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Beyond Trade Costs: Firms' Endogenous Access to International Markets

Armando Jose Garcia Pires

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by

Armando Jose Garcia Pires

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CRISIS, RESTRUCTURING AND GROWTH

This working paper is one of a series of papers and reports published by the Institute for Research in Economics and Business Administration (SNF) as part of its research programme "Crisis, Restructuring and Growth". The aim of the programme is to map the causes of the crisis and the subsequent real economic downturn, and to identify and analyze the consequences for restructuring needs and ability as well as the consequences for the long-term economic growth in Norway and other western countries. The programme is part of a major initiative by the NHH environment and is conducted in collaboration with The Norwegian Ministry of Trade and Industry, The Research Council of Norway, The Confederation of Norwegian Enterprise/ABELIA and Sparebanken Vest/Bergen Chamber of Trade and Industry/Stavanger Chamber of Trade and Industry.

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Beyond Trade Costs: Firms' Endogenous Access to International Markets

Armando J. Garcia Pires [*,†]

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Abstract

In this paper, we explore another factor besides trade costs that can affect firms' exports: strategic interaction between firms in R&D investment. Three results can be highlighted. First, the volume of trade is higher in the presence of R&D than in the absence of it, given that R&D reduces marginal costs. Second, like with reductions in trade costs, international trade grows with increases in the return on R&D, since technological progress enhances firms' competitiveness. Third, when firms differ in commitment power in R&D, the R&D leader plays strategically in R&D in order to become more competitive and to be more active in international markets than the R&D follower.

Keywords: R&D Investment, Commitment Power, Endogenous Asymmetric Firms, Market Access.

JEL Classification: F12, L13, L25.

[*]Institute for Research in Economics and Business Administration (SNF), Norwegian School of Economics (NHH), Breiviksveien 40, 5045 Bergen, Norway. Tel: +(47)55959622, Fax: +(47)55959439; E-mail: armando.pires@snf.no.

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1 Introduction

Trade costs are one of the main ingredients in the theoretical and the empirical models of international economics[1]. For instance, the most influential models in international economics developed in the last thirty years rely heavily on trade costs. This is the case for the 'new' trade theory (Krugman, 1980), the 'new' economic geography (Krugman, 1991), the multinational firms (Horstmann and Markusen, 1992) and the heterogeneous firms models (Melitz, 2003). In effect, in these models, trade costs give rise to the well-known home market effects, agglomeration effects, the proximity-concentration trade-off and the firm entry-exit productivity dynamics in export markets, respectively[2].

It therefore comes as no surprise that there is a long tradition of empirical studies that try to estimate the magnitude of trade costs in international trade (Moneta, 1959; Waters, 1970; Finger and Yeats, 1976; Harrigan, 1993; Rauch, 1999 and Hummels 1999, 2001). Also, the most influential empirical trade model is the gravity equation where trade costs are quintessential (see Anderson, 1979, Anderson and Wincoop, 2003, 2004, Chaney, 2008, McCallum, 1995, Santos Silva and Tenreyro, 2006, and Ullah and Inaba, 2011). Furthermore, some stylized facts on international trade are explained based on trade costs. For example, the exponential increase in the world trade in the last century (Baier and Bergstrand, 2001) and the "border puzzle" (McCallum, 1995, Trefler, 1995 and Anderson and Wincoop, 2003)[3].

[1]According to Anderson and Wincoop (2004), trade costs include all costs to deliver a good to a final user (other than the marginal cost of production): "transportation costs (both freight costs and time costs), policy barriers (tariffs and nontariff barriers), information costs, contract enforcement costs, costs associated with the use of different currencies, legal and regulatory costs, and local distribution costs (wholesale and retail)".

[2]The home market effect states that, due to trade costs and increasing returns to scale, countries with higher demand tend to have a disproportionally larger share of industry (Krugman, 1980), which in turn can trigger the agglomeration of economic activity in the larger regions as trade costs decrease (Krugman, 1991). The proximity-concentration trade-off (Horstmann and Markusen, 1992) refers to the trade-off between concentration of production to explore economies of scale (domestic strategy) and proximity to consumers to avoid trade costs (multinational strategy). The firm entry-exit productivity dynamics in export markets (Melitz, 2003) says that a reduction in trade costs can promote the entry of the more productive domestic firms in the export markets.

[3]The "border puzzle" refers to the empirical evidence that equally distant regions, trade much more with each other, even after correcting for trade barriers, if they are located in the same country than if they are located in different countries.

Another "puzzle" has received less attention: why international trade has continued to increase even after trade costs reductions have flattened out (Hummels, 1999, 2001). In fact, while in most part of the 20th century there was a clear negative correlation between trade costs and international trade, the same trend has not been as pronounced in the last thirty years. There are certainly many factors that can explain the decoupling of international trade and trade costs, and we discuss some of these reasons in section three. However, in this paper, we focus on one of the factors that could help to explain this puzzle: R&D investment and strategic competition in R&D.

Note, then, that in this paper we do not deny the importance of trade costs in international trade. However, we follow the industrial organization literature on innovation (see Spence, 1984), by highlighting the role of strategic interactions between firms in R&D investment on international trade. The basic ideas that we explore are the following. In the first place, R&D investment can affect trade patterns, since it increases the productivity of firms. Second, if this is the case, firms can also play strategically in R&D to affect rivals' exports and in the end trade flows. In the next section, we present empirical evidence on these two arguments.

With this purpose, we use a simple and stylized Cournot duopoly model with three R&D scenarios. In the first, firms do not invest in R&D (benchmark no R&D game). In the second, as in Leahy and Neary (1997), firms invest in process R&D that reduces marginal costs but increases fixed costs (symmetric commitment power in R&D game). The main difference of this game relatively to Leahy and Neary (1997) is that we do not consider export and R&D subsidies, and just focus on trade flows. In the third, following Garcia Pires (2009), we extend the previous case to allow firms to differ in their capacity to commit to the R&D decisions, i.e.: one firm moves in R&D before the rival (asymmetric commitment power in R&D game). Accordingly, the first game is used as a benchmark to compare with the second and third games. With these three games we derive two main results.

First, we show that trade is always higher in the presence of R&D (symmetric and asymmetric commitment power in R&D games) than in the absence of R&D (benchmark no R&D game), given that R&D reduces marginal costs. Additionally, higher efficiency of R&D, a metaphor for technological progress, promotes international trade, since the return on R&D activities (in the form of cost reductions) and, therefore also exports, increases with the efficiency of R&D. In this way, R&D investment can have similar effects to a reduction in trade costs in standard trade models.

The second set of results relates to the asymmetric commitment power in R&D game. We show that differences between firms in commitment power in R&D are a door opener for the R&D leader to affect international trade patterns by acting strategically against the R&D follower. To be more precise, the R&D leader over-invests in R&D in order to achieve higher competitiveness than the R&D follower. As a consequence, the former ends up exporting more than the latter or even being the only firm active in international markets. This result, that the more efficient firms tend to export more than the less efficient rivals, is in effect one of the most prominent stylized facts of international trade unveiled in recent years (see Bernard et al., 2003).

In this way, although asymmetries in commitment power in R&D give the R&D leader a first-mover advantage in the spirit of von Stackelberg (1934), the consequences are more pervasive than the standard output leader advantages. This is so because differences in commitment power in R&D can also endogenize competitiveness asymmetries in marginal costs between firms. In a standard Stackelberg model this is not possible, since independently of being an output leader or an output follower, firms are always symmetric in marginal costs and therefore in competitiveness.

In sections two and three, we present and discuss the available empirical evidence and the related literature on R&D and trade, respectively. In section four, we introduce the base model and define commitment power in R&D. In section five, we derive the production equilibrium. In section six, we study firms' access to international markets. In section seven, we look at the effects of technology on R&D. In section eight, we analyze how R&D affects international trade. In section nine, we discuss the robustness of the main assumptions in the paper. We conclude by discussing our results.

2 Empirical Evidence

In this paper we have two results. First, R&D investment can conduce to the same effects as reductions in trade costs, given that R&D can reduce marginal costs of production. Second, strategic competition in R&D can affect trade flows, since firms invest in R&D in order to affect rivals' strategic choices on R&D and therefore production and exports. It is important then to analyze the empirical evidence on these arguments and the related literature on R&D and trade. In this section, we report on the empirical evidence and turn to the related literature in the next section.

Unfortunately, in what concerns the second result (i.e.: that strategic investment in R&D affects trade flows), we have not been able to find any papers that study this issue directly. In our view, this is surprising since, as shown by Tybout (2003), strategic interactions are especially crucial in export markets, due to the fact that international competition is extremely fierce and among a small number of very powerful oligopolist firms. We therefore believe that there is room for future empirical work in this area.

In any case, there is evidence that the effects of commitment power in R&D on firms' innovation efforts correspond to the predictions in our model. For instance, Blundell et al. (1999) show a positive relationship between market power (a proxy for leadership) and innovation. This result holds in a panel with many sectors, but is stronger in high-technology sectors. Czarnitzki et al. (2008), in a sample of German manufacturing firms, study R&D intensity at the firm level. They find that R&D leaders invest more in R&D than other firms. In turn, Adams and Clemmons (2008) look at the innovation behavior of science based firms. They witness the persistence of firm leadership in their sample, due in particular to higher innovative activity. We can then also expect that R&D leadership has a positive impact on export behavior, since the empirical evidence shows that the more successful exporters have higher productivity and invest more in R&D than less successful exporters and domestic firms (Bernard et al., 2003). In other words, the more successful exporters can be considered R&D leaders and the less successful exporters and domestic firms, R&D followers.

