

# Strategic R&D Commitment and the Gains from Trade

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**Abstract:** This paper examines how trade liberalisation affects innovation, profits and welfare in a reciprocal markets model when firms pre-commit to R&D investment. First, we show that, for a range of trade costs, there are multiple equilibria, implying that the path of trade liberalisation is not unique. Second, welfare at “incipient” trade always exceeds welfare in autarky. Third, we show that, if the effectiveness of R&D is sufficiently high, trade *always* yields higher welfare than autarky. These new results suggests that when firms, operating in an oligopolistic environment, strategically pre-commit to R&D, the welfare gains from trade liberalisation are enhanced.

**JEL Codes:** F12, F13, F15, L13.

**Key words:** Reciprocal Markets, Strategic R&D Investment, Trade Costs, Trade Liberalisation, Effectiveness of R&D.

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## 1. Introduction

In this paper we examine how trade liberalisation affects welfare when firms invest in research and development (R&D). Central to our study is the behaviour of large and highly productive international firms. Firms that combine these characteristics have recently been described in the literature as “superstar firms” (Mayer and Ottaviano (2007); Neary (2010)). Recent empirical work suggests that it is the combination of exporting and investing in R&D that may explain the high productivity of these corporations.<sup>1</sup> There is an increased realisation, both in the academic community and among policy makers, that these corporate superstars, though only a small minority among all active firms, at the same time essentially drive the international performance of some countries.<sup>2</sup> In addition, the markets in which these large international R&D-intensive firms compete tend to be highly concentrated.<sup>3</sup> It is well documented that large firms behave differently compared to small firms. Large firms can use R&D –and indeed other investments– strategically in the battle with rivals, both to help them penetrate into foreign markets and defend their market share at home. Since models of perfect competition or monopolistic competition do not address strategic interaction between competitors, we model firms as setting their R&D in an oligopolistic environment.<sup>4</sup>

In oligopoly, R&D investment can be used by firms as a commitment device to ensure higher output and thus maintain and increase market share.<sup>5</sup> Process R&D improves a firm’s profitability in two ways: directly, through a reduction in production costs, and indirectly, through the effect on its rivals’ output. We show how this investment commitment has important implications for the effects of trade liberalisation on firm productivity and social welfare. We derive the comparative static effects of trade liberalisation on outputs, exports, R&D levels, profits and welfare. First, trade

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<sup>1</sup> See, for instance, Aw *et al.* (2008).

<sup>2</sup> The importance of large firms in international markets has also been discussed in the economic press (see, for instance, a relatively recent article in *The Economist* (“Big is Back” August 27, 2009).

<sup>3</sup> It is a stylised fact that only a few firms are responsible for the bulk of R&D expenditures. According to a recent report by Booz and Company (2012), “*The Global Innovation 1000*”, the top 100 biggest R&D spenders worldwide accounted for 62% of total R&D spending. Computing and Electronics companies alone accounted for 28% of total R&D spending. Other big R&D spenders are the healthcare and automobile sectors. All these sectors are dominated by a few big players.

<sup>4</sup> Explicitly modelling large firms’ behaviour can give new or additional insights in several real-world phenomena observed in international markets. Neary (2010) gives a list of examples.

<sup>5</sup> See the seminal paper by Fudenberg and Tirole (1984).

liberalisation tends to intensify the competition that firms face in their domestic markets. The literature on the link between competition and innovation offers conflicting views. There is the view, pioneered by Arrow (1962), that product market competition spurs innovation. In contrast, the Schumpeterian tradition (Schumpeter (1934, 1942)) emphasises that high rents give incentives for innovation.<sup>6</sup> More recently, Aghion *et al.* (2005), who in a panel data study found an inverted U-shaped relationship between increased competition and innovation, were able to reconcile the two competing views.<sup>7</sup> Second, trade liberalisation tends to create new export opportunities. With expanding markets, firms' incentive to innovate typically gets stronger.

Whether the combination of these two effects of trade liberalisation on innovation is positive or negative is *a priori* unclear. Some empirical studies suggest that the typical firm improves its productivity performance in response to lower trade costs (see, for instance, Krishna and Mitra (1998), Pavcnik (2002), Amiti and Konings (2007) and Fernandes (2007)). In a country-specific study, looking at the Colombian experience with trade liberalisation, Ederington and McCalman (2007) found that more liberal trade tended to raise productivity of the typical firm in industries with low barriers to entry, small technology gaps, large markets and large initial levels of protection. Bustos (2010) established that trade liberalisation raises the incentive of exporters to adopt a more advanced technology. By contrast, Trefler (2004) finds that a reduction in domestic tariffs has no significant impact on firm productivity.

Our model builds on the reciprocal markets (RM) model of trade liberalisation first developed by Brander (1981) and Brander and Krugman (1983). The original RM model

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<sup>6</sup> Other theoretical work has since appeared on the topic. Dasgupta and Stiglitz (1980), who showed that competition can lead to redundant R&D investment, was one of the seminal papers. Vives (2008) considers the link between competitive pressure and innovation and finds that more firms reduces the R&D spending per firm and an increase in the market size increases it. In our model moving from autarky to trade increases the number of competing firms and increases the market size available to them. Vives also finds that increasing the degree of product substitutability, increases cost reducing investment. Schmutzler (2013) builds on Vives (2008) and others to look at asymmetric firms. Gilbert (2006) provides a useful survey of the recent state of the competition and innovation debate.

<sup>7</sup> Typically adopting a partial equilibrium perspective, the industrial organisation literature has been particularly fascinated with the relationship between innovation and competition. However, other fields, such as the growth theory literature, have also contributed enormously to the study of this issue. This strand of the literature, using a general equilibrium perspective, has since Römer's work (1986, 1990) paid special attention to the process of knowledge capital accumulation.

was set up to consider multilateral trade liberalisation between two identical countries, with firms competing in a Cournot manner.<sup>8</sup> The pioneers of the RM model demonstrated that intra-industry trade can occur in equilibrium –even when goods are identical– and that welfare is U-shaped in trade costs: starting at prohibitively high trade costs, a small fall in trade costs first reduces welfare but, as trade costs fall further, welfare starts to increase.<sup>9</sup> Importantly, there is no investment in their model.

In a recent paper, Van Long *et al.* (2011) incorporate R&D investment in a RM model with trade liberalisation and combine it with an extension of the Melitz model with firm heterogeneity (Melitz (2003)). Since they focus on the firm selection effect of trade liberalisation on R&D, they justifiably assume that output decisions are made under asymmetric information and a firm's R&D investment has no effect on the output choice of rival firms. This assumption is equivalent to assuming that outputs and R&D are determined simultaneously by each firm.

Since we are interested in the effects of R&D decisions of large firms that behave strategically, we assume instead that R&D decisions are effectively made *prior to* output decisions and hence will affect rival firms' outputs. More specifically, we examine how firms may use innovation as a commitment device to adopt an aggressive stance both in the domestic and the export market. In modelling R&D investment, we follow the standard approach in models of strategic investment commitment, pioneered by d'Aspremont and Jacquemin (1988) (but, unlike the latter, we do so in an open-economy RM set-up). We show that whether or not firms pre-commit to R&D –i.e., prior to the outputs being set with the purpose of keeping the rival's output down– matters significantly for the welfare effects of trade liberalisation. Note that this aspect of investment choice is absent in Van Long *et al.* (2011); including strategic commitment to R&D in their model would make it intractable. Similarly, to ensure tractability of our model, we abstract from the firm selection effect of trade liberalisation on R&D, which they focus on. For these reasons, the results in our paper differ from theirs. Since the

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<sup>8</sup> For a recent survey on the literature on reciprocal markets models, see Leahy and Neary (2011).

