Losers, Winners and Prisoner's Dilemma 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 prisoner's 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, Airbus, Boeing.

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 this is especially true in political circles. As far as economic theory is concerned, though, the consensus has for a long time been inclined towards for the non-intervention case. In fact, the international trade theory under perfect competition advocates that free trade is in general optimal (Bhagwati, 1988).

In the 80's and in the 90's, however, the so-called strategic trade literature of Brander and Spencer (1985) challenged this vision a little by providing 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 (for example the Clinton administration) the following problem emerged: should governments target *winner* or *loser* 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 have *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 assess if industrial policies of different countries mainly follow the advise of economists by picking up *winners.* However we know that *loser* firms are very often chosen for support[2]. In fact, the helping *losers* cases are frequently commented in the media and as such attract a great deal of public attention. The classic example is Airbus, the European aircraft company[3]. It is sometimes argued that without the subsidies given by the European Union (EU), the (initial) *loser* Airbus would very easily have been beaten by the *winner* Boeing and would never have become

[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 comments see *The Economist*, June 25 2005, pp. 14 and pp. 90.

a *winner* as it is today. The second part of this argument, however, cannot 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's (1985) defense of intervention goes under some revision 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 agreeing not to intervene. In other words there is a policy *prisoner's 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?

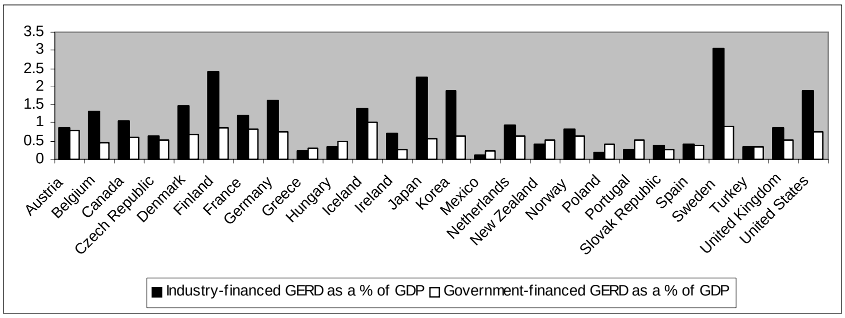
Moreover, in the Airbus-Boeing case this policy *prisoner's dilemma* predicts that if the US retaliates by also supporting Boeing, the Airbus subsidy advantage would simply vanish. However Airbus did not lose the lead even after the US started to subsidize Boeing. Actually, nowadays Airbus and Boeing compete "nose to nose" (*The Economist*, June 25 2005, pp. 90).

This paper then seeks to tackle two central results in the strategic trade literature: that governments shall support *winners* and that there is a *prisoner's dilemma* in international subsidy wars. Specifically, as in Dixit and Kyle (1985) we keep the Airbus *versus* Boeing case in the background. 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[4].

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 von Stackelberg, 1934). *Commitment* power in R&D refers to a firm ability to influence rivals' strategic choices through first-mover advantages in

[4] Cooper and Riezman (1989) endogenize the government decision on alternative policy instruments (quantity controls *versus* export subsidies). Hwang and Schulman (1993) also allow governments to decide not to 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)

R&D. In game terms this means that some firms choose R&D before others. 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 on 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.

The OECD governments have apparently recognized this given the great amount of public funds that they attribute to subsidize innovation (figure 1). In fact, not only has government financed R&D 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, especially because they are so widespread but theory tells 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's dilemma*). This is so because the EU government's R&D support to the *loser* Airbus can help her 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 von 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 a 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:

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

where q is 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:

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

where C is the marginal cost, Γ is the fixed cost, 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^{*}. Also, both Airbus and Boeing bear the same trade costs, i.e.: $t = t^{*}$.

2.2 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's (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, only the former holds[5].

In the light of the Airbus-Boeing example we then assume that Boeing has a first-mover advantage in R&D against Airbus[6].