In what concerns our first result (i.e.: that R&D investment can promote international trade), start by looking at the aggregate data on R&D and trade. We focus on the OECD area, since R&D data are not easily available for other regions of the world. In figure 1, we show the evolution of exports and R&D investment in the OECD from 1988 to 2009 (the data in figure 1 are in logarithms)[4]. We can see that since the late 1980's, exports in the OECD have increased at the same pace as R&D investment. This occurred, as mentioned in the introduction, at the same time as the slowdown in the decline of trade costs became more pronounced. Figure 2 shows the correlation between exports and R&D investment in the OECD. As anticipated from figure 1, we find a very strong correlation between R&D and exports in the OECD (see figure 2). This is a very simple exercise, since it says nothing about causation. However, it is at any rate illustrative of the centrality of

[4]All data from http://www.oecd.org/statistics/.

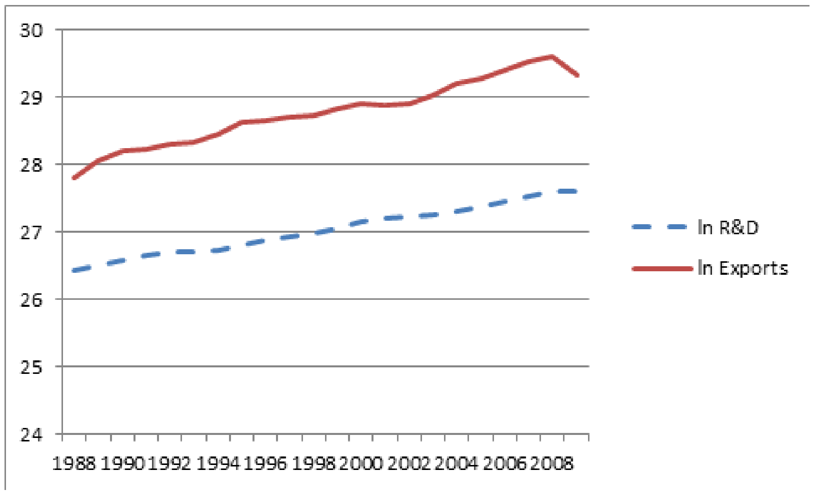

Figure 1: R&D and Exports in the OECD

R&D for international trade.

There are, however, some studies at both the macro and the micro level that indicate that the causation runs from R&D investment to trade. We start with the macro data studies. Most of these studies also focus on the OECD area, again due to data availability problems. Gustavsson et al. (1999) show that international competitiveness and trade flows are determined by investment in R&D at both the firm and the domestic industry level. Braunerhjelm and Thulin (2008), point out that an increase in R&D expenditures of one percentage point implies a three percentage point increase in high-technology exports. Montobbio (2003) confirms the importance of technological variables for the world market shares of individual countries. Sanyal (2004) presents evidence that innovation intensity has a positive and significant impact on bilateral trade performance. Furthermore, at the sectoral level, innovation intensity affects bilateral trade performance positively mainly in the high-technology sectors. In turn, Sterlacchini and Venturini (2011) show that the long run elasticity of total factor productivity with respect to the stock of R&D capital varies greatly across countries. According to them, this helps to partially explain the difference in performance of manufacturing industries across countries.

In turn, Gustavsson et al. (1999), Mancusi (2008) and Laursena and Meliciani (2012) confirm the centrality of knowledge spillovers and absorp-

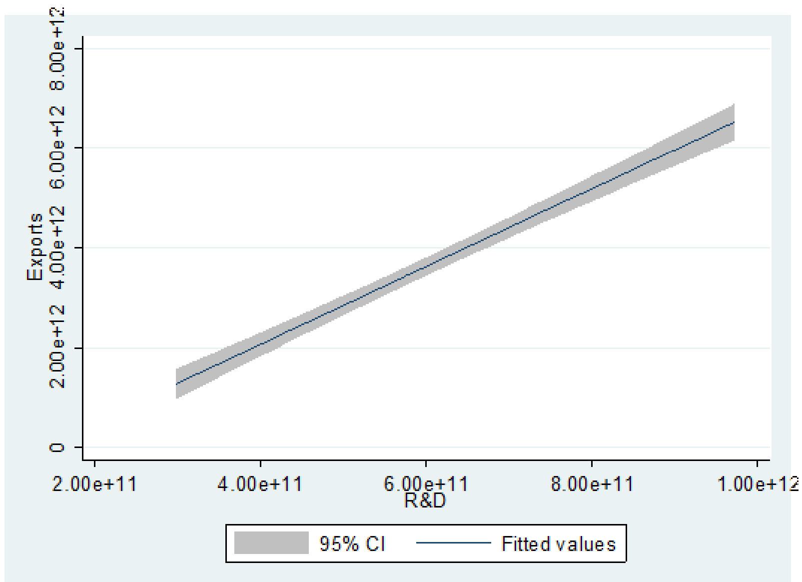

Figure 2: Correlation between R&D and Exports in the OECD

tive capacity for international trade. Gustavsson et al. (1999) highlights the fact that the investment in embodied technical progress has stronger impact in medium and high technology industries. Mancusi (2008) demonstrates that knowledge spillovers and absorptive capacity are particularly effective for the innovative productivity of technologically laggard countries. Laursena and Meliciani (2012) find that international knowledge flows have a positive and significant impact on export market shares in information and communication technologies industries. They also show that small open economies benefit more than other countries from international knowledge flows.

At the micro level, we also have evidence that confirms that R&D investment has a positive causal impact on the export performance of firms. Aw et al. (2011) use a micro panel data of firms in the Taiwanese electronics industry. They find a significant interaction effect between exporting and R&D investments and future productivity, after controlling for size, age and current productivity. Ganotakis and Love (2011), in turn focus on a sample of new technology based firms in the UK. They show that innovators are more likely to export, although on entering export markets successful innovation does not increase subsequent export intensity. The study of Caldera (2010) is based on a panel of Spanish firms. She presents evidence of a positive effect of firm innovation on the probability of participation in export markets. Lachenmaier and Wöβmannt (2006), in turn, use German micro data. They find that innovation leads to an increase of roughly seven percent in the export share of German manufacturing firms, with the effect being stronger in technology-intensive sectors.

3 Related Literature

We now turn to the related literature on R&D and trade. The relationship between R&D and trade has mainly been analyzed in three strands of the trade literature: the strategic trade literature (Spencer and Brander, 1983), the trade and growth literature (Grossman and Helpman, 1991) and the heterogeneous firms literature (Melitz, 2003).

The strategic trade literature looks at the effects of government subsidies on the exports of firms. Most of this literature focuses on export subsidies, but Leahy and Neary (1997) also analyze the effects of R&D subsidies. Leahy and Neary (1997) show that the strategic behavior of firms in R&D justifies R&D subsidies, especially when R&D spillovers are high, since R&D cooperation is reduced. In Leahy and Neary (1997) all firms have the same level of commitment power in R&D, in particular if they choose R&D levels before setting production levels, i.e.: both firms play strategically in R&D. In this way, the model of Leahy and Neary (1997) is similar to our symmetric commitment power in R&D game, with the exception that we do not consider R&D subsidies. However, it differs from our asymmetric commitment power in R&D game where firms differ in the level of commitment power in R&D. In this sense, the paper of Leahy and Neary (1997) has a different focus from ours: they look at R&D subsidies when firms are symmetric in commitment power in R&D, while we focus on trade flows and on the effects of having firms with asymmetric commitment power in R&D.

In turn, the trade-growth literature studies the channels through which innovation affects growth and trade (Grossman and Helpman, 1991). Firms in the industrial sector operate under monopolistic competition and they buy innovations from a perfectly competitive innovative sector. In this way, innovations are an intermediate product for the industrial sector. Furthermore, the innovative sector performs product R&D investment. The higher the rate of inventions in the innovative sector, the higher the rate of growth of the economy. Trade integration can accelerate the rate of growth of the world economy, since duplication of innovations is eliminated and the market for innovations becomes larger. In addition, if R&D spillovers are global (instead of local), firms in poor countries can benefit from innovations in rich countries. Our paper differs from this literature in that we look at process R&D instead of product R&D, we consider strategic interactions between firms and we do not focus on economic growth but on trade flows.

The heterogeneous firms literature analyzes the effects on international trade of productivity differences across firms. The standard model of this literature is Melitz (2003), which generates firm heterogeneity randomly by allocating productivity levels to firms according to some *ex-ante* statistical distribution. In this way, productivity differences between firms are exogenous. The main result in this literature is that only the more productive firms enter the foreign markets, because only these firms can pay the fixed costs of exporting. The literature on heterogeneous firms and R&D usually starts from this set-up and then look at the effects of trade liberalization (i.e.: reduction in trade costs) on innovation and trade.