<sup>9</sup> Clarke and Collie (2003) examine the welfare effects of free trade in a RM model under Bertrand duopoly with differentiated products and show that, in that set-up, there are always gains from trade.

topic of our paper is similar, but the set-up and hence the results are different, we argue that our paper is complementary to theirs.

Clearly, if trade costs are sufficiently high, then –just as in the RM model without investment– no trade can occur and the firms are monopolists in their domestic markets. We find that multilateral trade liberalisation increases R&D-spending and firm productivity for all trade costs at which trade actually occurs and always benefits consumers. We find that, as trade costs are lowered from the prohibitive level, we initially pass through a region of trade costs in which there are two stable equilibria. At one of these, there is intra-industry trade and at the other, there is no trade. Further liberalisation leads to a disappearance of the no-trade equilibrium. When trade occurs, profits are U-shaped in trade costs but always remain below the autarky profit level. Our welfare results differ from those in the standard RM model in the sense that it is not necessarily true that limited trade liberalisation lowers welfare below the autarky welfare level. In fact, we show that, if R&D is sufficiently effective in lowering production costs, trade *always* yields higher welfare than autarky. The reason for this lies in the fact that firms choose investment prior to outputs with the intention to strategically *manipulate* their rivals' behaviour. We show that, although this strategic behaviour is mutually harmful to firms –in a symmetric set-up, the R&D game is a prisoner's dilemma–, it encourages innovation, benefits consumers and is welfare improving in an overall sense. So, while governments have an incentive to open up sectors in which firms are investing intensively in R&D to foreign competition, they can at the same time expect a resistance to such liberalisation by those innovating firms.

In Section 2, we develop a RM model with R&D investment. In Section 3, we derive firms' innovation reaction functions. In section 4, we determine the equilibria of the game for different levels of trade costs. We subsequently discuss the effects of multilateral trade liberalisation on R&D, consumer surplus, profits and overall welfare in section 5. Section 6 examines the effect of market size, firm efficiency and policy asymmetries on the model's results. Section 7 concludes.

## **2. The model**

Consider two countries, “Home” and “Foreign”, and two firms, 1 and 2. Firm 1 produces and invests in Home, and is fully owned by Home residents while firm 2 produces and invests in Foreign and is Foreign owned. Firms produce homogeneous goods<sup>10</sup> and are identical in all other respects. When firms compete in the same market, they do so as Cournot competitors. The Home and the Foreign market are segmented.<sup>11</sup> Demand in Home and Foreign is given by:

$$p = a - Q \tag{1a}$$

and

$$p^* = a - Q^*, \tag{1b}$$

respectively, with  $Q = q_1 + q_2$  and  $Q^* = q_1^* + q_2^*$ ;  $q_i$  refers to output by firm  $i$  ( $i = 1, 2$ ) intended for sale in Home and  $q_i^*$  refers to output intended for Foreign. Note that variables referring to the Foreign market are starred. If firms want to sell in their rival’s domestic market, they export and face per unit trade costs,  $t$ . We follow the original RM model and assume that  $t$  is not a tariff. Instead, one can interpret the trade cost as a non-tariff barrier or a transport cost.<sup>12</sup>

Each firm undertakes process R&D; hence, a firm’s R&D affects its marginal production costs. Let  $c_i = \bar{c} - x_i$ , where  $x_i$  represents the reduction in marginal production cost generated by the R&D firm  $i$  has undertaken. Henceforth, we will refer to  $x_i$  as the level of innovation by firm  $i$ . R&D expenditure is represented by  $k_i$ , which is defined as  $k_i \equiv x_i^2 / 2\eta$ ;  $\eta$  is the effectiveness of R&D. Note that R&D expenditure,  $k_i$ , is convex in  $x_i$ , implying that R&D expenditure reduces marginal production cost at a diminishing rate (since  $dc_i / dk = -\sqrt{\eta / 2k}$ , we have  $d^2c_i / dk^2 > 0$ ). This plausible assumption is imposed to ensure an interior solution. Profits of firm 1 and firm 2 are then given by:

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<sup>10</sup> The extension to differentiated products is straightforward but adds nothing to the analysis other than extra notation.

<sup>11</sup> This is a key assumption in RM type models and implies no resale between markets so that, in principle, market prices could differ internationally.

<sup>12</sup> Naturally, this has welfare implications as there will not be any tariff revenues to be returned to consumers. Including tariff revenues would actually strengthen the gains from trade liberalisation.

$$\pi_1 = (p - c_1)q_1 + (p^* - c_1 - t)q_1^* - k_1 \quad (2a)$$

and

$$\pi_2 = (p^* - c_2)q_2^* + (p - c_2 - t)q_2 - k_2 \quad (2b),$$

respectively.

A country's welfare is the sum of its consumer surplus ( $CS$ ) and the profit of its own firm (for simplicity, we assume firms are entirely owned by domestic residents). For the Home country, welfare is given by:

$$W = CS + \pi_1 \quad (3)$$

where  $CS = Q^2 / 2$ .

Note that we assume that firms are *ex ante* symmetric and markets are equal in size. These assumptions are relaxed in section 6.

### 3. The game

Firms play a two-stage game, in which they simultaneously choose innovation levels,  $x_i$  ( $i=1,2$ ), in the first stage and subsequently choose outputs for each market in the second stage. Hence, output levels will depend on innovation levels. Since we must solve the game by backward induction, we begin by considering the output-setting stage before considering optimal choice of R&D.

#### 3.1. Stage 2: Outputs

At the output stage, firms take R&D-levels as given. When both firms are active in both markets, respective Cournot-Nash outputs for firm 1 and firm 2 for the "Home" country market are:

$$q_1^C = (A + t + 2x_1 - x_2) / 3 \quad (4a)$$

and

$$q_2^C = (A - 2t + 2x_2 - x_1) / 3, \quad (4b)$$

while they produce:

$$q_1^{*C} = (A - 2t + 2x_1 - x_2) / 3 \quad (5a)$$

and

$$q_2^{*C} = (A + t + 2x_2 - x_1) / 3 \quad (5b)$$

for the “Foreign” market. For convenience we have defined  $A \equiv a - \bar{c}$ ; superscript  $C$  refers to Cournot-Nash outputs. For  $t > 0$ , it is clear from expressions (4a)-(5b) that each firm has a larger market share in its domestic market than in the export market. Also, exports are decreasing in trade costs.

It is obvious that, at sufficiently high trade cost, firms do not trade and autarky prevails ( $q_2 = q_1^* = 0$ ). Each firm is then a monopolist in its domestic market, with Home monopoly output given by:

$$q_1^M = (A + x_1) / 2, \quad (6)$$

with superscript  $M$  indicating monopoly.