2.3 Technology

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

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

where θ is the cost-reducing effect of R&D, γ is the cost of R&D and c is the initial marginal cost. In turn, f is an exogenous fixed cost that we assume

[5] *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.

[6] We are then following Hamilton and Slutsky (1990) idea that when the first-mover advantage is not endogenous (like in our model), this can still be justified by exogenous factors as incumbent-entrant relations that make one firm a leader. In our opinion, this undoubtedly applies to the Boeing-Airbus case, since Boeing was the indisputable leader of the market prior to Airbus entry.

that the EU government pays for Airbus[7]. Boeing has already paid for f^* but has otherwise a similar cost structure to Airbus with $c = c^*$, $\theta = \theta^*$ and $\gamma = \gamma^*$, i.e.: Boeing and Airbus have the same 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:

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

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

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 such support[8].

We then consider four R&D subsidy cases: the *benchmark no government active*, where neither country subsidizes R&D (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 by upper-scripts B, EU, US and $EU + US$, respectively. These four cases are shown in matrix format in figure 2.

2.5 Timing of the Game

Figure 3 defines the timing of the game. In the first stage governments decide on whatever to subsidize or not. In the second stage governments (depending

[7]We believe that this had happened in reality for Airbus and therefore we abstract from these costs in our analysis.

[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).

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

Figure 2: Subsidy Cases

Game / Stage	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

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 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 as usual by backward induction. However, in spite of considering alternative 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 respects outputs and R&D.

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 subsidy game being played. As such outputs are just equal to:

$$q = \frac{D-t+2\theta k-\theta k^*}{3b}$$
$$q^* = \frac{D-t+2\theta k^*-\theta k}{3b} \text{ for } \forall \text{ subsidy cases} \quad (5)$$

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 with Boeing. Since Boeing has *commitment* power in R&D, her FOC in relation to k^* is:

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

The first and second terms on the right hand side of equation 6 are usually called the non-strategic and the strategic motive for R&D, respectively[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:

$$\frac{d\Pi}{dk} = \frac{\partial\Pi}{\partial k} \quad (7)$$

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

$$\gamma (k)^{EU+US} = \theta (q)^{EU+US} + (s)^{EU+US} \quad (8)$$
$$\gamma (k^*)^{EU+US} = \frac{4\theta}{3} (q^*)^{EU+US} + (s^*)^{EU+US} \quad (9)$$

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 envelope 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 the 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 $q > 0$ and the second order condition (SOC) holds (see Appendix A), the sign of Airbus' profits depends only on s. In particular, if $s = 0$ (US and B cases), Π is unambiguously positive, i.e.: Airbus enters the market. If $s \neq 0$ (EU and $EU + US$ cases) the sign of Π depends on whether s is a subsidy or a tax. If s is a subsidy, Π is always positive and therefore Airbus always enters the market. If s is instead a tax, Π can either be positive or negative depending on the level of 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 property, from now on we will call the game in this paper endogenous asymmetry subsidy game in order to differentiate it from the exogenous asymmetry subsidy games of de Meza (1986) and Neary (1994).

[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 the EU government decides not to subsidize, the EU welfare is just equal to Airbus' profits (i.e.: $W = \Pi$ for B and US cases). When the EU government pays 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, the EU government subsidy under the EU case is (see Appendix A):

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

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, $(s^*)^{EU+US}$ 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, a government incentive to intervene depends 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:

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

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

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

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

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. Accordingly, we do not want, in any event, the *leader* to exit the market. As shown in Appendix A this is so as long as:

$$0 < \eta < \frac{3-\sqrt{3}}{2} \tag{18}$$

Furthermore, equation 18 is also sufficient to guarantee that under all subsidy cases, Airbus outputs and R&D levels as well as the EU and the US

R&D subsidies are always positive[12]. Thus in the context of this model it is never optimal to tax R&D.