Atkeson and Burstein (2010), for instance, show that a reduction in trade costs raises the process innovation investment of the exporting firms relatively to that of the non-exporting firms. In this way, trade liberalization amplifies the productivity advantages of the exporting firms relatively to the non-exporting firms, given that the former at the outset are more productive than the latter. Schröder and Sørensen (2012) analyze the effects of exogenous technological progress in the dynamics of entry and exit of firms. They show that higher productivity firms survive longer, most firm closures are young firms, higher productivity exporters are more likely to continue to export compared to less productive exporters, and market exits as well as firm closures are typically preceded by periods of contracting market shares. Costantini and Melitz (2008), in turn, analyze firm-level adjustments to trade liberalization when firms invest in R&D. In their model, R&D investment is subject to sunk costs, and innovation involves a trade-off between the costs and the returns of R&D. They show that firms decisions are determined by non-technological factors such as the timing of trade liberalization announcements (anticipated *versus* non-anticipated) and the speed of liberalization (gradual *versus* sudden). In particular, firms innovate in anticipation of announcements of trade liberation.

Baldwin and Robert-Nicoud (2007) introduce economic growth *à la* Grossman and Helpman (1991) in the Melitz (2003) model. They show that freer trade raises productivity, since similarly to Atkeson and Burstein (2010), the more efficient firms invest more (static effect). However, it slows economic growth (dynamic effect), since the less efficient firms become even more laggard on productivity. Besides looking at the effects of trade liberalization on trade and growth in a heterogeneous firms framework, Baldwin and Robert-Nicoud (2007) raise another issue that is central to this paper. Here, we focus on an R&D trade-off between marginal and fixed costs of production: when a firm increases the investment in R&D, it can reap lower marginal costs at the expense of higher fixed costs. As we have discussed in the introduction, there are however other channels that can affect trade flows, and Baldwin and Robert-Nicoud (2007) point out one: reductions on fixed costs through technological progress, instead of marginal cost as in our paper. In fact, they demonstrate that reductions in fixed costs can also be a driver of world trade. Similarly, if firms differ in fixed costs (in contrast to marginal costs), they will also end up with different levels of market access.

There are then different ways from the one proposed in this paper to reconcile the evidence on the "puzzle" of the flattening of trade costs and the continuing increase in trade flows. From the evidence presented in section two, however, we believe that the mechanism presented in this paper is valid. However, we do not claim that this is the only channel at work. Future empirical work on these different channels could certainly be very helpful by elucidating us on the relative importance of each one of them.

In any case, in the heterogeneous firms literature, productivity differences between firms are invariably exogenous, since firms' competitiveness, and therefore market access, depends only on exogenous factors such as trade costs and the fixed costs of entry in foreign markets. An exception is Ederington and McCalman (2009). They generate endogenous heterogeneity across firms as a result of firms' choice of technology. In particular, Ederington and McCalman (2009) analyze how reductions in trade costs affect firms' incentives to choose between different cost-reducing technologies. They find that trade liberalization reduces the likelihood of an industrial shakeout, because firms adopt more efficient cost structures.

Similarly to Ederington and McCalman (2009), we also endogenize competitiveness asymmetries between firms, but via a different channel, i.e.: differences in commitment power in R&D. In fact, in the asymmetric commitment power in R&D game, productivity asymmetries between firms are produced endogenously as a result of the strategic responses in R&D of the R&D leader and the R&D follower. We then argue that strategic interactions between firms can also contribute to the discussion in the trade literature about productivity differences across firms and countries.

The introduction of strategic interactions between firms is the main contribution of this paper. As already mentioned, the heterogeneous firms literature disregards strategic interaction between firms, since it adopts the monopolistic competition framework. However, as is well known from the industrial organization literature, strategic interactions are at the core of productivity differences across firms (see Cabral and Mata, 2003). Furthermore, as we have pointed out in the previous section, strategic interactions seem also to be particularly important in international trade (Tybout, 2003). In fact, as shown by the heterogeneous firm literature, only an extremely small share of firms with very high market power are active in export markets (Bernard et al., 2003). This means that competition in export markets is of the oligopoly type, i.e.: with very few and very powerful actors. Our model, with a duopoly Cournot model and strategic interactions between firms, seems fit to analyze this issue.

4 Model

The world economy consists of two symmetric countries, home and foreign, and two firms, the home firm and the foreign firm (foreign variables are indicated by an asterisk). In this sense, our model is not a full-fledged general equilibrium trade model. The simplicity, however, allows us to introduce strategic competition in R&D. In our view, this ingredient is interesting, because it is usually absent from trade models. This is due to the fact that the majority of trade models assume monopolistic competition. For a review of trade models with oligopolistic competition see Neary (2010).

The home firm and the foreign firm produce a homogenous good to sell in the domestic market and to export. In the sequel, since the model is symmetric, we concentrate our attention on the home country and on the home firm. Equations for the foreign country and for the foreign firm apply by symmetry. The home firm and the foreign firm face the following indirect demand in the home country:

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

where q is the domestic sales of the home firm and x^* is the exports of the foreign firm to the home country (similar interpretation holds for q^* and x).

Likewise, $a > 0$ and $b > 0$ stand for the intercept of demand and an inverse measure of market size, respectively.

Profits by the home firm can be written as:

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

where $t > 0$ is an indicator of all barriers to trade. In turn, C and Γ are the home firm's marginal and fixed costs, respectively. Similar to what is common in international trade models, we assume that $t = t^*$. This means that the home firm and the foreign firm have the same level of exogenous access to international markets. In reality, however, trade costs can be endogenous to firms' decisions. A firm can for instance invest in distribution channels. However, we follow the trade literature by assuming that trade costs are exogenous (see Anderson and Wincoop, 2004).

From equation 2 we can see the effects of a reduction in trade costs (t). We have that trade liberalization increases the marginal revenue from exports and therefore promotes international trade[5]. In the same way, we can also note that a reduction in trade costs is equivalent to a reduction in marginal costs (C). The effects of a reduction in t and C will be seen more clearly when we derive the expressions for exports (x and x^*).

In our model, however, firms' access to export markets does not depend only on the exogenous factor trade costs; it also depends on endogenous factors, in particular R&D investment. Specifically, as in Leahy and Neary (1997), we introduce process R&D investment that reduces marginal costs (C) but increases fixed costs (Γ). For the home firm this amounts to:

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

where k is R&D investment by the home firm, $\theta > 0$ is the cost-reducing effect of R&D, $\gamma > 0$ is the cost of R&D and $c > 0$ and $f > 0$ are the initial marginal and fixed costs of production (i.e.: without R&D), respectively. We implicitly assume that the fixed costs, f, are sufficiently high to not promote entry, but sufficiently low to not make the two firms exit the market.

[5] In an international context, trade costs can also affect collusive behavior (Andree, 2012) and industry concentration (Jørgensen and Schröder, 2003). We abstract from these issues in this paper.

In line with what is standard in the trade literature, we assume that the foreign firm has a similar cost structure with $c = c^*$, $f = f^*$, $\theta = \theta^*$ and $\gamma = \gamma^*$. In our case, this assumption is important because it allows us to show that the competitiveness asymmetries between firms are generated in our model endogenously.

4.1 Three R&D Games

In this paper, we investigate how R&D and differences in commitment power in R&D affect international trade. We then compare three games that differ in the nature of R&D competition. In the first game, firms cannot invest in R&D (i.e.: $k = k^* = 0$). This game is used as the benchmark. In the second game, the home firm and the foreign firm invest in R&D with symmetric commitment power in R&D. In the third game, the home firm and the foreign firm also invest in R&D, but now the two firms have asymmetric commitment power in R&D (as in Garcia Pires, 2009). In particular, in the third game, and without loss of generality, we assume that the home firm has a first-mover advantage in R&D. As defended by Hamilton and Slutsky (1990), in order to justify the first-mover advantage, we can think of the home firm as an incumbent that moves in R&D before the entrant foreign firm. However, since the focus of this paper is not on firms' entry decisions, we abstract from this issue here. See Spence (1977) for incumbent-entrant models.

According to Bagwell (1995), a firm has commitment power in R&D when the R&D decisions have commitment value for the output stage, i.e.: R&D levels are chosen at a previous stage to output. When a firm has no commitment power the firm sets outputs and R&D levels simultaneously. Thus, when a firm has commitment power, it can use R&D with two objectives: to improve its own productive efficiency and also to affect the rival's strategic decisions. When a firm does not have commitment power in R&D, only the former holds.

In the rest of the paper, variables referring to each of these three games are identified by the following subscripts, respectively: B for the benchmark no R&D game, S for the symmetric commitment power in R&D game and A for the asymmetric commitment power in R&D game.

4.2 Timing of the Three Games

The benchmark no R&D game is a one shot game in outputs (q_B, x_B, q_B^*, x_B^*). The symmetric commitment power in R&D game has two stages. At the first stage, the home firm and the foreign firm decide on R&D investment (k_S, k_S^*). At the second stage they choose outputs (q_S, x_S, q_S^*, x_S^*). The asymmetric commitment power in R&D game also has two stages. However, now at the first stage only the home firm moves in R&D (k_A). At the second stage, the foreign firm decides simultaneously on R&D levels (k_A^*) and outputs (q_A^*, x_A^*), while the home firm moves on outputs (q_A, x_A).