Note that expressions (4a)-(5b) indicate that, given sufficiently low  $x_i$ , sufficiently high  $x_j$  ( $j \neq i$ ) and high enough trade cost, it is possible that even when output for the domestic market is positive, firm  $i$  is not able to export. Hence, we distinguish between four possible export status combinations: two-way trade, (E,E), one way-trade with firm 1 exporting while firm 2 does not, (E,0), one-way trade with firm 2 exporting while firm 1 does not, (0,E), and autarky, (0,0).

### 3.2. Stage 1: Innovation

In this subsection –as a first step to considering the different possible equilibria in section 4– we derive a firm’s innovation best response function under the different regimes, (0,0), (E,E), (0,E) and (E,0). For expositional purposes and without loss of generality, we will adopt the perspective of firm 1. The best response function for firm 2 is derived analogously.

#### 3.2.1. Autarky

In autarky, profit maximisation implies  $d\pi_1 / dx_1 = -q_1(dc_1 / dx_1) - dk_1 / dx_1 = 0$ . In this case investment is simply chosen to minimise total costs given output. We can rewrite this as  $d\pi_1 / dx_1 = q_1 - x_1 / \eta = 0$ , which yields:

$$x_1 = \eta q_1 \quad (7)$$



The marginal production cost reduction chosen by firm 1 in autarky is therefore given by:

$$x_1^{00} = \frac{\eta}{2 - \eta} A, \quad (8)$$

where we use superscript 00 to indicate that neither firm exports (autarky). Clearly,  $x_1^{00}$  is independent of  $x_2$ .

### 3.2.2. Two-way trade

At this point, a note on terminology is in order. When firms meet in one or more markets, investment also serves as a commitment device to be more aggressive in the output setting stage and thus to reduce rival output. In those circumstances quantity-competing firms choose investment above the cost minimising level. Following Fudenberg and Tirole (1984) and Tirole (1988), we refer to choosing investment above the cost-minimising level to influence the rival's output choice as choosing investment "strategically".

Bearing all this in mind, let us consider firm 1's  $x_1$  best-response function when there is two-way trade, that is, when both firms export to each other's domestic market. Firm 1's first-order condition for innovation is now given by:

$$\frac{d\pi_1}{dx_1} = \frac{\partial\pi_1}{\partial x_1} + \frac{\partial\pi_1}{\partial q_2} \frac{\partial q_2^C}{\partial x_1} + \frac{\partial\pi_1}{\partial q_2^*} \frac{\partial q_2^{*C}}{\partial x_1} = 0 \quad (9)$$

with  $\partial\pi_1/\partial x_1 = q_1 + q_1^* - x_1/\eta$ ,  $\partial\pi_1/\partial q_2 = -q_1$ ,  $\partial\pi_1/\partial q_2^* = -q_1^*$  and  $dq_2^C/dx_1 = dq_2^{*C}/dx_1 = -1/3$  from expressions (4b) and (5b); note that  $\partial\pi_1/\partial q_1 = \partial\pi_1/\partial q_1^* = 0$  from the final stage. The second and third terms on the right-hand side of expression (9) are both positive and capture the effect of strategic investment commitment in the Home and Foreign markets, respectively. Since these two terms – which were not present in the autarky case – are positive, the first term on the right-hand side has to be negative. This in turn implies that investment is chosen above the cost-minimising level. Expression (9) can be rewritten as  $(4/3)(q_1 + q_1^*) - x_1/\eta = 0$ , implying:

$$x_1 = (4/3)\eta(q_1 + q_1^*) \quad (10)$$

It is instructive to compare expressions (7) and (10). When firms are engaged in trade, they have access to a wider market (producing  $q_1 + q_1^*$  for the domestic and the export market, instead of just  $q_1$  for the domestic market) and hence invest more in innovation. Crucially, when firms engage in two-way trade, innovation also affects their profits indirectly, i.e., firms will choose their investment trying to manipulate rival output. As a result, trading firms do not only invest more in R&D, they also choose more R&D investment *per unit of output* (in autarky, the investment-to-output ratio is  $\eta$ , while here it is  $(4/3)\eta$ ). We refer to the increase in the investment-to-output ratio, resulting from the strategic investment commitment, as an increase in “the aggressiveness of investment”.

Substituting for optimally chosen output levels in expression (10), Firm 1’s best response function, denoted by  $R_1^{EE}(x_2)$ , is:<sup>13</sup>

$$R_1^{EE}(x_2) = \frac{(4/9)(2A-t) - (8/9)x_2}{1 - (16/9)\eta} \eta \quad (11)$$

### 3.2.3. One-way trade

We now turn to firm 1’s innovation best-response function when there is only one-way trade. We first derive its best response function when it does not export ( $q_1^* = 0$ ) and faces competition in its domestic market from firm 2 ( $q_1$  and  $q_2$  are given by expressions (4a) and (4b), respectively). The first-order condition for  $x_1$  is then:

$$\frac{d\pi_1}{dx_1} = \frac{\partial\pi_1}{\partial x_1} + \frac{\partial\pi_1}{\partial q_2} \frac{\partial q_2^C}{\partial x_1} = 0 \quad (12)$$

with  $\partial\pi_1/\partial x_1 = q_1 - x_1/\eta$ ,  $\partial\pi_1/\partial q_2 = -q_1$ , and  $\partial q_2^C/\partial x_1 = -1/3$ . The second term on the right-hand side of expression (12) is positive and captures the effect of strategic investment commitment in the home market where the firm faces competition from the rival firm. Again, strategic commitment implies that investment is chosen above the cost-minimising level. Firm 1’s best response function is now denoted by  $R_1^{0E}(x_2)$ ,

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<sup>13</sup> To ensure stability in all cases we restrict  $\eta$  to be less than 0.375.

where, here and henceforth, the first superscript refers to firm 1's exporting status, while the second refers to firm 2's (thus, the superscript 0E indicates that firm 1 is not exporting while firm 2 is exporting). It is given by:

$$R_1^{0E}(x_2) = \frac{(4/9)[(A+t) - x_2]}{1 - (8/9)\eta} \eta \quad (13)$$

Next, we derive firm 1's innovation best response function when firm 1 exports to and competes in Foreign with firm 2, but does not face any competition from firm 2 in its domestic market ( $q_2 = 0$ ,  $q_1^{*C}$  and  $q_2^{*C}$  are given by expressions (5a) and (5b), respectively, while  $q_1^M$  is given by (6)). The first-order condition for  $x_1$  is then:

$$\frac{d\pi_1}{dx_1} = \frac{\partial\pi_1}{\partial x_1} + \frac{\partial\pi_1}{\partial q_2^*} \frac{\partial q_2^{*C}}{\partial x_1} = 0 \quad (14)$$

with  $\partial\pi_1/\partial x_1 = q_1 + q_1^* - x_1/\eta$ ,  $\partial\pi_1/\partial q_2^* = -q_1^*$ , and  $dq_2^{*C}/dx_1 = -1/3$ . Now, the best response for firm 1 is:

$$R_1^{E0}(x_2) = \frac{(17/18)A - (8/9)t - (4/9)x_2}{1 - (25/18)\eta} \eta \quad (15)$$

#### 4. Equilibrium outcomes

In this section we derive the equilibrium innovation and trading outcomes at different levels of trade costs. Before doing this we consider two symmetric candidate equilibria. Clearly, at high enough trade costs the countries do not trade. For low enough trade costs, given ex-ante symmetry between firms, symmetric two-way trade is a clear candidate for an equilibrium. We now fully characterise these two symmetric candidate equilibria, autarky and two-way trade, and subsequently determine the range of trade costs for which each of these is an equilibrium outcome.

