(2-\eta)} q^* dq^* - \left(s^* + \tfrac{\theta}{3} q^*\right) dk^* \tag{A9}$$

Now just divide equation A9 by dk^* and substitute for s^* to get the optimal R&D subsidy for the US under the US and the $EU + US$ cases as shown in the text (equation 13).

Sign of q^* and k^* As mentioned in the main text, we want that at least the *leader* Boeing has positive outputs and R&D levels. This can be check by making q^* and k^* equal to zero and solve for η. Given the SOC, q^* and k^* are positive in the alternative R&D subsidy cases if:

$$\begin{aligned} (q^*)^B \text{ and } (k^*)^B &> 0 \text{ if } 0 < \eta < \tfrac{7-\sqrt{13}}{4} \text{ and } 1 < \eta < \tfrac{9}{8} \\ (q^*)^{EU} \text{ and } (k^*)^{EU} &> 0 \text{ if } 0 < \eta < \tfrac{3-\sqrt{3}}{2} \text{ or } 2 - \tfrac{\sqrt{7}}{2} < \eta < \tfrac{9}{8} \\ (q^*)^{US} \text{ and } (k^*)^{US} &> 0 \text{ if } 0 < \eta < \tfrac{7-\sqrt{22}}{3} \text{ and } 1 < \eta < \tfrac{9}{8} \end{aligned} \tag{A10}$$

In turn, in the $EU + US$ case, q^* and k^* are always positive if the SOC holds. Then the most restrict condition for having positive q^* and k^* is:

$$0 < \eta < \tfrac{3-\sqrt{3}}{2} \text{ and } 1 < \eta < \tfrac{9}{8} \tag{A11}$$

The interval $1 < \eta < 9/8$ is excluded from the analysis since it gives comparative static results that make little sense (for example countries prefer equilibriums where only the rival country intervenes).

It is easy to check that as long as equation 18 in the main text holds q and k are also always positive under all subsidy cases. Furthermore, this condition also assures that the same happens with R&D subsidies s and s^*.

Winners and Losers in the Benchmark case

$$\begin{aligned} (q)^B - (q^*)^B &= -\tfrac{(D-t)\eta}{b(9-2\eta(7-2\eta))} < 0 \\ (k)^B - (k^*)^B &= -\tfrac{(D-t)\theta}{\gamma b(9-2\eta(7-2\eta))} < 0 \end{aligned} \tag{A12}$$

As long as equation 18 in the main text holds, the proof follows.

Pick Who?

$$\begin{aligned} (s)^{EU} - (s^*)^{US} = \theta\,(D-t)\,\tfrac{54-\eta(210-\eta(301-\eta(199-8\eta(8-\eta))))}{b(3-2\eta)(9-4\eta(4-\eta))(9-\eta(14-3\eta))(2-\eta)} > 0 \\ (s)^{EU+US} - (s^*)^{EU+US} = \theta\,(D-t)\,\tfrac{6-\eta(14-\eta(9-2\eta))}{b(54-\eta(159-2\eta(74-\eta(26-3\eta))))} > 0 \end{aligned} \tag{A13}$$

As long as equation 18 holds, the proof follows.

Winners and Losers in the EU and the $EU+US$ cases

$$\begin{aligned}(q)^{EU}-(q^*)^{EU} &= 2\left(D-t\right)\tfrac{\eta^2}{b(3-2\eta)(9-4\eta(4-\eta))}>0\\ (k)^{EU}-(k^*)^{EU} &= 2\theta\left(D-t\right)\tfrac{\eta}{\gamma b(3-2\eta)(9-4\eta(4-\eta))}>0\\ (q)^{EU+US}-(q^*)^{EU+US} &= \tfrac{\eta^2(D-t)}{b(54-\eta(159-2\eta(74-\eta(26-3\eta))))}>0\\ (k)^{EU+US}-(k^*)^{EU+US} &= \tfrac{\eta\theta(D-t)}{b\gamma(54-\eta(159-2\eta(74-\eta(26-3\eta))))}>0 \qquad \text{(A14)}\end{aligned}$$

As long as equation 18 holds, the proof follows.