Note that the strategic R&D literature (Spence, 1984, Fudenberg and Tirole, 1984, Leahy and Neary, 1997) usually assumes that firms have symmetric commitment power in R&D. We differ from this literature, by considering a game where firms have asymmetric commitment power in R&D.

In this sense, the asymmetric commitment power in R&D game is a type of Stackelberg (1934) leader game, since the home firm has a first-mover advantage in R&D. However, as will be seen below, the asymmetric commitment power in R&D game differs in one important aspect from standard Stackelberg output leader models. In particular, the R&D leader advantages, unlike the output leader advantages, allow us to endogenize competitiveness asymmetries between firms in marginal and fixed costs.

We are now ready to define the production equilibrium of the three games.

5 Production Equilibrium

As usual the model is solved by backward induction. From the first order conditions (FOCs) for outputs, we obtain[6]:

$$\begin{aligned} q &= \tfrac{D+t+2\theta k-\theta k^*}{3b} \\ x &= \tfrac{D-2t+2\theta k-\theta k^*}{3b} \\ q^* &= \tfrac{D+t+2\theta k^*-\theta k}{3b} \\ x^* &= \tfrac{D-2t+2\theta k^*-\theta k}{3b}. \end{aligned} \tag{4}$$

[6]It can be easily checked that for all games in the paper (benchmark no R&D game, symmetric commitment power in R&D game and asymmetric commitment power in R&D game), the second order conditions (SOCs) for outputs are always satisfied.

To simplify the notation, we make $D = (a - c) > 0$, where D represents the firms' initial cost competitiveness, i.e.: without R&D investment. As is standard in oligopolist trade models, we make $D - t > 0$, so that firms are not restricted *à priori* from the export markets (see Neary, 2010). Note, however, as we will see below, that this assumption does not guarantee *per se* that firms are always able to export.

The important point to make from equation 4 is that a reduction in trade costs (t) conduces to an increase in the exports of both the home and the foreign firm (x and x^*). This is a property that is common to different types of imperfect competition trade models with either monopolistic or oligopolistic competition (see Krugman, 1980 and Brander, 1981, respectively). It is this observation that makes trade costs central for the empirical literature on trade costs and trade, in which the gravity model is central (see Anderson and Wincoop, 2004).

From equation 4, we can also see that, similarly to what occurs with a reduction in trade costs (t), a reduction in the marginal costs without R&D (c) also conduces to an increase in the exports of the home and the foreign firm (x and x^*). In our model, however, marginal costs (C and C^*) can be asymmetric for the home and the foreign firm, if they invest differently on R&D, i.e.: $k \neq k^*$. Remember that $C = c - \theta k$ and $C^* = c - \theta k^*$. In other words, when $C = C^*$ due to $k = k^*$, then a reduction in marginal costs will be equivalent to a reduction in trade costs for both the home and the foreign firm. However, when $C \neq C^*$ due to $k \neq k^*$, reductions in marginal costs will affect differently the home and the foreign firm. In any case (with $C = C^*$ or $C \neq C^*$), investment in R&D has the potential to increase exports since it reduces marginal costs. In this way, our model draws on the attention to two points. First, a reduction in marginal costs can have similar implications for international trade as a reduction in trade costs. Second, if firms differ in the level of R&D investment, then they will also have different marginal costs, which leads to asymmetric effects on firms' exports.

Having said this, we can note that by making $k = k^* = 0$ in equation 4, we have the output expressions for the benchmark no R&D game:

$$\begin{aligned} q_B &= q_B^* = \tfrac{D+t}{3b} \\ x_B &= x_B^* = \tfrac{D-2t}{3b}. \end{aligned} \tag{5}$$

where q_B and x_B represent the local sales and the exports, respectively, of the home firm in the benchmark case with no R&D (q_B^* and x_B^* refer to the same variables but for the foreign firm).

For the symmetric commitment power in R&D game and the asymmetric commitment power in R&D game, however, we have to proceed to the R&D expressions. The FOCs for R&D, though, depend on a firm's commitment power in R&D. We illustrate this with the home firm's FOC for R&D, since the home firm has commitment power in R&D under all R&D games (the symmetric commitment power in R&D game and the asymmetric commitment power in R&D game). Accordingly, the home firm's FOC for R&D under the symmetric commitment power in R&D game and the asymmetric commitment power in R&D game can be decomposed into three terms:

$$\frac{d\Pi_i}{dk_i} = \frac{\partial\Pi_i}{\partial k_i} + \frac{\partial\Pi_i}{\partial q_i^*}\frac{dq_i^*}{dk_i} + \frac{\partial\Pi_i}{\partial x_i^*}\frac{dx_i^*}{dk_i} \text{ with } i = S, A. \tag{6}$$

The first term on the right hand side of equation 6 is usually labeled as the non-strategic motive for R&D, while the second and third terms are typically referred to as the strategic motives for R&D[7]. Hence, R&D is said to be strategic if the second and the third terms are non-zero. This happens when a firm chooses R&D at a previous stage to outputs, i.e.: a firm has commitment power in R&D. Conversely, R&D is said to be non-strategic if the second and third terms are zero. This occurs when a firm chooses R&D and outputs simultaneously, i.e.: a firm has no commitment power in R&D.

Summing up, when a firm has commitment power in R&D (i.e.: the home firm and the foreign firm in the symmetric commitment power in R&D game and the home firm in the asymmetric commitment power in R&D game), it has a FOC for R&D similar to the one in equation 6. In turn, when a firm has no commitment power in R&D (i.e.: the foreign firm in the asymmetric commitment power in R&D game), it has a FOC for R&D without the second and third terms in equation 6. As a result, the home firm's R&D expressions are similar under both the symmetric commitment power in R&D game and the asymmetric commitment power in R&D game, but the same does not occur for the foreign firm:

$$k_i = \frac{4\theta}{3\gamma}(q_i + x_i) \text{ with } i = S, A, \tag{7}$$

[7] The whole FOC for R&D for the home firms is $\frac{d\Pi}{dk} = \frac{\partial\Pi}{\partial k} + \frac{\partial\Pi}{\partial q}\frac{dq}{dk} + \frac{\partial\Pi}{\partial x}\frac{dx}{dk} + \frac{\partial\Pi}{\partial q^*}\frac{dq^*}{dk} + \frac{\partial\Pi}{\partial x^*}\frac{dx^*}{dk}$. However, from the FOCs for outputs, we have $\frac{\partial\Pi}{\partial q} = \frac{\partial\Pi}{\partial x} = 0$. The SOCs for R&D are in the appendix.

$$k_S^* = \frac{4\theta}{3\gamma}\left(q_S^* + x_S^*\right), \tag{8}$$

$$k_A^* = \frac{\theta}{\gamma}\left(q_A^* + x_A^*\right), \tag{9}$$

where k_S and k_A represent the R&D investment of the home firm in the symmetric commitment power in R&D game (home and foreign firm move simultaneously in R&D) and the asymmetric commitment power in R&D game (the home firm moves before the foreign firm in R&D), respectively. Similarly, k_S^* and k_A^* refer to the same variables, but for the foreign firm.

We can now see that in the symmetric commitment power in R&D game, the home firm and the foreign firm have symmetric incentives to invest in R&D, since they have symmetric commitment power in R&D (see equations 7 and 8). On the contrary, in the asymmetric commitment power in R&D game, the home firm and the foreign firm have asymmetric incentives to invest in R&D once they have asymmetric commitment power in R&D (see equations 7 and 9). In particular, the home firm (the R&D leader) over-invests in R&D relatively to the foreign firm (the R&D follower) by a proportion of $\frac{4}{3}$, in order to influence the rival's strategic choices (outputs and R&D).

Note that this differs from standard duopoly R&D models (like Leahy and Neary, 1997), where duopolists invest symmetrically since they have symmetric commitment power in R&D. Furthermore, over-investment in R&D is independent of differences in commitment power in R&D, i.e.: over-investment in R&D also occurs if the rival has commitment power in R&D (as in the symmetric commitment power in R&D game). In other words, over-investment in R&D is the result of Cournot behavior and of a firm choosing R&D before outputs, not of a firm moving in R&D before the rival.

With the output expressions (equation 4) and the R&D expressions (equations 7 to 9), we can find the production equilibrium of the R&D games (symmetric commitment power in R&D game and asymmetric commitment power in R&D game). For the symmetric commitment power in R&D game, we have to solve equations 4, 7 and 8 simultaneously:

$$\begin{aligned} q_S &= q_S^* = \frac{3D+t(3-4\eta)}{b(9-8\eta)} \\ x_S &= x_S^* = \frac{3D-2t(3-2\eta)}{b(9-8\eta)} \\ k_S &= k_S^* = \frac{4\theta(2D-t)}{b\gamma(9-8\eta)}, \end{aligned} \tag{10}$$

where q_S and x_S represent the local sales and the exports of the home firm in the symmetric commitment power in R&D game (home and foreign firm move simultaneously in R&D). Again q_S^* and x_S^* refer to the same variables, but for the foreign firm. Also, like in Leahy and Neary (1997), we have that:

$$\eta = \frac{\theta^2}{\gamma b} \tag{11}$$

where η represents the "relative" return on R&D. A high η stands for 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 the cost of R&D (γ). The reverse holds for low η. In this sense, η can be interpreted as a metaphor for technological progress.