When *autarky* prevails, firms' innovation levels are given by expression (8). Use of (8) in expression (6) gives the autarky output level:

$$q_1^{00} = A/(2 - \eta). \quad (16)$$

With *two-way trade*, the symmetric equilibrium investment level is obtained from (11) and the corresponding reaction function for firm 2, and is given by:

$$x_i^{EE} = \frac{(4/9)\eta(2A-t)}{1-(8/9)\eta} \quad i=1,2 \quad (17)$$

Use of this in the expression for outputs (expressions (4a)-(5b)) yields:

$$q_1^{EE} = q_2^{*EE} = \frac{A+t(1-(4/3)\eta)}{3-(8/3)\eta} \quad (18a)$$

and

$$q_2^{EE} = q_1^{*EE} = \frac{A-t(2-(4/3)\eta)}{3-(8/3)\eta}. \quad (18b)$$

From expression (18b), it is clear that (E,E) cannot be an equilibrium for  $t > \hat{t} = A/[2-(4/3)\eta]$ . However, as the next lemma shows, this does not imply that autarky, (0,0), cannot be an equilibrium *below*  $\hat{t}$ .

**Lemma:** *When firms commit to R&D levels prior to choosing outputs in a reciprocal-market setting, the critical trade cost level above which trade cannot occur in equilibrium,  $\hat{t}$ , differs from the critical trade cost level below which autarky cannot prevail,  $\tilde{t}$ , with  $\tilde{t} < \hat{t}$ .*

**Proof:** At firms' investment levels in autarky ( $x_1^{00} = x_2^{00} = x^{00}$ ), firms do not export provided  $t$  is sufficiently high. However, at  $t < \tilde{t}$  and  $x^{00}$ , two-way trade will occur, i.e.,  $q_2^C(x^{00}, t) = q_1^{*C}(x^{00}, t) > 0$ . At  $t = \tilde{t}$ , we have  $q_2^C(x^{00}, \tilde{t}) = q_1^{*C}(x^{00}, \tilde{t}) = 0$ . Using expressions (4b) (or (5a)) and (8), we obtain  $\tilde{t} = A/(2-\eta)$ .

At firms' equilibrium investment level with two-way trade ( $x_1^{EE}(t) = x_2^{EE}(t) = x^{EE}(t)$ ), exports are positive provided  $t$  is sufficiently small. At  $t = \hat{t}$ , two-way trade ceases, i.e.,  $q_2^C(x^{EE}(\hat{t}), \hat{t}) = q_1^{*C}(x^{EE}(\hat{t}), \hat{t}) = 0$ . Using (18b), we obtain  $\hat{t} = A/(2-(4/3)\eta)$ .

Comparing the expressions for  $\tilde{t}$  and  $\hat{t}$ ,  $\tilde{t} < \hat{t}$  follows immediately. ■

Using the lemma, we now determine the equilibrium outcomes for the entire range of  $t$ . We refer to trade costs in the interval  $[\tilde{t}, \hat{t}]$  as “high”, while trade costs above  $\hat{t}$  are “prohibitive”.

#### 4.1. Equilibrium outcomes for “high” trade costs

In this subsection we determine the equilibrium outcomes for  $t \in [\tilde{t}, \hat{t}]$ , that is, for the range of trade costs over which we cannot *a priori* exclude either trade or autarky. This particular region of trade costs is the most complex one in the sense that the reaction functions needed to determine the equilibria will cross all the different trading regimes. Thus, using each firm's innovation best response function for each trading regime, as derived in subsection 3.2, we now need to show how the various regime-specific segments of the innovation reaction function fit together.

We proceed as follows. We first demarcate the different trading regimes in  $(x_1, x_2)$ -space in figure 1a. Subsequently, we trace out the innovation reaction function for firm 1 as it passes through these different trading regimes. This is illustrated in figure 1b. Finally, we use the reaction functions of firm 1 and firm 2 to derive the equilibrium (see figure 2).

[Figure 1a and b about here]

To enable us to demarcate the different trading regimes, figure 1a depicts what we will refer to as the zero-export loci for firm 1 and firm 2, respectively labelled by  $q_1^* = 0$  and  $q_2 = 0$ . In fact, these represent the non-negative export constraint for each firm when they are binding. From expression (5a), it is clear that when the non-negative export constraint for firm 1 is binding, it implies:

$$A - 2t + 2x_1 - x_2 = 0 \tag{19a}$$

Similarly, when the non-negative export constraint for firm 2 is binding, it implies:

$$A - 2t + 2x_2 - x_1 = 0 \tag{19b}$$

from expression (4b). In figure 1a, to the left of the  $q_1^* = 0$ -locus, Home and Foreign R&D-level combinations are incompatible with Home exports and hence  $q_1^* = 0$ . Similarly, below the  $q_2 = 0$ -locus, Home and Foreign R&D-level combinations are incompatible with Foreign exports. So, the two zero-export loci divide the  $(x_1, x_2)$ -space up in four areas. Figure 1b depicts firm 1's full best response function (in bold) as it passes through the different areas.

In area 1, two-way trade, (E,E), prevails, hence  $R_1^{EE}(x_2)$  (expression (11)) is firm 1's best-response function in that area. More specifically, it applies for  $x_2 \in [\bar{x}_2, \bar{\bar{x}}_2]$  only. For  $x_2 > \bar{\bar{x}}_2$  in figure 1b (area 2 in figure 1a), firm 1's best response to  $x_2$  is  $R_1^{0E}(x_2)$  (expression (13)). Let us now turn to area 3 of Figure 1a, in which neither firm is exporting ( $q_1^* = q_2 = 0$ ), and hence each firm chooses its R&D as a monopolist firm in autarky; in other words, firm 1's optimal  $x_1$ -level is given by  $x_1^{00}$  (expression (8)). Firm 1 will choose the autarky  $x_1$ -level as its best response to  $x_2$  for  $x_2 \in [\underline{x}_2, \underline{\underline{x}}_2]$  in figure 1b. When  $x_2$  falls below  $\underline{\underline{x}}_2$ , firm 1 exports to Foreign, but firm 2 remains active only in its own domestic market (area 4 of figure 1a), hence firm 1's best response is given by  $R_1^{E0}(x_2)$  (expression (15)).

So far, we have not yet determined firm 1's best response for  $x_2$ -values ranging between  $\underline{x}_2$  and  $\bar{x}_2$ . In contrast to the pure autarky region, for this range of  $x_2$ , firm 1 does choose R&D "strategically" (i.e., above the cost minimising level, as explained in subsection 3.2.2.). However, because firm 2's non-negative export constraint binds, it places a limit on firm 1's strategic investment (since rival exports can, of course, never be induced to turn negative) and R&D is chosen to reduce firm 2's imports to exactly zero. We will refer to such a scenario as one of export "deterrence". Using (19a), the export deterring innovation reaction function of firm 1 can be written explicitly as:

$$R_1(x_2) \Big|_{q_2=0} = A - 2t + 2x_2 \quad (20)$$

Table 1 summarises the different sections of the best response function for firm 1. Figure 2 depicts both firms' innovation reaction functions, where firm 2's best response function, derived in an analogous way and completely symmetric, is depicted by the bold dashed kinked line.