Welfare Comparisons Endogenous Asymmetry R&D Game As long as equation 18 holds the EU and the US welfare ranking satisfy respectively:

$$\begin{gathered}(W)^{EU}-(W)^{EU+US}=\tfrac{3(D-t)^2\theta^4}{b^3\gamma^2(9-4\eta(4-\eta))^2(3-2\eta)^2(54-\eta(159-2\eta(74-\eta(26-3\eta))))^2}\\ \left(\begin{array}{c}8748-74\,358\eta+272\,457\eta^2-564\,516\eta^3+730\,020\eta^4-614\,322\eta^5\\ +340\,460\eta^6-122\,792\eta^7+27\,632\eta^8-3512\eta^9+192\eta^{10}\end{array}\right)>0\\ (W)^{EU+US}-(W)^{B}=\tfrac{(D-t)^2\theta^2}{2\gamma b^2(54-\eta(159-2\eta(74-\eta(26-3\eta))))^2(9-2\eta(7-2\eta))^2}\\ \left(\begin{array}{c}2916-23\,004\eta+79\,749\eta^2-158\,718\eta^3+197\,972\eta^4\\ -158\,380\eta^5+80\,172\eta^6-24\,552\eta^7+4116\eta^8-288\eta^9\end{array}\right)>0\\ (W)^{B}-(W)^{US}=\tfrac{3(D-t)^2\eta^2}{2b(2-\eta)(9-\eta(14-3\eta))^2(9-2\eta(7-2\eta))^2}\\ \left(108-\eta\left(474-\eta\left(779-\eta\left(588-\eta\left(199-24\eta\right)\right)\right)\right)\right)>0 \qquad \text{(A15)}\end{gathered}$$

$$\begin{gathered}(W^*)^{US}-(W^*)^{B}=\tfrac{3\eta^3(D-t)^2}{2b(9-\eta(14-3\eta))^2(2-\eta)^2(9-2\eta(7-2\eta))^2}\\ \left(45-\eta\left(178-\eta\left(265-2\eta\left(91-\eta\left(28-3\eta\right)\right)\right)\right)\right)>0\\ (W^*)^{B}-(W^*)^{EU+US}=\tfrac{(D-t)^2\theta^2}{2\gamma b^2(9-2\eta(7-2\eta))^2(54-\eta(159-2\eta(74-\eta(26-3\eta))))^2}\\ \left(\begin{array}{c}11\,664-78\,408\eta+218\,133\eta^2-324\,582\eta^3+278\,324\eta^4\\ -137\,264\eta^5+35\,692\eta^6-3240\eta^7-384\eta^8+72\eta^9\end{array}\right)>0\\ (W^*)^{EU+US}-(W^*)^{EU}=\tfrac{3(D-t)^2\theta^6}{2b^4\gamma^3(54-\eta(159-2\eta(74-\eta(26-3\eta))))^2(3-2\eta)^2(9-4\eta(4-\eta))^2}\\ \left(\begin{array}{c}5589-40\,392\eta+122\,292\eta^2-202\,824\eta^3+202\,980\eta^4\\ -127\,560\eta^5+50\,608\eta^6-12\,288\eta^7+1664\eta^8-96\eta^9\end{array}\right)>0 \qquad \text{(A16)}\end{gathered}$$

Note that the sign of all of these welfare relations depends only in the multiplicative term that is only a function of η. An easy way to check the sign of these equations is then to plot the expression in parenthesis in the interval given by equation 18. Doing that, the results stated above follow.

B Appendix: Stackelberg Leader Model

Consider a standard Stackelberg model with two firms, Airbus and Boeing. Firms compete just in outputs and therefore governments can only subsidize exports (s). Boeing has a first mover advantage in outputs, but both Airbus and Boeing have equal marginal and fixed costs (i.e.: $C = C^*$ and $\Gamma = \Gamma^*$). Demands are as given in equation 1 in the text. The timing of the game is: in stage 1 countries decide if they adopt or not a subsidy policy; in stage 2 the governments that have opted in stage 1 to intervene choose the export subsidy; in stage 3 Boeing chooses output levels; in stage 4 Airbus decides if she enters; in Stage 5 in case of entry Airbus chooses outputs.

Airbus' profits can be written as follow:

$$\Pi = (P - C - t)\, q - \Gamma + sq \tag{B1}$$

A similar expression applies for Boeing. Solving now the model; the general output expressions for Airbus and Boeing in the $EU + US$ case are:

$$(q)^{EU+US} = \tfrac{a-t-C+3s-2s^*}{4b}$$

$$(q^*)^{EU+US} = \tfrac{a-t-C+2s^*-s}{3b} \tag{B2}$$

The expressions for the other export subsidies cases are very similar: in the EU case s^* is eliminated from equation B2, in the US case instead s is dropped and in the *benchmark* case both s and s^* cancel out.