For the asymmetric commitment power in R&D game, we need to solve equations 4, 7 and 9 simultaneously:

$$\begin{aligned}
q_A &= \frac{3D(1-2\eta)+t\left((3-11\eta)+8\eta^2\right)}{b(9-4\eta(7-4\eta))} \\
x_A &= \frac{3D(1-2\eta)-t\left((6-17\eta)+8\eta^2\right)}{b(9-4\eta(7-4\eta))} \\
q_A^* &= \frac{D(3-8\eta)+t\left((3-10\eta)+8\eta^2\right)}{b(9-4\eta(7-4\eta))} \\
x_A^* &= \frac{D(3-8\eta)-t\left(2(3-9\eta)+8\eta^2\right)}{b(9-4\eta(7-4\eta))} \\
k_A &= \frac{4\theta(2D-t)(1-2\eta)}{b\gamma(9-4\eta(7-4\eta))} \\
k_A^* &= \frac{\theta(2D-t)(3-8\eta)}{b\gamma(9-4\eta(7-4\eta))},
\end{aligned} \tag{12}$$

where q_A and x_A represent the local sales and the exports, respectively, of the home firm in the symmetric commitment power in R&D game (the home firm moves before the foreign firm in R&D). Again q_A^* and x_A^* refer to the same variables, but for the foreign firm.

When the home firm and the foreign firm are symmetric in commitment power in R&D (the symmetric commitment power in R&D game), then, they also end up being symmetric in every other respect (equation 10), given that strategic over-investment in R&D by one firm is offset by similar behavior by the rival. As such, strategic investment in R&D *per se* does not make firms asymmetric. In this way, the symmetric commitment power in R&D game does not differ from the benchmark no R&D game, since firms in the two games are symmetric (equations 5 and 10). However, when the home firm and the foreign firm are asymmetric in commitment power (the asymmetric commitment power in R&D game), they become endogenously asymmetric (equation 12), once the home firm can impose the R&D leader advantage on the foreign firm (the R&D follower). In the next sections, we analyze the consequences of this endogenous asymmetry in international trade.

6 Firms' Access to International Markets

In this section, we study firms' access to international markets under the benchmark no R&D game, the symmetric commitment power in R&D game and the asymmetric commitment power in R&D game. The parameter of interest is trade costs (t). In order to do this, we first investigate how the autarchy threshold level of trade costs for the home firm and the foreign firm ($\hat{t}$ and $\hat{t}^*$, respectively) differs between the different games; and second how exports and R&D are affected by changes in trade costs.

We start by analyzing the trade conditions (i.e.: the autarchy threshold level of trade costs). To compute $\hat{t}$ and $\hat{t}^*$ we need to solve the export expressions (equations 5, 10 and 12) for trade costs (t). Using equation 5, we obtain for the benchmark no R&D game:

$$\hat{t}_B = \hat{t}_B^* < \tfrac{D}{2}. \tag{13}$$

For the symmetric commitment power in R&D game, from equation 10:

$$\hat{t}_S = \hat{t}_S^* < \tfrac{3D}{2(3-2\eta)}. \tag{14}$$

For the asymmetric commitment power in R&D game, from equation 12:

$$\begin{aligned} \hat{t}_A &< \tfrac{3D(1-2\eta)}{6-\eta(17-8\eta)} \\ \hat{t}_A^* &< \tfrac{1}{2}\tfrac{D(3-8\eta)}{3-\eta(9-4\eta)}. \end{aligned} \tag{15}$$

Since in the benchmark no R&D game and in the symmetric commitment power in R&D game, the home firm and the foreign firm are always symmetric (equations 5 and 10), they also have the same level of access to international markets (equations 13 and 14). On the contrary, given that the asymmetric commitment power in R&D game the home firm and the foreign firm become endogenously asymmetric in competitiveness due to differences in commitment power in R&D (equation 12), they also end up with different levels of access to international markets (equation 15).

As shown in appendix, in order for the trade conditions to be satisfied we need that:

$$0 < t < \tfrac{D}{2}. \tag{16}$$

And also:

$$0 < \eta < \tfrac{3}{8}. \tag{17}$$

First note that equation 17 is more restrictive than the SOC for R&D (i.e.: $0 < \eta < \frac{9}{16}$, see appendix). Second, equations 17 and 16 guarantee that domestic sales (q_i and q_i^*, with $i = B, S, A$) are always positive, ruling out monopoly cases. Furthermore, equation 16 ensures that we always have two-way trade in the benchmark no R&D game and in the symmetric commitment power in R&D game and at least one-way trade in the asymmetric commitment power in R&D game. To see this, note that as $\eta \to 0$, $\hat{t}_S \to \frac{D}{2}$ and as $\eta \to \frac{3}{8}$, $\hat{t}_S \to \frac{2D}{3}$, i.e.: $\frac{D}{2} < \hat{t}_S < \frac{2D}{3}$. In turn, for the asymmetric commitment power in R&D game we have that $\eta \to 0$, $\hat{t}_A \to \frac{D}{2}$ and also $\hat{t}_A^* \to \frac{D}{2}$; however, when $\eta \to \frac{3}{8}$, $\hat{t}_A \to D$ but $\hat{t}_A^* \to 0$, i.e.: $\frac{D}{2} < \hat{t}_A < D$ and $0 < \hat{t}_A^* < \frac{D}{2}$.

As such, when the relative return on R&D (η) is relatively high the foreign firm can find it difficult to export, since $t > 0$ and the threshold level of trade costs that allows the foreign firm to export tends to zero. In other words, for high η, $\hat{t}_A^* \to 0$ and therefore it is more likely that $t > \hat{t}_A^*$, reducing the profitability of the exports of the foreign firm. In fact, as $\eta \to \frac{3}{8}$, the foreign firm might not find it profitable to export. As will be seen in the next section, this occurs because when the relative return on R&D is high, the R&D leader can more easily exercise the first-mover advantage over the R&D follower. In any case, then, similar to Melitz (2003), our model can also differentiate between exporters and purely domestic firms.

It is important to remark that it is not necessarily a drawback that in the asymmetric commitment power in R&D game under certain circumstances the foreign firm will not be able to export. With this property, and contrary to standard trade models (like Krugman, 1980 or Brander, 1981), we do not need to assume that firms in different countries face different trade costs in order to have firms with asymmetric levels of access to export markets. Accordingly, in the asymmetric commitment power in R&D game, even firms that face the same trade costs, can have different international market access. Also contrary to Melitz (2003), we do not need to assume that firms have *à priori* different productivity levels, in order for only the more productive firms to export. In our model, this occurs endogenously as a result of strategic investment in R&D. Here, then, firms' access to international markets depends not only on trade costs, but also on R&D competition.

We can now study the relations between exports, R&D and trade costs. The following hold as long as equations 17 and 16 are satisfied:

$$\begin{aligned}
\frac{dx_B}{dt} &= \frac{dx_B^*}{dt} = -\frac{2}{3b} < 0 \\
\frac{dx_S}{dt} &= \frac{dx_S^*}{dt} = -\frac{2(3-2\eta)}{b(9-8\eta)} < 0 \\
\frac{dk_S}{dt} &= \frac{dk_S^*}{dt} = -\frac{4\theta}{b\gamma(9-8\eta)} < 0 \\
\frac{dx_A}{dt} &= -\frac{(6-17\eta)+8\eta^2}{b(9-4\eta(7-4\eta))} < 0 \\
\frac{dx_A^*}{dt} &= -\frac{2(3-9\eta)+8\eta^2}{b(9-4\eta(7-4\eta))} < 0 \\
\frac{dk_A}{dt} &= -\frac{4\theta(1-2\eta)}{b\gamma(9-4\eta(7-4\eta))} < 0 \\
\frac{dk_A^*}{dt} &= -\frac{\theta(3-8\eta)}{b\gamma(9-4\eta(7-4\eta))} < 0.
\end{aligned} \tag{18}$$

Not surprisingly, under all games (benchmark no R&D, symmetric commitment power in R&D and asymmetric commitment power in R&D), exports are reduced when trade costs increase. As we discussed in the introduction, this effect has been one of the main focuses in the trade literature. Interestingly, however, a reduction in trade costs increases R&D expenditures. What this means is that R&D investment, since it reduces marginal costs, can magnify the effects of a reduction in trade costs on international trade. We should see in the next section that this is an important mechanism in our model.