*[Table 1 about here]*

There are three equilibria (see figure 2). The equilibrium at point O is stable and implies autarky; the autarky innovation level for each firm is given by expression (8). The

equilibrium at point E is also stable and involves two-way trade; the two-way trade equilibrium level of innovation for each firm is given by expression (17) above.

[Figure 2 about here]

The equilibrium at point U is unstable; at U, each firm produces for its domestic market only and chooses its R&D to keep its rival's exports equal to zero. Using equations (19a) and (19b) and denoting the implied innovation levels by  $x_1|_{q_2=0}$  and  $x_2|_{q_1^*=0}$ , we have:

$$x_1|_{q_2=0} = x_2|_{q_1^*=0} = 2t - A \quad (21)$$

(Note that these are positive when  $t \in [\tilde{t}, \hat{t}]$  since we then have  $t > A/2$ ). Following standard practice in the oligopoly games literature, we will restrict attention to the stable equilibria. However, we prefer not to select which of the stable equilibria is the most “reasonable” one since there is no consensus in the literature on how to do this.<sup>14</sup> In the next two subsections, we examine what happens at trade costs outside the  $[\tilde{t}, \hat{t}]$  interval.

#### **4.2. Equilibrium outcome for “prohibitive” trade costs**

When trade costs increase, area 3 in Figure 1a expands at the expense of area 1. In fact, for  $t > \hat{t}$ , the two-way trade equilibrium has now disappeared (as has the unstable equilibrium). This case is depicted in Figure 3a; the reaction functions intersect only once (at point O); now, autarky is the unique equilibrium.

[Figures 3a and b about here]

#### **4.3. Equilibrium outcome for “low” trade costs**

Suppose that trade costs decrease below  $\tilde{t}$ . As a result, for  $t < \tilde{t}$ , the zero-export locus  $q_1^* = 0$  in Figure 1 shifts to the left, while the other zero-export locus,  $q_2 = 0$ , shifts down. Hence, area 3 in Figure 1 contracts, whereas area 1 expands. Below  $\tilde{t}$ , the autarky equilibrium has vanished and, with it, the unstable equilibrium. Figure 3b shows

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<sup>14</sup> Although there is no consensus on what equilibrium selection criteria one should use, profits in autarky exceed profits under trade (as we will show in section 5.2). Hence, from the firms' perspective, autarky would Pareto-dominate free trade.

an example of what the innovation reaction functions look like in that case. They only intersect once (at point E); only the two-way trade equilibrium remains.

#### 4.4. Equilibrium outcomes at different trade costs

The following proposition summarises the equilibrium outcomes at different levels of trade costs.

**Proposition 1:** *When firms commit to R&D levels prior to choosing outputs in a reciprocal-market setting,*

- (i) *two-way trade is the unique equilibrium for  $t < \tilde{t}$  ;*
- (ii) *autarky is the unique equilibrium for  $t > \hat{t}$  ;*
- (iii) *there are three equilibria when the trade cost lies between  $\tilde{t}$  and  $\hat{t}$  ( $\tilde{t} \leq t \leq \hat{t}$ ): two-way trade, reciprocal export deterrence and autarky.*

**Proof:** (i) For  $t < \tilde{t}$ , autarky cannot prevail (see lemma). Even at the autarky investment level ( $x_1^{00} = x_2^{00} = x^{00}$ ), there would be trade ( $q_2^{EE}(x^{00}, t) = q_1^{*EE}(x^{00}, t) > 0$ ). With trade, optimal investment is given by expression (17) and equilibrium output levels by expressions (18a)-(18b).

(ii) For  $t > \hat{t}$ , there is no trade (see lemma), and each firm is a monopolist in its domestic market; hence, autarky prevails. The autarky investment level is given by expression (8) and output is by expression (16).

(iii) For  $t \in [\tilde{t}, \hat{t}]$ , given that firm  $j$  invests  $x_j^{00}$ , firm  $i$ 's best response is  $x_i^{00}$ . Hence, autarky is an equilibrium. However, given that firm  $j$  invests  $x_j^{EE}$ , firm  $i$ 's best response is  $x_i^{EE}$  and exports are positive at the symmetric investment level  $x^{EE}(t)$  with  $t < \hat{t}$ . Hence, two-way trade is an equilibrium too. In fact, a firm can choose an investment level to keep rival output in the former's domestic market down to zero. The rival's best response to this is to do the same. Hence,  $x_1|_{q_2=0} = x_2|_{q_1^*=0}$ , implying that each firm deters its rival from its domestic market is the third equilibrium. ■

#### 4.5. Equilibrium outcomes in the simultaneous-move benchmark

In our model firms commit to their R&D level in stage one and then choose outputs in the second stage. Hence, the R&D is chosen “strategically” to affect rival outputs. To see how important this feature of the model is for the welfare benefits of trade liberalisation, we will later compare our results with those obtained in the hypothetical alternative in which R&D and outputs are chosen simultaneously. In that hypothetical case, which we



will henceforth refer to as the simultaneous-move (“non-strategic”) benchmark, firms cannot use their investments to manipulate rivals strategically. Unlike in our model with R&D commitment –and even when trading–, firms now simply set investment levels to minimise costs. Instead of choosing investment according to (10), firms now choose investment according to:

$$x_1 = \eta(q_1 + q_1^*) \quad (22)$$

Compared to autarky (expression (7)), firms invest more (as they produce for the export market as well), but their innovation-to-output ratio ( $\eta$ ) is the same as in autarky; in short, investment is chosen less aggressively than when firms precommit to R&D investment. Substituting for outputs in (22), we obtain:

$$(x_1^{EE})^S = \frac{(1/3)\eta(2A-t)}{1-(2/3)\eta} \quad (23)$$

where S refer to the simultaneous-move benchmark case.

Also, in the hypothetical benchmark, it is straightforward to show that there is only one threshold,  $t' = A/(2-\eta)$ , above which autarky is the unique equilibrium and below which the trading equilibrium is unique (note that  $t' = \tilde{t}$ ). This means that, unlike in our full model with strategic commitment to investment, there is no region with multiple equilibria in the simultaneous-move benchmark.

## 5. Multilateral trade liberalisation

In this section, we investigate how innovation, profits, consumer surplus and welfare are affected as trade costs change and discuss to what extent the effect on these variables is different in the simultaneous-move benchmark. Starting at a prohibitive level, we lower the trade cost parameter  $t$ , until it is zero, thereby effectively capturing a process of multilateral trade liberalisation. As countries first liberalise trade and as  $t$  falls below  $\hat{t}$  but remains above  $\tilde{t}$ , they enter a region in which there are two stable equilibria (see Proposition 1): countries will *either* remain in autarky, *or* start to engage in two-way trade. Only when trade liberalisation is sufficiently drastic, i.e., implying a fall in trade costs such that  $t$  falls below  $\tilde{t}$ , will two-way trade be guaranteed. In short, the path of trade liberalisation is not unique. While a limited degree of trade liberalisation may

generate trade between the countries involved, it does not guarantee it. Instead, the integrating countries may be “trapped” in autarky until a more radical degree of trade liberalisation is attained.