We can now give a final statement on the entry decision of Airbus. Given that $q > 0$ from equation 18, then, and as shown in the previous section, if $s = 0$ (B and US cases) Airbus enters the market. For $s \neq 0$ simply substitute in equation 10 for the optimal EU subsidy (equation 12) to obtain:

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

Hence, as long as the SOC holds Airbus profits are always positive. This means that neither the higher commitment power of Boeing, nor the EU R&D subsidy nor the US R&D subsidy are sufficient to deter entry by Airbus[13].

5 Winners and Losers: Whom to Pick?

In order to assess if governments should 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 turns out that the relation between Airbus and Boeing in the *benchmark* case is (see Appendix A for proof):

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

It comes as no surprise that 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 advantages 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 the subsidy policy should target: the *winners* or the *losers*? As

[12]Also if equation 18 does not hold, as will be seen bellow, comparative static results do not make much economic sense.

[13]Since the EU pays for f and the remaining Airbus fixed costs are endogenous to her R&D choices (see equation 3), the case for entry deterrence in this model is weak. Accordingly, Airbus chooses R&D so it does not prevent her to enter the market. If f is not paid by the EU, then like in Spence (1977), Airbus would face a threshold level of entry f. Obviously, this would not change our analysis for f bellow this threshold.

mentioned above, the literature on the field defends that governments should help *winners*. For example in de Meza (1986) and Neary (1994) the less cost competitive the domestic firm is, 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.

There are however some differences between the models by de Meza (1986) and Neary (1994), and ours. The most important one is that in de Meza (1986) and in Neary (1994) competitiveness asymmetries between firms are exogenous while here they are endogenous[14]. This distinction is important given that by endogenizing competitiveness we are able to challenge a number of central results from the strategic trade literature.

The first consequence of the endogenous asymmetry property 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, 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 completely alters the competitiveness relation between Airbus and Boeing. This is so not only when just the EU intervenes but also when both governments are active (see Appendix A):

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

The EU therefore uses the R&D subsidy to recover Airbus' competitiveness disadvantage. 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 give rise to *profit-shifting effects*. As a result, when these

[14]Another difference is that in de Meza (1986) and Neary (1994) firms compete solely in outputs and therefore governments can only subsidize exports.

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, it is never possible for a subsidy policy to restrain the more competitive firms to be a *winner*.

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. Remember that Boeing is more competitive than Airbus merely due to the *commitment* power advantages that she possesses. On the one hand, this allows Boeing to strategically over-invest in R&D in order to push Airbus down into her reaction function. However on the other hand, the EU can counterbalance this *commitment* advantage of Boeing by giving a subsidy to Airbus, so that Boeing cannot use R&D strategically against Airbus[15].

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 that the EU gives to Airbus (see equation 21). As a result of this, the EU intervention places Boeing at a competitive disadvantage relatively to Airbus, independently of the US government's action (see equation 22)[16].

6 Subsidize or Not: a Prisoner's Dilemma?

This section asks if in the context of the model in this paper governments face a policy *prisoner's dilemma* when deciding on whether subsidize the local firm or not. As we have already discussed in the introduction, the answer so far in the strategic trade literature has been of the affirmative type: 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):

[15] Accordingly, the EU government plays strategically against Boeing so that Boeing cannot play strategically in R&D against Airbus.

[16] 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.

EU \ US	**Not-Subsidize** **($s^*=0$)**	**Subsidize** **($s^*\neq0$)**
Not-Subsidize **(s=0)**	(3,2)	(4,1)
Subsidize **($s\neq0$)**	(1,4)	(2,3)

Figure 4: Endogenous Asymmetry Game

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

The US welfare is highest when only the US subsidizes R&D, second highest when neither the US nor the EU subsidize, third highest when both countries subsidize and lowest when only the EU subsidizes. The EU has a different welfare ranking: the EU welfare is highest when only the EU is active, second highest when both governments are active, third highest when no government is active and lowest when only the US is active[17].