Next, we would like to know under which game trade is easier for firms. We therefore analyze the relationship between the different autarchy threshold levels of trade costs, $\hat{t}_B$, $\hat{t}_S$, $\hat{t}_A$ and $\hat{t}_A^*$. We have:

$$\begin{aligned}
\hat{t}_A - \hat{t}_S &= \frac{3\eta D}{2(6-\eta(17-8\eta))(3-2\eta)} > 0 \\
\hat{t}_S - \hat{t}_B &= \frac{\eta D}{3-2\eta} > 0 \\
\hat{t}_B - \hat{t}_A^* &= -\frac{\eta D(1-4\eta)}{2(3-\eta(9-4\eta))} \lesseqgtr 0.
\end{aligned} \tag{19}$$

It can be easily seen that $\hat{t}_B > \hat{t}_A^*$ if $\eta > \frac{1}{4}$; and the reverse for $\eta < \frac{1}{4}$. Two cases then arise that depend on the return on R&D (η): $\hat{t}_A > \hat{t}_S > \hat{t}_B > \hat{t}_A^*$ for $\eta > \frac{1}{4}$ and $\hat{t}_A > \hat{t}_S > \hat{t}_A^* > \hat{t}_B$ for $\eta < \frac{1}{4}$. If the return on R&D is relatively high ($\eta > \frac{1}{4}$), trade is more easy for the R&D leader (the home firm in the asymmetric commitment power in R&D game), and more difficult for the R&D follower (the foreign firm in the asymmetric commitment power in R&D game). In the second and third places in the market access ranking come respectively the firms with symmetric commitment power in R&D (the home firm and the foreign firm in the symmetric commitment power in R&D game) and the firms that do not invest in R&D (the home firm and the foreign firm in the benchmark no R&D game). In turn, if the return on R&D is relatively low ($\eta < \frac{1}{4}$), the third and fourth positions in the market access ranking change. The firm with low commitment power (the foreign firm in the asymmetric commitment power in R&D game) starts to have better market access than the firms that do not invest in R&D (the home firm and the foreign firm in the benchmark no R&D game). In other words, and as we will see in the next section, the R&D follower benefits from softer R&D competition (low η), because the R&D leader finds it more difficult to exercise the first-mover advantage in R&D.

What this tells us is that endogenous factors, such as strategic competition in R&D, are central for a firm's involvement in international markets. In particular, through investment in R&D, the R&D leader can affect not only its own level of access to international markets but also that of competitors. In the next section, we explore this issue further.

7 Technology and R&D

Before analyzing the effects of R&D on trade, an important intermediate step is to look at the influence of the R&D parameters, θ and γ (i.e.: technology), on R&D. We start with the symmetric commitment power in R&D game and then turn to the asymmetric commitment power in R&D game.

In the symmetric commitment power in R&D game, it can be noted that, as long as equations 16 and 17 hold, the relationship between R&D investment (k_S and k_S^*) and the R&D parameters is:

$$\begin{aligned} \frac{dk_S}{d\theta} &= \frac{dk_S^*}{d\theta} = \frac{4(2D-t)(9+8\eta)}{b\gamma(9-8\eta)^2} > 0 \\ \frac{dk_S}{d\gamma} &= \frac{dk_S^*}{d\gamma} = -\frac{36(2D-t)b\theta}{b^2\gamma^2(9-8\eta)^2} < 0 \end{aligned} \quad (20)$$

We then have that when firms have symmetric commitment power on R&D, R&D investment increases with the return on R&D (θ) and decreases with the cost of R&D (γ). In the symmetric commitment power in R&D game, therefore, the higher the cost-reducing effect of R&D and the lower the cost of R&D (i.e.: the higher the relative return on R&D, η), the higher the investment in R&D. Furthermore, this effect is symmetric for both the home and the foreign firm.

In turn, in the asymmetric commitment power in R&D game, as long as equations 17 and 16 hold, the relation between R&D investment (k_A and k_A^*) and the R&D parameters is:

$$\begin{aligned} \frac{dk_A}{d\theta} &= \frac{4(2D-t)(9+2\eta(4\eta(4\eta+1)-13))}{b\gamma((9-4\eta(7-4\eta)))^2} > 0 \\ \frac{dk_A}{d\gamma} &= -\frac{4(2D-t)(9-4\eta(9-10\eta))b\theta}{b^2\gamma^2((9-4\eta(7-4\eta)))^2} < 0 \\ \frac{dk_A^*}{d\theta} &= \frac{(2D-t)(27+4\eta(8\eta+11)(4\eta-3))}{b\gamma((9-4\eta(7-4\eta)))^2} \lesseqgtr 0 \\ \frac{dk_A^*}{d\gamma} &= -\frac{(2D-t)(27+16\eta(11\eta-9))b\theta}{b^2\gamma^2((9-4\eta(7-4\eta)))^2} \lesseqgtr 0 \end{aligned} \quad (21)$$

When firms are asymmetric in commitment power in R&D, the R&D parameters affect asymmetrically the R&D levels of the R&D leader (home firm) and the R&D follower (foreign firm). The R&D leader behaves with regard to the R&D parameters in the same way as in the symmetric commitment power in R&D game (equation 20), i.e.: R&D conducted by the R&D leader increases with the return on R&D (θ) and decreases with the cost of R&D (γ). However, this might not necessarily hold for the R&D follower. For the R&D follower, R&D only increases with the return on R&D for low values of θ, whereas for high values of θ, R&D decreases with θ. Also, for the R&D follower, R&D only decreases with the costs of R&D for low values of γ, whereas for high values of γ, R&D by the R&D follower increases with γ. This means that R&D by the R&D follower has a U-shaped relation with θ and an inverse U-shaped relation with γ.

The rationale for this result is the following. For high values of the return on R&D (θ) and for low values of the cost of R&D (γ), the R&D leader finds it easier to exercise the R&D leadership over the R&D follower. The opposite occurs for low values of θ and for high values of γ. In other words, when the relative return on R&D ($\eta = \frac{\theta^2}{\gamma b}$) is high (high θ and low γ), the R&D leader gains a competitive advantage over the R&D follower, and *vice versa* when the relative return on R&D is low.

We can now better understand the result that the R&D follower faces more difficulties exporting when the relative return on R&D is high. When the relative return on R&D is high, investment in R&D by the R&D leader increases relatively to the R&D follower. As a result, the R&D leader finds it easier to enter the export markets, and the opposite is true for the R&D follower, since the marginal costs advantage of the former increases relatively to that of the latter. As we will see in the next section, this has important consequences for international trade patterns.

8 R&D and Trade

In this section, we analyze the impact of R&D on international trade. We start by studying how the relative return on R&D, η (i.e.: technology) affects the trade conditions and exports, $\hat{t}_i$, $\hat{t}_i^*$, x_i and x_i^*, with $i = S, A$. For the symmetric commitment power in R&D game, as long as equations 17 and 16 are satisfied, we have that:

$$\begin{aligned} \frac{d\hat{t}_S}{d\eta} &= \frac{d\hat{t}_S^*}{d\eta} = \frac{3D}{(3-2\eta)^2} > 0 \\ \frac{dx_S}{d\eta} &= \frac{dx_S^*}{d\eta} = \frac{12(2D-t)}{b(9-8\eta)^2} > 0. \end{aligned} \tag{22}$$

When firms are symmetric in commitment power (symmetric commitment power in R&D game), then, higher return on R&D (high η) makes trade easier for both the home firm and the foreign firm (equation 22).

In turn, for the asymmetric commitment power in R&D game, as long as equations 17 and 16 are satisfied, we have:

$$\frac{d\left(\hat{t}_A\right)}{d\eta} = \frac{3D(5-16\eta(1-\eta))}{(6-\eta(17-8\eta))^2} > 0$$
$$\frac{d(x_A)}{d\eta} = \frac{3(2D-t)(5-16\eta(1-\eta))}{b(9-4\eta(7-4\eta))^2} > 0$$
$$\frac{d\left(\hat{t}^*_A\right)}{d\eta} = \frac{D(3-8\eta(3-4\eta))}{2(3-\eta(9-4\eta))^2} \lesseqgtr 0$$
$$\frac{d\left(x^*_A\right)}{d\eta} = \frac{2(2D-t)(3-\eta(24-32\eta))}{b(9-4\eta(7-4\eta))^2} \lesseqgtr 0. \tag{23}$$

Note that $\frac{d\left(\hat{t}^*_A\right)}{d\eta}$ and $\frac{d\left(x^*_A\right)}{d\eta}$ are positive for $0 < \eta < \frac{3-\sqrt{3}}{8}$ but negative for $\frac{3-\sqrt{3}}{8} < \eta < \frac{3}{8}$. Then, when the home firm and the foreign firm are asymmetric in commitment power in R&D, and contrary to the symmetric commitment power in R&D game, it is only the R&D leader (the home firm) that will always benefit with increases in η. The R&D follower (the foreign firm) can experience a deterioration of the level of access to international markets when the return on R&D is relatively high. The rationale for this result is that, as discussed in the previous section, when the return on R&D is very high, the home firm can use the first-mover advantage in R&D more effectively to force the foreign firm to export less.