As we have seen above, given our assumption that the countries are symmetric and the multilateral trade liberalisation takes a symmetric form, the equilibria themselves are always symmetric. We can therefore focus on the effects of trade liberalisation on Home as the effects on Foreign are identical.

### 5.1. Innovation

Figure 4a depicts the level of innovation, captured by the cost reduction,  $x_i$ , as a function of trade costs. In our model with strategic investment commitment, firms’ innovation levels when they are engaged in trade are –as discussed in section 3.2– different from those chosen when firms are in autarky. With trade, they can expect to sell more as they have access to a wider market, which tends to raise the return on investment. Furthermore, when firms compete on the same markets with each other, R&D is – as we have seen – chosen more aggressively than in autarky to affect rival outputs: firms choose more R&D investment *per unit of output* when they face a rival firm in head-to-head competition than they do in the absence of trade. In the figure, the solid curve,  $x_i^{EE}$ , represents innovation with two-way trade,  $x_i^{00}$  is innovation under autarky, and the dashed curve,  $x_i|_{q_2=0}$ , depicts innovation with mutual export deterrence.

[Figures 4a, b, c and d about here]

In section 4.5 we introduced the hypothetical simultaneous-move (“non-strategic”) benchmark case in which firms cannot precommit to investment before outputs are set. When engaged in trade, firms’ innovation levels in our model (see Figure 4a) are higher at each level of trade costs than the innovation levels in the hypothetical benchmark (depicted in Figure 4b). In both figures, the cost reduction is linear in the trade cost when the firm is trading, with lower  $t$  leading to more innovation. However, when firms strategically precommit to R&D, their R&D investment *per unit of output* is higher than

in the benchmark case. Notice that, for  $t \in [\tilde{t}, \hat{t}]$  in Figure 4a, there is, at given  $t$ , a gap between the innovation function  $x^{EE}(t)$  and  $x^{00}$ . By contrast, there is no gap between the innovation function  $(x^{EE}(t))^S$  and  $x^{00}$  (at given  $t$ ) in Figure 4b and no region with multiple equilibria.

### 5.2. Profits

Figure 4c represents how trade affects firms' profits when firms choose investment strategically. As depicted in the figure, there is a discrete fall in profits when firms start to trade. This is due to the fact that, compared to monopolist firms under autarky, trading firms choose their investment more aggressively. In fact, from the point of view of the firms, trade is a prisoner's dilemma outcome. In the simultaneous-move benchmark game, profits (not depicted) do not exhibit a discrete drop when firms start trading as in that case investment is not chosen more aggressively than in autarky.

Profits are, both in our model with strategic precommitment to R&D and in the benchmark, U-shaped in trade cost and higher in autarky than under completely free trade. In the neighbourhood of free trade, the trade cost works like a tax, reducing the firms' profits. However, when trade costs are nearly prohibitive, they, although reducing profits on export sales, serve to protect the now relatively much more important own market profits from import competition. Hence, in this region profits increase in trade costs.

### 5.3. Consumer surplus

To see how trade affects consumers when firms set R&D before outputs, we examine how trade costs affect consumer surplus (see Figure 4d). Consumption of the imperfectly competitive good increases for two reasons as trade is liberalised. Firstly, total output increases at given R&D levels due to the fall in the level of the trade costs. Secondly, the increase in R&D resulting from trade liberalisation leads to a further increase in output. The net result is that trade liberalisation reduces the price of imperfectly competitive good and raises consumer surplus. Note that the price is always lower and the consumers

are better off under trade, no matter how small the volume of trade, than they are under autarky.

Note that, at given  $t$ , trade will always result in lower prices and thus higher consumer surplus, when firms pre-commit to R&D than in the simultaneous-move benchmark.

#### 5.4. Welfare

We calculate welfare in the two stable equilibria, autarky and two-way trade. Using expressions (8) and (16) into the expression for welfare (3) yields the welfare level in autarky, which –with symmetry– is equal to:

$$W^{00} = \left( \frac{3-\eta}{2} \right) \left( \frac{A}{2-\eta} \right)^2 \quad (24)$$

We will use the welfare level in autarky as a reference point for calculating the welfare gains from trade liberalisation.

Under two-way trade, maximised Home profits can be written as

$$\pi_1^{EE} = (q_1^{EE})^2 + (q_1^{*EE})^2 - k_1^{EE} \text{ with } k_1^{EE} = \frac{(x_1^{EE})^2}{2\eta} \text{ and } x_1^{EE} = \frac{4}{3}\eta(q_1^{EE} + q_1^{*EE})$$

from the first-order condition for optimal R&D choice. We use (3) to write the expression for welfare under two-way trade as  $W_1^{EE} = W_2^{EE} = \left( \frac{1}{2} - \frac{8}{9}\eta \right) (Q^{EE})^2 + (q_1^{EE})^2 + (q_2^{EE})^2$ , where we have made use of symmetry between firms and markets to write the welfare function as a function of Home market outputs alone. Substituting for the expressions for outputs yields:

$$W^{EE}(t) = \frac{1}{9-8\eta} \left\{ 4A(A-t) + \frac{1}{2}(11-8\eta)t^2 \right\} \quad (25)$$

Figures 5a and b represent how trade costs affects welfare when firms pre-commit to investment before setting output levels. We see that welfare is higher under free trade ( $t = 0$ ) than autarky. Welfare as a function of trade costs inherits the property of being U-shaped from the profit function and it reaches a minimum at a level of trade costs that we refer to as  $\tilde{t}$ .

**Proposition 2:** *When firms commit to R&D levels prior to choosing outputs in a reciprocal-market setting, welfare in the trading equilibrium reaches a minimum at  $\tilde{t}$ , with  $\tilde{t}$  increasing in the degree of R&D effectiveness ( $\eta$ ).*

**Proof:** From (25) it is straightforward to verify that  $W^{EE}(t)$  is a convex function.  $W^{EE}(t)$  reaches a minimum at  $\tilde{t}$ , with  $dW^{EE}(\tilde{t})/dt = -\frac{1}{9-8\eta}[4A - (11-8\eta)t] = 0$ ; this implies  $\tilde{t} = 4A/(11-8\eta)$ . Clearly,  $d\tilde{t}/d\eta > 0$ . ■

In the simultaneous-move benchmark, a small reduction in trade costs from the prohibitive level *always* results in welfare falling below the autarky level. This hypothetical benchmark is represented in Figure 5c. When firms commit to R&D before setting output, it remains true that, at high levels of trade costs, a small reduction in  $t$  can lead to a fall in welfare. However, when the trade cost is high enough for autarky and trade to co-exist as equilibrium outcomes, i.e., for  $t \in [\tilde{t}, \hat{t}]$ , the trading equilibrium *always* yields higher welfare (see Figures 5a and b).

[Figures 5a, b and c about here]

**Proposition 3:** *When firms commit to R&D levels prior to choosing outputs in a reciprocal-market setting, welfare in the trading equilibrium is always higher than in autarky when the trade cost lies between  $\tilde{t}$  and  $\hat{t}$  ( $\tilde{t} \leq t \leq \hat{t}$ ).*

**Proof:** The proof is broken down into three steps. We first show that  $W^{EE} > W^{00}$  at  $t = \tilde{t}$ . Subsequently, we show  $dW^{EE}/dt > 0$  for  $t > \tilde{t}$ . Finally,  $\tilde{t} > \hat{t}$  is shown.