As a consequence of this welfare ranking, the non-cooperative equilibrium of the endogenous asymmetry game is to have both countries subsidizing R&D (see figure 4)[18]. However, contrary to the standard result in the strategic trade literature, the EU does not face a policy *prisoner's dilemma*: the EU is always better off by intervening than by not intervening. The opposite is the case for the US that by subsidizing R&D ends up in a two-country intervention scenario where the US is worse off than in the non-intervention case[19].

The rational for the inexistence of a policy *prisoner's dilemma* in this model, lies in the strategic nature of R&D, i.e.: it is not sufficient to have

[17] If 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: both countries prefer that the rival country intervenes alone. This is a rather strange result that confirms the choice made for the parameter space where the game is valid.

[18] Numbers in figure 4 indicate the position in the welfare rank: 1 for the first place and 4 for the last place.

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

asymmetric firms or *leader-follower* set-ups. Actually, if we repeat the exercise carried out here in a standard Stackelberg *leader* model or in an exogenous asymmetry subsidy model (like Neary, 1994), our results are not totally replicated. We do this in Appendix B for the Stackelberg *leader* model and in Appendix C for the exogenous asymmetry model.

Start with the Stackelberg output *leader* game, where Boeing has a first-mover advantage in outputs. Since firms compete just in outputs, governments can only use export subsidies (see Appendix B for details). Obviously under this set-up Boeing is also a *winner* and Airbus is a *loser*. However now for both the US and the EU the optimal subsidy under all subsidy cases is zero. Thus, the policy *prisoner's dilemma* does not even arise in the Stackelberg model, given that countries have no incentives to intervene.

The adoption of a *leader-follower* framework, then, is not enough to justify the results in this paper. This is so because in spite of the similarities, our model differs from the Stackelberg one in some important ways. In particular, the main difference between the two models is that in our model competitiveness is endogenous, while in Stackelberg it is exogenous.

Specifically, in our endogenous asymmetry subsidy game, competitiveness depends on both the firms' R&D decisions and on the governments' policy choices. Accordingly, the *leader* advantages of the higher *commitment* firm do not necessarily make her a *winner*, since through R&D subsidies, governments can affect firms' incentives to innovate. In effect, an EU subsidy offsets Boeing's leader advantage because by making Airbus (the lower commitment firm) to invest more in R&D, it will also make Boeing (the higher commitment firm) to reduce outputs (see equation 5 and equation 9).

On the contrary, in the Stackelberg game competitiveness is fixed: firms always have the same marginal and fixed costs. In particular, the Stackelberg *leader* is only able to influence outputs and not competitiveness. However by influencing the rival's outputs, the Stackelberg *leader* becomes a *winner* independently of the governments' actions. This is so because a subsidy by the *follower* firm government is not able to control for the *leader* output advantage. Then, the *follower* firm government sees no point in intervention since this is always ineffective, while the *leader* firm government has no need to intervene given that the *leader* is an undisputable *winner*.

Take now the exogenous asymmetry subsidy model (Neary, 1994) where Boeing is exogenously more competitive than Airbus ($c > c^*$)[20]. Therefore

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

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

Figure 5: Exogenous Asymmetry Game (Boeing very competitive)

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 just compete in outputs (see more in Appendix C).

Under this set up there are two Nash equilibrium configurations: the first holds when Boeing's competitiveness is sufficiently large ($(a - c^*)$ big) and the second when this is small. When Boeing is very competitive, the exogenous asymmetry subsidy game has the same equilibrium as in our model: intervention by the EU and the US (see figure 5). Now however, both countries face a *prisoner's dilemma*. 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 an intervention equilibrium that penalizes both.

If Boeing is not very competitive, the Nash equilibrium of the exogenous asymmetry subsidy game is also to have both countries subsidizing the respective local firm (see figure 6). However now the US does not face a policy *prisoner's dilemma*. Then if the *winner* Boeing has only a small cost competitiveness advantage it might be optimal for the US to subsidize the local firm without having to fear retaliation.