To see this more clearly, we analyze the implications of the endogenous competitiveness asymmetry property of the asymmetric commitment power in R&D game. In the asymmetric commitment power in R&D game, as mentioned above, firms become endogenously asymmetric due to differences in commitment power in R&D. In effect, in spite of the fact that the home firm and the foreign firm are initially symmetric ($c = c^*$), they end up producing and investing differently in R&D. It is therefore important to know more about the competitiveness asymmetries between the home firm and the foreign firm. Note then, that, as long as equations 17 and 16 are satisfied, the following relations hold:

$$k_A - k^*_A = \frac{\theta(2D-t)}{b\gamma(9-4\eta(7-4\eta))} > 0$$
$$(q_A + x_A) - (q^*_A + x^*_A) = \frac{2\theta^2(2D-t)}{b^2\gamma(9-4\eta(7-4\eta))} > 0$$
$$x_A - x^*_A = \frac{\theta^2(2D-t)}{\gamma b^2(9-4\eta(7-4\eta))} > 0$$
$$x_A - q^*_A = \frac{2\eta(D-8t\eta)+9t(3\eta-1)}{b(9-4\eta(7-4\eta))} > 0$$
$$\hat{t}_A - \hat{t}^*_A = \frac{\eta D(9-4\eta(7-4\eta))}{2(6-\eta(17-8\eta))(3-\eta(9-4\eta))} > 0. \tag{24}$$

Relatively to the R&D follower, the R&D leader is more efficient (i.e.: invests more in R&D, $k_A > k_A^*$), is larger in size (i.e.: produces more, $q_A + x_A > q_A^* + x_A^*$) and is more active internationally (i.e.: exports more, $x_A > x_A^*$). In fact, the competitiveness level of the home firm is so high that it ends up selling more in the foreign country than the foreign firm itself (i.e.: $x_A > q_A^*$). Furthermore, since $\hat{t}_A > \hat{t}_A^*$, in the interval $\hat{t}_A^* < t < \hat{t}_A$, only the home firm will be able to export. In fact, the relation $\hat{t}_A > \hat{t}_A^*$ can already be seen from equation 19. Similarly to Melitz (2003), and as we have already explained above, in the asymmetric commitment power in R&D game, we can also have a positive self-selection of firms into the export markets (i.e.: only the more competitive firms export)[8].

So far, we have investigated the effects of R&D on trade at the firm level. However, we are also interested in knowing what happens to trade volumes in the three games (the benchmark no R&D game, the symmetric commitment power in R&D game and the asymmetric commitment power in R&D game). We can show that trade volumes in the three games equal:

$$\begin{aligned} X_B = x_B + x_B^* &= \tfrac{2(D-2t)}{3b} \\ X_S = x_S + x_S^* &= \tfrac{2(3D-2t(3-2\eta))}{b(9-8\eta)} \\ X_A = x_A + x_A^* &= \tfrac{2D(3-7\eta)-t(12-\eta(35-16\eta))}{b(9-4\eta(7-4\eta))}. \end{aligned} \tag{25}$$

It then follows:

$$\begin{aligned} X_S - X_A &= \tfrac{\eta(2D-t)(3-8\eta)}{b(9-4\eta(7-4\eta))(9-8\eta)} > 0 \\ X_A - X_B &= \tfrac{\eta(2D-t)(7-16\eta)}{3b(9-4\eta(7-4\eta))} > 0. \end{aligned} \tag{26}$$

Trade volumes are higher when firms have symmetric commitment power in R&D. In turn, trade volumes are lower when firms do not invest in R&D. In the middle of the ranking is the scenario where firms have asymmetric commitment power in R&D. The reason for $X_S > X_A$ is that, as we have seen above, in the asymmetric commitment power in R&D game, the R&D follower has poorer market access than firms in the symmetric commitment

[8] There are two explanations in the literature of why exporting firms are more productive than domestic firms: positive self-selection into the export markets (as in Melitz, 2003); and learning-by-export (see Clerides et. al., 1998).

power in R&D game (equation 19). In this sense, trade is more encouraged when firms are symmetric in competitiveness (the symmetric commitment power in R&D game) than when firms are asymmetric in competitiveness (the asymmetric commitment power in R&D game). At any rate, the possibility to invest in R&D increases trade volumes relatively to the case where R&D investment is not possible.

The role of R&D can be even more far-reaching than just increasing international trade relatively to the no-R&D-scenario. In fact, the relationship between the volume of trade and the return on R&D (η) is:

$$\begin{gathered}\frac{dX_S}{d\eta} = \frac{24(2D-t)}{b(81-16\eta(9-4\eta))} > 0 \\ \frac{dX_A}{d\eta} = \frac{(2D-t)(21-16\eta(6-7\eta))}{b(81-8\eta(63-2\eta(67-8\eta(7-2\eta))))} > 0.\end{gathered} \tag{27}$$

When R&D is more efficient (i.e.: higher η), like low trade costs, R&D increases the volume of trade for both the symmetric commitment power in R&D game and the asymmetric commitment power in R&D game. In effect, it is no surprise that under the symmetric commitment power in R&D game the volume of trade increases with the return on R&D, since both x_S and x_S^* also increase with η (equation 22). In the asymmetric commitment power in R&D game, however, this result is noteworthy, since x_A^* decreases with the return on R&D when η is high (equation 23). This means that the increase in exports for the R&D leader compensates for the reduction in exports that might occur for the R&D follower.

In this way, R&D competition can help to explain two stylized facts about international trade patterns: the increase in the world trade in the last century (Baier and Bergstrand, 2001); and asymmetries in the export behavior of firms, i.e.: more competitive firms export more (Bernard et al., 2003). First, the increase in the world trade might have been the result not only of a secular reduction in trade costs, but also of technological competition (R&D investment) and technological progress (high η). Accordingly, investment in R&D and higher efficiency of innovative activities facilitate access to international markets, because they make exports more profitable. Second, asymmetries in the export behavior of firms can be the outcome of strategic interactions in R&D. In fact, we have seen that the technological leader can use R&D strategically with the objective to deter the technological laggard from the export markets.

9 Robustness of Results

In this section, we comment on the robustness of the results of our model. In particular, we discuss the following generalizations: oligopolistic competition and market entry; Bertrand competition; product R&D, R&D spillovers, learning-by-doing and patents; heterogeneous firms and the effects of R&D investment on the extensive and the intensive margin; international mergers; public policy (R&D and export subsidies) and mixed duopoly markets. These generalizations are particularly important for the two R&D games in the paper (symmetric and asymmetric commitment power in R&D games), and we therefore focus the discussion on these two games.

With oligopolistic competition and symmetric commitment power in R&D all firms would invest strategically in R&D. As argued by Fudenberg and Tirole (1984), as the number of firms increases in the market, strategic investment becomes less effective, since strategic investment by one firm tends to be canceled by the rivals' strategic investment. This means that the second and third terms in equation 6 would tend to vanish, i.e.: firms would tend to invest at the social optimum without waste of resources in over-investment. In any case, even in the extreme case where strategic investment is canceled, R&D investment would continue to allow firms to reduce marginal costs. Therefore we should continue to expect higher trade volumes when firms invest in R&D than when firms do not do so. If firms differ in commitment power in R&D, and if there are many firms with commitment power in R&D, the same canceling effect on strategic investment that we have just discussed would arise. If however, there are few firms with commitment power in R&D, these firms would be able to play strategically against the firms with no commitment power in R&D and restrict their output levels. In this way, with oligopoly (with strategic or no strategic investment in R&D), our results with a duopoly market structure would not be much changed.

Free entry and exit would lead us to analyze the short and the long run equilibrium. In the long run, the strategic motive for R&D would be canceled, since profits would tend to zero, which would require that the strategic terms in equation 6 are also zero (Neary, 2010). However, in the short run the same effects as in the duopoly case would be at play. At any rate, in the short or in the long run, R&D would continue to reduce marginal costs. Therefore, again, there is no reason to believe that free entry and exit would alter the result that R&D increases trade flows relatively to scenarios with no R&D.

If we take into account price competition, the outcome would depend on whether we introduce differentiated products or not. As shown by Fudenberg and Tirole (1984) when firms invest in R&D, products are homogeneous and firms compete *à la* Bertrand, firms under-invest in R&D in order to soften price competition, i.e.: the second and third terms in equation 6 are negative. In this sense, with Bertrand competition and homogeneous goods we should expect that the magnification effect of trade via R&D is smaller with Bertrand competition than with Cournot competition. Note, however, that in spite of this, trade would still be higher than in a scenario with no R&D, since R&D would continue to reduce marginal costs. If instead of homogeneous products we have differentiated products, however, the result that firms over-invest in R&D is restored, and therefore the main conclusions from our duopoly-Cournot model would continue to hold.

Product R&D, R&D spillovers, learning-by-doing and patents on international trade are explored by Grossman and Helpman (1991) in the context of monopolistic competition models with CES demand (see also Tingvall and Poldahl, 2011; Espínola-Arredondo and Muñoz-García, 2011 and Llorca Vivero, 2001). They show that product R&D increases international trade since consumers across countries like variety, and therefore wish to consume products invented in other countries. R&D spillovers and learning-by-doing can augment these effects since they allow producers in different countries, especially in more poor countries, to enter the innovation race. Patents have the traditional two-side influence on innovation. On the one hand, patents guarantee future profits and therefore promote innovation, since they protect firms from imitation by rivals. On the other hand, patents limit the R&D spillovers to other firms. Note that with oligopolistic competition, as monopolistic competition models have no strategic interaction between firms, besides the effects above, we could expect some additional outcomes. For example, patents could lead to first-mover advantages of the type we explore in this paper. Also, R&D spillovers could drive firms to under-invest in R&D to limit R&D competition, similarly to what happens with Bertrand competition with homogeneous goods.

The introduction of heterogeneous firms of the Melitz (2003) type would lead us to consider the influence of R&D investment on the extensive and the intensive margin. With heterogeneous firms only the more efficient firms would be able to access the exports markets. This effect is present in the asymmetric commitment power in R&D game, where the R&D follower can be excluded from international trade by the R&D leader due to higher cost competitiveness of the later. In this way, our model also considers the effects of R&D on the intensive margin, given that the more efficient firms (the R&D leader) export more than the less efficient firms (the R&D follower), which might not export at all. However, in our set-up with just two firms and no entry and exit, we cannot look at the effects of R&D investment on the extensive margin, i.e.: how R&D affects entry and exit of firms. With more than two firms, entry-exit and heterogeneous firms, R&D could make the more competitive domestic firms start to export and the less competitive domestic firms exit the market.