(i) The use of  $\tilde{t} = A/(2-\eta)$  in expression (25) yields

$$W^{EE}(\tilde{t}) = \frac{1}{9-8\eta} \left[ 4A^2 - 4\frac{A^2}{2-\eta} + \left( \frac{11}{2} - 4\eta \right) \frac{A^2}{(2-\eta)^2} \right].$$

Welfare in autarky is given by

(24). Given these expressions for  $W^{EE}(\tilde{t})$  and  $W^{00}$ ,  $W^{EE}(\tilde{t}) > W^{00}$  follows.

(ii) We have  $dW^{EE}(t)/dt = \frac{(11-8\eta)}{(9-8\eta)}[t - \tilde{t}]$ , hence  $W^{EE}$  monotonically increases in  $t$  ( $dW^{EE}/dt > 0$ ) for  $t > \tilde{t}$  with  $\tilde{t} = 4A/(11-8\eta)$  (see proof of proposition 2).

(iii) Since  $\tilde{t} = \frac{A}{2-\eta} > \frac{4A}{11-8\eta} = \hat{t}$ , we have  $W^{EE}(t) > W^{00}$  for  $\tilde{t} \leq t \leq \hat{t}$ . ■

As explained in section 5.1, firms that face competition through trade chose their R&D investment levels more aggressively than in autarky: R&D per unit of output is therefore

higher than in autarky. This strategic aggressiveness in choosing R&D when firms face a rival firm in head-to-head competition increases in  $\eta$ , the relative effectiveness of R&D. While this reduces a firm's profit below the autarky profit level (see Figure 4c), it raises consumer surplus above the autarky level (see Figure 4d) and it does so by more if the relative effectiveness of R&D is higher. As a result, a vertical gap opens up between the  $W^{EE}$  and the  $W^{00}$  loci (see Figures 5a and 5b). When the relative effectiveness of R&D is very small, this gap is not very significant and the minimum of the  $W^{EE}$ -locus still lies below  $W^{00}$ . As  $\eta$  rises a threshold is eventually passed whereby the  $W^{EE}$  is everywhere higher than that of  $W^{00}$  and welfare in the trading equilibrium exceeds welfare under autarky for all trade costs. This case is depicted in Figure 5a. As will be formally stated in proposition 4, when the effectiveness of R&D ( $\eta$ ) is sufficiently high, welfare with trade –no matter how limited that trade is– is higher than in autarky. It is precisely the fact that firms pre-commit strategically to R&D and hence choose a level of R&D above the level that minimises costs that allows for the *possibility* that the trading equilibrium *guarantees* higher welfare than autarky. Evidently, when R&D effectiveness is low, welfare with trade can fall below the level under autarky. This is illustrated in Figure 5b.

**Proposition 4:** *When firms commit to R&D levels prior to choosing outputs in a reciprocal-market setting, welfare in the trading equilibrium exceeds welfare under autarky for all trade costs, provided that the degree of R&D effectiveness,  $\eta$ , is sufficiently high.*

**Proof:** Since  $W^{EE}$  reaches a minimum at  $t = \tilde{t}$ ,  $W^{EE} > W^{00} \forall t$ , if  $W^{EE}(\tilde{t}) > W^{00}$ . We can make use of (24) and (25) to show that this condition implies  $\frac{1}{9-8\eta} \left\{ 4A(A-\tilde{t}) + \frac{1}{2}(11-8\eta)\tilde{t}^2 \right\} > \frac{3-\eta}{2(2-\eta)^2} A^2$ , using  $\tilde{t} = 4A/(11-8\eta)$ . This condition simplifies to  $\frac{4A^2}{11-8\eta} > \frac{3-\eta}{2} \frac{A^2}{(2-\eta)^2}$ , which further reduces to  $\eta > 1/3$ . ■

So, pre-commitment to R&D investment in the trading equilibrium, combined with a sufficiently high degree of R&D effectiveness, will in fact *ensure* that trade is socially superior to autarky for every degree of trade liberalisation. Without such pre-commitment –i.e., in the hypothetical simultaneous-move benchmark– even a high degree of R&D

effectiveness cannot prevent welfare from falling below the autarky level for some levels of trade liberalisation.

## 6. Asymmetries

In the previous sections, we assumed that all aspects of the model are symmetric. In this section, we relax the symmetry assumptions and explore the role of different types of asymmetries. To avoid an excessive taxonomy of cases, we focus in particular on one type of asymmetry, i.e., market size asymmetry. We also briefly mention how asymmetric trade liberalisation and cost asymmetries between firms affect our results.

### 6.1. Asymmetric market size

In this subsection we allow for the markets to differ in size. The Home and Foreign firms remain *ex ante* identical with identical production and innovation cost functions. However, even under autarky the *ex ante* identical firms will have different cost outcomes as the firm located in the larger market produces more given the higher domestic demand. Hence, its incentive to innovate is stronger, leading to more innovation and thus resulting in lower marginal production costs. However, when trade costs are zero, each firm can serve both markets equally well and equilibrium outputs, innovation and costs are the same for both firms.

As trade costs fall from the prohibitive level, it is *a priori* not obvious which market will be invaded first. On the one hand, since export markets are particularly attractive when they are large, one could argue that firms with small domestic markets have a larger incentive to penetrate those export markets than firms with a large domestic market; this would imply that the larger market will be invaded first. On the other hand, since innovation is positively correlated with firm size, firms with a large domestic market have, prior to entering potential export markets, invested more in innovation than their counterparts with a smaller sized domestic market and are hence lower-cost larger firms, which will find it easier to penetrate those export market. This would imply that the smaller country will be invaded first. We explore these issues below.

To capture the market size asymmetry formally, we amend the demand function in expression (1a) and assume the demand in Home is now given by  $p = a - \frac{1}{S}Q$ , where  $S$

captures Home market size. We normalise the Foreign market size,  $S^*$ , setting it equal to one (hence, demand in Foreign is given by expression (1b)). Without loss of generality, we assume the Home market is larger than the Foreign market,  $S > 1$ . Hence, Home and Foreign firm Cournot equilibrium outputs for the Home market are now given by  $q_1^C = S(A + t + 2x_1 - x_2)/3$  and  $q_2^C = S(A - 2t + 2x_2 - x_1)/3$ , while output expressions for the Foreign market, (5a) and (5b), remain valid.

Let us first examine the effect of  $S > 1$  on the innovation reaction functions. Note that the zero-export loci, still given by expressions (19a) and (19b) and depicted in Figure 1, are independent of  $S$ . The  $R_1^{0E}$ ,  $R_1^{EE}$ ,  $x_1^{00}$  and  $R_1^{E0}$  sections of firm one's best response function (depicted for the symmetric case in Figure 1) all move to the right as  $S$  increases. Firm two's best response is only affected by  $S$  if it exports to Home (thus, the sections  $x_2^{00}$  and  $R_2^{E0}$  of firm two's innovation reaction function remain unchanged): as  $S$  increases, the  $R_2^{0E}$  and  $R_2^{EE}$  sections move outwards (i.e., they rotate clockwise around the points at which they intersect the  $q_2 = 0$  locus). Note that the first superscript of  $R_i$  refers to firm one's export status, while the second indicates the export status of firm two.