Passing now to the export subsidy stage, it happens that under all government intervention cases the export subsidy for both Airbus and Boeing is zero. To see this note that the EU welfare function equals:

$$W = \Pi - sq \tag{B3}$$

Totally differentiate this equation to obtain:

$$dW = \tfrac{\partial W}{\partial q} dq + \tfrac{\partial W}{\partial q^*} dq^* \tag{B4}$$

After solve for the partial derivatives:

$$dW = (a - 2bq - bq^* - C - t)\, dq - bqdq^* \tag{B5}$$

From Airbus' FOC, the first term on the right hand side of equation B5 equals s. For the second term use instead Boeing's FOC:

$$P - C - t + s^* - \tfrac{b}{2}q^* = 0 \tag{B6}$$

Since $P = (a + C + t - s - bq^*)/2$, substitute this in equation B6 and solve for q^* to obtain:

$$bq^* = \tfrac{(a - C - t - s + 2s^*)}{2} \tag{B7}$$

Totally differentiate this expression to get simply that $dq^* = 0$. Then $dW = sdq$, i.e.: $s = 0$.

For the US subsidy, note that since Boeing has a first mover advantage in outputs $\partial W^*/\partial q = 0$. Then dW^* simplifies to:

$$dW^* = \left(P - C - t - \tfrac{b}{2}q^*\right) dq^* \tag{B8}$$

From Boeing's FOC, the term on the right hand side of equation B8 equals s^*. Therefore once again we have $s^* = 0$.

This implies that the entry decision of Airbus simplifies to $\Pi = bq^2 - \Gamma$. In other words, the entry decision of Airbus depends only on the size of fixed costs (Γ). However to make the Stackelberg model comparable to the endogenous asymmetry subsidy model in the main text we assume that Γ never deters entry of Airbus. We can for example assume that the EU government, besides the potential export subsidy, always pays Γ.

C Appendix: Exogenous Asymmetries Model

Take a standard Cournot model with two firms Airbus and Boeing that compete just in outputs. Boeing has lower marginal costs ($C > C^*$), but both firms have equal fixed costs ($\Gamma = \Gamma^*$). Demand is given by equation 1 in the main text. The timing of the game is: in stage 1 countries decide if they adopt or not a subsidy policy; in stage 2 the governments that have chosen to intervene decide on the amount of the export subsidy; in stage 3 firms choose outputs[23].

The output stage equilibrium in the $EU + US$ case is then:

$$(q)^{EU+US} = \frac{a-t-2C+C^{*}+2s-s^{*}}{3b}$$

$$(q^{*})^{EU+US} = \frac{a-t-2C^{*}+C+2s^{*}-s}{3b} \quad \text{(C1)}$$

The expressions for the other subsidies cases are very similar to equation C1: in the EU case s^{*} is eliminated, in the US case instead s is dropped and in the *benchmark* case both s and s^{*} cancel out.

To find the optimal subsidy under the exogenous asymmetries model start from equations B3, B4 and B5 above for the Stackelberg model. After, solve Boeing's FOC for q^{*} and totally differentiating the resulting expression to get $dq^{*} = (-1/2)dq$. As such dW simplifies to:

$$dW = -\left(s - \frac{bq}{2}\right) dq \quad \text{(C2)}$$

Proceed in the same fashion for the US. Taking the example of the $EU + US$ case, the optimal subsidy under the exogenous asymmetry game is then:

$$\begin{aligned} (s)^{EU+US} &= \frac{b}{2}(q)^{EU+US} \\ (s^{*})^{EU+US} &= \frac{b}{2}(q^{*})^{EU+US} \end{aligned} \quad \text{(C3)}$$

Subsidy levels for the other subsidy cases are just similar: for $(s)^{EU}$ just substitute in equation C3 for $(q)^{EU}$ and for $(s)^{US}$ substitute for $(q)^{US}$.

From here it is possible to derive the explicit expressions for outputs and export subsidies under the alternative subsidy cases:

$$\begin{aligned} (q)^{B} &= \frac{a-t-2C+C^{*}}{3b} \\ (q^{*})^{B} &= \frac{a-t-2C^{*}+C}{3b} \end{aligned} \quad \text{(C4)}$$

[23] In this game there is no entry decision by Airbus, because Boeing in spite of having a cost advantage it does not move first.

$$\begin{aligned}(q)^{EU} &= \tfrac{a-t-2C+C^*}{2b}\\(q^*)^{EU} &= \tfrac{a-t-3C^*+2C}{4b}\\(s)^{EU} &= \tfrac{a-t-2C+C^*}{4}\end{aligned}\qquad\text{(C5)}$$

$$\begin{aligned}(q)^{US} &= \tfrac{a-t-3C+2C^*}{4b}\\(q^*)^{US} &= \tfrac{a-t-2C^*+C}{2b}\\(s^*)^{US} &= \tfrac{a-t-2C^*+C}{4}\end{aligned}\qquad\text{(C6)}$$

$$\begin{aligned}(q)^{EU+US} &= \tfrac{2(a-t-3C+2C^*)}{5b}\\(q^*)^{EU+US} &= \tfrac{2(a-t-3C^*+2C)}{5b}\\(s)^{EU+US} &= \tfrac{a-t-3C+2C^*}{5}\\(s^*)^{EU+US} &= \tfrac{a-t-3C^*+2C}{5}\end{aligned}\qquad\text{(C7)}$$