The effects of international mergers would again depend on whether firms have symmetric or asymmetric commitment power in R&D. If firms have symmetric commitment power in R&D, a merger would conduce to the well-known merger paradox. The merging firms would be worse off while the non-merging firms would be better off, since the latter would have fewer competitors (Salant et al., 1983), i.e.: decreasing the number of firms would raise industry profits and per firm profit, but the merger firms would obtain a relatively smaller share of the industry profits. If firms have asymmetric commitment power in R&D, though, the merger paradox might not hold. This is so, since when an R&D leader merges with a rival, by reducing the number of competitors, the merger would increase the first-mover advantage in R&D of the merging entity. Therefore, the profits of the merging firms could increase relatively to the non-merging firms.

R&D and export subsidies in set-ups where firms have symmetric commitment power have been explored in the strategic trade literature (Leahy and Neary, 1997). However, to our knowledge, this has not been the case when firms have asymmetric commitment power in R&D. With symmetric commitment power in R&D, a government has incentives to subsidize local firms in order to promote them to export more than foreign rivals. However, if all governments subsidize local firms, no country gains a trade advantage. If firms differ in commitment power, the country where the R&D leader is located will not have incentives to subsidize the local firm, since the role of a subsidy is to make the local firm play Stackelberg against foreign rivals, and the R&D leader already has this advantage. The opposite would be the case for the R&D follower. The country that hosts the R&D follower could try to introduce a subsidy to cancel the first-mover advantage of the R&D leader in favor of the domestic R&D follower.

In a scenario where private firms compete with public firms (mixed duopoly), the first question to ask is whether we should model the public firms with or without commitment power in R&D. In the literature on mixed oligopolies it is usually assumed that public firms operate to maximize welfare (Matsumura, 1998). In the context of our model this would mean that the public firms would not invest strategically in R&D. Therefore, we would have private firms investing strategically in R&D against public firms investing non-strategically. Contrary to the mixed oligopoly literature, however, the presence of the public firms would not conduce to "regulation by participation" for the private firms, since the former would not be able to compel the latter to not invest strategically in R&D. In this sense, in a mixed duopoly, we should expect that the results from the asymmetric commitment power in R&D game are replicated.

10 Discussion

In this paper, we have analyzed how firms' access to international markets is affected by R&D competition. In order to study this issue, we have compared three games that differ in terms of R&D competition. In the first game, firms do not invest in R&D; in the second, firms invest in R&D with symmetric commitment power in R&D; and in the third, firms invest in R&D with asymmetric commitment power in R&D. From the comparison of these three scenarios, we found that, irrespective of commitment power in R&D, trade volumes are always higher when firms invest in R&D than when they do not. However, trade volumes are higher when firms have symmetric rather than asymmetric commitment power in R&D. Furthermore, technological progress (i.e.: higher efficiency of R&D) increases the volume of trade, similarly to what occurs with low transport costs in standard trade models.

We have also shown that asymmetries in commitment power in R&D can be used to endogenize competitiveness asymmetries between firms. In particular, we have showed that the R&D leader becomes endogenously more competitive than the R&D follower, since it invests more in R&D, and therefore achieves lower marginal costs than the latter. As a consequence, the R&D leader also has better access to export markets than the R&D follower. Furthermore, the only firm that might not benefit from technological progress is the R&D follower. The reason for this is that technological progress makes competition against the R&D follower much fiercer, since it makes it easier for the R&D leader to exercise the first-mover advantage.

In this way, this paper contributes to the literature on R&D and trade, which can be divided into three strands: the strategic trade literature (Leahy and Neary, 1997); the trade-growth literature (Grossman and Helpman, 1991); and the heterogeneous firms literature (Atkeson and Burstein, 2010). Relatively to the strategic trade literature, we have changed the focus from R&D subsidies to R&D competition. Furthermore, we have added the asymmetric commitment power game in R&D, with an R&D leader and an R&D follower. To our knowledge, this scenario has not previously been analyzed in this literature. In what concerns the trade-growth literature, we do not consider economic growth or product R&D, and focus instead on process R&D. Also in our model, R&D is performed by the firms themselves and not by an outside perfect competitive sector. Compared to the heterogeneous firms literature, asymmetries between firms are generated endogenously as a result of firms' strategic choices in R&D, and not exogenously as a result of an *ad-hoc* statistical distribution of productivity. In addition, we consider strategic interactions between firms, which are overlooked in the trade-growth and heterogeneous firms literature. We then present an alternative channel to explain how R&D can promote trade and why firms are asymmetric in competitiveness and in the level of access to international markets: strategic competition in R&D.

Future research should try to test empirically some of the predictions of our model. First, it should analyze whether the observed increase in R&D expenditures in the world economy over the last century has contributed to the increase in trade flows, and whether this R&D-trade effect continued after the flattening out of trade costs. This exercise requires time series on trade flows, trade costs and R&D investment across countries and industries. Second, it should test whether countries and industries that invest more on R&D, trade more with each other than countries and industries that invest less on R&D, since we should expect that the former are more competitive in international markets than the latter. For this analysis it is necessary to look at a cross-section of data on R&D expenditures and trade flows across countries and industries. Third, it should study R&D leaders and their behavior in international markets relatively to R&D followers. Investigating this requires firm level data in order to identify R&D leaders and R&D followers and how they differ in terms of export performance. By answering these questions, we will gain a better understanding of the interconnections between trade and R&D competition.

A Appendix

Second order condition for R&D In the symmetric commitment power in R&D game, the home firm and the foreign firm have the same SOC for R&D, in particular: $\frac{d^2\Pi_S}{d(k_S)^2} = \frac{d^2\Pi_S^*}{d\left(k_S^*\right)^2} = -\frac{\gamma(9-16\eta)}{9} < 0$. Then, the SOC for R&D under the symmetric commitment power in R&D game only holds if $0 < \eta < \frac{9}{16}$. In turn, in the asymmetric commitment power in R&D game, the home firm and the foreign firm have different SOCs for R&D. The SOC for R&D for the home firm is $\frac{d^2\Pi_A}{d(k_A)^2} = -\frac{\gamma(9-16\eta)}{9} < 0$, while for the foreign firm is $\frac{d^2\Pi_A^*}{d\left(k_A^*\right)^2} = -\frac{\gamma(3-4\eta)}{3} < 0$. As such, in the asymmetric commitment power in R&D game, the two SOCs for R&D are only satisfied if $0 < \eta < \frac{9}{16}$. Then the symmetric and the asymmetric commitment power in R&D games have the same SOC for R&D.

Trade conditions Standard trade models usually make two restrictions on the trade conditions (equations 13 to 15 in our model). First, that the trade conditions are positive (given that $t > 0$) and second that the level of t satisfies the trade conditions (i.e.: that trade is possible).

We start with the restriction that $\hat{t}_B$, $\hat{t}_S$, $\hat{t}_A$ and $\hat{t}_A^*$ are positive. Since $D > 0$, $\hat{t}_B$ is always positive. However, the same might not be the case for $\hat{t}_S$, $\hat{t}_A$ and $\hat{t}_A^*$. From the SOC for R&D ($0 < \eta < \frac{9}{16}$) and equations 13 and 15; $\hat{t}_S$, $\hat{t}_A$ and $\hat{t}_A^*$ are always positive if equation 17 in the main text holds.

We turn now to the restriction that trade costs do not forbid trade. Autarchy scenarios can be easily eliminated from the symmetric games (benchmark no R&D game and symmetric commitment power in R&D game). In fact, as long as $t < \frac{D}{2}$, two-way trade is always possible in these two games. In the asymmetric commitment power in R&D game, however, matters are not so straightforward. In fact, with $t < \frac{D}{2}$, we can only guarantee that the home firm is always going to be able to export, i.e.: the same might not occur for the foreign firm, since as $\eta \rightarrow \frac{3}{8}$, $\hat{t}_A^* \rightarrow 0$. Then, in the asymmetric commitment power in R&D game with $t < \frac{D}{2}$, we can assure that one-way trade always arises (from home to foreign), but not necessarily two-way trade.

The strategy we follow is to restrict the parameter space to always encompass at least one-way trade. This is so as long as equation 16 in the main text is satisfied.

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In this paper, we explore another factor besides trade costs that can affect firms' exports: strategic interaction between firms in R&D investment. Three results can be highlighted. First, the volume of trade is higher in the presence of R&D than in the absence of it, given that R&D reduces marginal costs. Second, like with reductions in trade costs, international trade grows with increases in the return on R&D, since technological progress enhances firms' competitiveness. Third, when firms differ in commitment power in R&D, the R&D leader plays strategically in R&D in order to become more competitive and to be more active in international markets than the R&D follower.

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SAMFUNNS- OG NÆRINGSLIVSFORSKNING AS

Institute for Research in Economics and Business Administration

Helleveien 30
N-5045 Bergen
Norway
Phone: (+47) 55 95 95 00
E-mail: snf@snf.no
Internet: http://www.snf.no/

Trykk: Allkopi Bergen