The reason for this result is that when Boeing competitiveness is low, Airbus competitiveness $(a - c)$ is even lower given that $c > c^*$. Thus since in the exogenous asymmetry subsidy game governments shall support *winners* and the optimal subsidy decreases with the competitiveness disadvantage of the local firm, the EU subsidy to Airbus is very small, i.e.: the EU *profit-shifting effects* are negligible. Therefore for the US a subsidy war with the EU is not very threatening. Consequently, the US welfare under the two governments' active case can be higher than in the *benchmark* case.

What the exogenous asymmetry subsidy game tells us is that to avoid the policy *prisoner's dilemma* it is not enough to have asymmetric firms. How-

EU \ US	**Not-Subsidize ($s^*=0$)**	**Subsidize ($s^*\neq0$)**
Not-Subsidize (s=0)	(2,3)	(4,<u>1</u>)
Subsidize (s≠0)	(<u>1</u>,4)	(<u>3</u>,<u>2</u>)

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

ever having asymmetric firms can reduce this *dilemma*, given that countries may also have asymmetric incentives to intervene. This highlights the importance of incorporating asymmetric firms in standard trade models, given that heterogeneities introduce new dimensions in international trade questions.

In this sense our paper relates to 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]. We have showed however 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 can at most aspire to confirm the existing competitiveness relations.

Summing up: when a local firm suffers from an endogenous competitive disadvantage, government intervention in form of R&D subsidies can aim at changing the competitiveness balance in the local firm's favor. The endogenous asymmetries subsidy game in this paper therefore presents a special case where countries do not lose by subsidizing R&D 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 of the elasticity of demand for imports a country might gain by imposing a tariff even if the other countries strike back. The implications of our 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

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

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 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[22].

Quaero is a typical example of a strategic trade policy. Brander and Spencer's (1985) seminal paper showed that in fact countries might 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 also to support Google. With that the *Quaero* subsidy advantage would simply be cancelled out. In the end though both countries would be worse off than in the non-intervention case: *Quaero* would not win the competitive battle anyway and both the US and the EU would just waste tax payers money.

In addition if we consider that Google is (exogenously) more competitive than *Quaero*, then according to the strategic trade policy, the European governments are making 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 at a 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 to Boeing.

This paper has tried to give some explanations for the Airbus-Boeing case. In particular, 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 defended in

[22] According to the French President Jacques Chirac the project is undertaken "in the image of the magnificent success of Airbus" (quoted in The Economist, March 11 2006, supplement Technology Quarterly pp. 10).

the strategic trade literature, *losers* can also be supported to become *winners* and there is no *prisoner's dilemma* in international subsidy wars.

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

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

In this sense this paper is not a defense of government intervention. As we have mentioned at the end of the previous 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 (such as government subsidization of R&D) can also subvert the competitiveness game.

Our paper therefore 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: competition is different in the aircraft and in the Internet industry and as such nor may the effects of government support coincide.

A Appendix: General Proofs

Second Order Condition To find the Airbus SOC, substitute in equation 2 for equation 5 and compute the second order derivatives in order to k:

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

The same SOC holds for Boeing. This implies that for the SOC to be satisfied we need that:

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

R&D subsidy To compute the optimum EU R&D subsidy begin by totally differentiating W (equation 11 in the text)[23]:

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

Since $\partial W/\partial q = \partial \Pi/\partial q = 0$, then, equation A3 simplifies to:

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

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 solve $d\Pi^*/dk^* = 0$ for k^* and subsequently totally differentiate the ensuing expression to get: $dk^*/b = (4\theta/3b\gamma)\, dq^*$. As such dq^* equals:

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

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

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

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

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

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

This implies that the corresponding of equation A4 for the US is:

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

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

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

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

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

Sign of q^* and k^* We want that at least the *leader* Boeing has positive outputs and R&D levels. To check this make q^* and k^* from the alternative R&D subsidy cases equal to zero. Given the SOC, then:

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

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

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

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 holds q and k are also always positive under all subsidy cases. Furthermore, this condition also assures that the same happens with s and s^*.