In order to have positive outputs under all subsidy cases we need that[24]:

$$a > t + 3C - 2C^* \qquad\text{(C8)}$$

This equation also makes export subsidies under all subsidy cases positive. The relation between s and s^* in the different subsidy cases is therefore:

$$\begin{aligned}(s^*)^{US} - (s)^{EU} &= \tfrac{3}{4}\left(C - C^*\right) > 0\\(s^*)^{EU+US} - (s)^{EU+US} &= C - C^* > 0\end{aligned}\qquad\text{(C9)}$$

With exogenous asymmetries governments then must support winners.

In terms of welfare ranking of the different subsidy cases, for the EU we always have:

$$(W)^{EU} > (W)^{B} > (W)^{EU+US} > (W)^{US} \qquad\text{(C10)}$$

[24]This is obtained by making $(q)^{US}$ or $(q)^{EU+US}$ equal to zero and solve for a.

$$(W)^{EU} - (W)^{B} = \frac{(a-t-2C+C^*)^2}{72b} > 0 \tag{C11a}$$

$$(W)^{B} - (W)^{EU+US} = \frac{(a-t)(7(a-t)-22C^*+8C)+(C-C^*)(47C^*-62C)+7CC^*}{225b} > 0 \tag{C11b}$$

$$(W)^{EU+US} - (W)^{US} = \frac{7(a-t+2C^*-3C)^2}{400b} > 0 \tag{C11c}$$

It is straight forward to check that equations C11a and C11c are positive. To see that the same happens with equation C11b note that this equation is convex in a with two solutions: $t + \left((11C^* - 4C) \pm 15\sqrt{2}\,(C - C^*)\right)/7$. Since equation C8 is more restrict than the two previous solutions for a, then, the above relation holds.

Instead for the US, the welfare ranking has two different configurations. The first holds if Boeing cost competitiveness is sufficiently large ($a - C^*$ big), explicitly $a > t + \left((11C - 4C^*) - 15\sqrt{2}\,(C - C^*)\right)/7$:

$$(W^*)^{US} > (W^*)^{B} > (W^*)^{EU+US} > (W^*)^{EU} \tag{C12}$$

$$(W^*)^{US} - (W^*)^{B} = \frac{(a-t-2C^*+C)^2}{72b} > 0 \tag{C13a}$$

$$(W^*)^{B} - (W^*)^{EU+US} = \frac{(a-t)(7(a-t)-22C+8C^*)-(C-C^*)(47C-62C^*)+7CC^*}{225b} > 0 \tag{C13b}$$

$$(W^*)^{EU+US} - (W^*)^{EU} = \frac{7(a-t-3C^*+2C)^2}{400b} > 0 \tag{C13c}$$

Equations C13a and C13c are easy to verify that are positive. In what respects equation C13b, note that this equation is convex in a with two solutions: $t + \left(11C - 4C^* \pm 15\sqrt{2}\,(C - C^*)\right)/7$. Then the result follows.

If Boeing's competitiveness is however sufficiently low ($a - C^*$ small), specifically $t + 3C - 2C^* < a < t + \left((11C - 4C^*) - 15\sqrt{2}\,(C - C^*)\right)/7$, the US welfare ranking is instead:

$$(W^*)^{US}_{EX} > (W^*)^{EU+US}_{EX} > (W^*)^{B}_{EX} > (W^*)^{EU}_{EX} \tag{C14}$$

$$(W^*)^{US} - (W^*)^{EU+US} = \frac{(a-t)(9(a-t)-4C^*-14C)+(C-C^*)(44C^*-39C)+9CC^*}{200b} > 0 \quad \text{(C15a)}$$

$$(W^*)^{EU+US} - (W^*)^{B} = -\left((W^*)^{B} - (W^*)^{EU+US}\right) > 0 \quad \text{(C15b)}$$

$$(W^*)^{B} - (W^*)^{EU} = \frac{(a-t)(7(a-t)-4C-10C^*)-(C-C^*)(20C-17C^*)+7CC^*}{144b} > 0 \quad \text{(C15c)}$$

To check for the sign of equation C15b proceed in the same way as for equation C13b. For equation C15a note that this equation is convex in a with two solutions: $t + 3C - 2C^*$ (that is simply equation C8) and $t + (22C^* - 13C)/9$. Since the first solution is more strict than the second one, then the above relation is satisfied. In what relates to equation C15c, again this equation is convex in a with two solutions: $t + 2C - C^*$ and $t - (10C - 17C^*)/7$. Since equation C8 is more strict than these two solutions the proof follows.

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