Winners and Losers in the Benchmark case

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

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

Whom to Pick?

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

As long as equation 18 holds, the proof follows.

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

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

As long as equation 18 holds, the proof follows.

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

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

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

These welfare relations are all equal to a fraction term and a multiplicative term. It is straightforward to check that all of the fraction terms are always positive, i.e.: the sign of all of the welfare relations above depend only on the multiplicative terms. In turn, the multiplicative terms are only a function of η. Therefore, an easy way to check the sign of these welfare relations is to plot the three expressions in parenthesis in the interval given by equation 18. Doing that, the results stated above will follow.

B Appendix: Stackelberg Leader Model

Consider a standard Stackelberg model with two firms, Airbus (the entrant) and Boeing (the incumbent). Firms just compete in outputs and therefore governments can only subsidize exports. Boeing has a first-mover advantage in outputs, but both Airbus and Boeing have equal marginal costs ($c = c^*$). Boeing has already paid the exogenous fixed costs of entry f^*, while the EU pays for Airbus ones (f). Demands are as given in equation 1 in the text. The timing of the game is: in stage 1 the US and the EU decide wether or not adopt a subsidy policy; in stage 2, when it applies, the EU picks s and the US picks s^*; in stage 3 Boeing chooses q^*; in stage 4 Airbus decides whether or not enter; in Stage 5 in case of entry Airbus chooses q.

Airbus profits can be written as follows:

$$\Pi = (P - c - t)\, q - f + sq \qquad \text{(B1)}$$

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

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

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

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 s is dropped, and in the *benchmark* case both s and s^* cancel out.

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

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

Totally differentiate this equation to obtain:

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

Then 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 Boeing's FOC:

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

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

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

Totally differentiate this expression to get that $dq^* = 0$. Thus $dW = sdq$, i.e.: $s = 0$[24].

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

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

[24] The entry decision of Airbus then simplifies to $\Pi = bq^2$: Airbus always enters the market.

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

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 ($f = f^*$), which are sufficiently low to not promote exit. Demand is given by equation 1 in the text. The timing of the game is: in stage 1 countries decide whether or not to adopt 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[25].

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

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

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

The expressions for the other subsidies cases are very similar to equation C1: in the EU case s^* is eliminated, in the US case 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. Solve Boeing's FOC for q^* and totally differentiate the resulting expression to get $dq^* = (-1/2)dq$. As such dW simplifies to:

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

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:

$$(s)^{EU+US} = \frac{b}{2}\,(q)^{EU+US}$$
$$(s^*)^{EU+US} = \frac{b}{2}\,(q^*)^{EU+US} \tag{C3}$$

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

[25] In this game there is no entry decision by Airbus, because Boeing does not move first.

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

$$\begin{aligned} (q)^{B} &= \tfrac{a-t-2c+c^{*}}{3b} \\ (q^{*})^{B} &= \tfrac{a-t-2c^{*}+c}{3b} \end{aligned} \tag{C4}$$

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

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

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

In order to have positive outputs under all subsidy cases we need that[26]:

$$a > t + 3c - 2c^{*} \tag{C8}$$

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

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

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

With exogenous asymmetries, governments then must support winners.

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

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

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

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

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

It is simple 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 and has 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, the proof follows.

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

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

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

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

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

Equations C13a and C13c are easy to verify that are positive. In what respects equation C13b, note that this equation is convex in a and has 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:

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

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

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

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

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: equation C8 and $t + (22c^* - 13c)/9$. Since the first solution is stricter than the second one, then the proof follows. 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 also follows.

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