Next, we will discuss the effects of multilateral trade liberalisation, starting with a situation of autarky, and then lowering trade costs until trade is fully liberalised. When market sizes differ sufficiently, we find that, unlike in the symmetric case, there is no region with multiple equilibria. This allows us to distinguish between a “large” and a “small” market asymmetry, where the former is defined as a market asymmetry that is sufficiently large to exclude multiple equilibria for all trade costs. As will be explained, the “small” market asymmetry case combines features of the large market asymmetry case and the case with market symmetry.

### 6.1.1. Large asymmetry

We first discuss how asymmetric markets affect the path of trade liberalisation when the Home market is sufficiently large relative to the Foreign market to exclude multiple equilibria for all trade cost. Starting at autarky for prohibitive trade costs, the first equilibrium that prevails as trade costs are lowered involves the Foreign firm, producing



for its domestic market only, deterring exports from the Home firm into Foreign: as  $t$  falls below the prohibitive level, the Foreign firm's R&D investment increases to deter firm 1's exports and welfare in Foreign rises (in Home, nothing changes relative to autarky). As  $t$  continues to fall, it will reach a level at which exports from the Home firm will no longer be blocked and one-way trade occurs with the Home firm exporting to Foreign (this equilibrium is illustrated in Figure 6a at point E0): R&D and profits of the Home firm start to increase as  $t$  falls –as does Home welfare–, while the Foreign firm's R&D and profits as well as Foreign welfare start to fall. A further lowering of  $t$ , leads to another unique equilibrium: the Home firm, exporting to Foreign, now deters the Foreign firm from exporting to Home. This equilibrium involves even higher levels of R&D for the Home firm and higher Home welfare. At even lower  $t$  levels, this equilibrium is replaced by the two-way trade equilibrium: Home firm R&D and profits start to decline, whereas the Foreign firm's R&D and profit levels increase, with firms' R&D-levels and profits converging when trade is fully liberalised (at  $t = 0$ ).

Consumer surplus and welfare are highest in both the large and the small country when trade is fully liberalised. However, the market size asymmetry affects firm profits differently: profits of the firm with the large domestic market reach a maximum at intermediate trade costs (when there is one-way export from Home to Foreign) while, provided that the Home market is sufficiently large, profits of the firm with the small domestic market reach a maximum at full trade liberalisation. Hence, complete trade liberalisation between different-sized countries is likely to be supported by firms in small countries. However, since full liberalisation results in firms investing and producing the same quantities, it is likely to be heavily opposed by firms in large countries. Those firms would favour moderate trade liberalisation instead, as they can then use the advantage of being based in the bigger country with a larger home market to become the stronger firm with a higher investment level in comparison with their rival.

*[Figures 6a and b about here]*

### 6.1.2. Small asymmetry

When the difference in market size between potential trading partners is relatively small, then –as in the symmetric case– multiple equilibria can occur at certain levels of trade costs. However, like in the large market size asymmetry case, the equilibria themselves tend to be asymmetric. While there are no other types of equilibria than the ones that occur in the cases featuring market size symmetry and large market size asymmetry, the actual pattern of equilibria at different trade costs with small market size asymmetries can be very complex. We illustrate this by sketching one possible scenario of trade liberalisation. Again, starting at trade costs that yield autarky as a unique equilibrium, as  $t$  is gradually lowered, another stable equilibrium emerges –co-existing with the autarky equilibrium–, involving the Home firm exporting to Foreign but deterring exports from the Foreign firm while exporting to Foreign itself (this equilibrium co-exists with an unstable equilibrium in which both firms deter rival exports from their respective domestic market). As trade costs are lowered further, another set of multiple equilibria prevails, depicted in Figure 6b: the autarky equilibrium ceases to exist and is replaced by an equilibrium in which the Foreign firm deters exports from the Home firm while serving only its own domestic market (indicated by point D0), while the other two equilibria (the Home firm deterring exports from the Foreign firm while exporting to Foreign itself, indicated by point ED, and the unstable equilibrium, indicated by point U) co-exist with this new equilibrium. When trade costs are lower still, a unique equilibrium (ED) prevails, in which the Home firm deters exports from the Foreign firm while exporting to Foreign itself. Eventually, when trade costs are lowered enough, two-way trade emerges as the only equilibrium.

## **6.2. Asymmetric costs**

We have assumed up to now that the Home and Foreign firms are *ex ante* symmetric in the sense that they face the same production and investment cost functions. We have seen that, even then –for instance, if their national market sizes differ– firms can end up with different innovation levels and marginal production costs. Now, suppose that the firms have different firm-specific cost parameters. We will be brief and simply mention an additional issue that can arise when firms, rather than the size of their domestic market, are *ex ante* asymmetric. More specifically, if the lower-cost firm had a sufficiently large

cost advantage over its rival, the former may actually end up forcing its high-cost counterpart from its own *domestic* market and can then act as a global monopolist.

### **6.3. Asymmetric trade liberalisation**

In our model, trade costs are symmetric and are reduced in a symmetric way to capture multilateral trade liberalisation. However, there are clearly many asymmetric trade cost cases; these would give the firm facing the lower trade cost a cost advantage that would in many respects be similar to the case in which firms have different firm-specific production or investment costs. In this subsection, we focus on one natural case of asymmetric trade costs, i.e., the case of unilateral trade liberalisation, in which only the Home country liberalises trade.<sup>15</sup> Clearly, the benefits of unilateral liberalisation to Home will be less than those of multilateral liberalisation as Home firm profits are lower as there is no penetration of the rival market. However, if a multilateral trade agreement cannot be reached, does it pay for an individual country to liberalise trade unilaterally, and, if so, how much trade liberalisation should such a unilateral move entail to ensure it is welfare improving?

Returning to our initial assumption of symmetric countries and firms, and starting from autarky, we briefly mention what happens if the Home country were to gradually lower trade costs,  $t$ , unilaterally (trade costs incurred by the Home firm to export to Foreign,  $t^*$ , are kept at the prohibitive level). Assume throughout that there is no export from Home to Foreign ( $q_1^* = 0$ ). The Foreign firm only exports when its non-negativity constraints on exports,  $q_2 \geq 0$ , is not binding. As  $t$  starts to fall below the Home trade costs that allow the Home firm to shelter as an unthreatened monopolist in the Home market, we first obtain the unique equilibrium in which the Home firm deters exports of the Foreign firm from its Home market. To do so, the Home firm chooses a higher investment in innovation than in unthreatened autarky, which implies that domestic output and consumer surplus will be higher too. This also leads to an increase in Home welfare despite the fact that no actual trade takes place. Thus, even without actual trade

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<sup>15</sup> Neary (2002) considers the effect of the unilateral removal of a quota on investment in an oligopoly model that does not use the reciprocal markets framework. His paper does not provide a welfare analysis.

occurring, the threat of import competition raises domestic innovation and welfare. This will continue to be the case as  $t$  falls further until it reaches a threshold at which Foreign imports will no longer be deterred. From then on, the equilibrium will involve trade with the Foreign firm exporting to Home. The Home firm, which now loses market share, invests less, while the Foreign firm expands its investment. Consumer surplus continues to rise but Home firm profits fall as  $t$  falls. Welfare falls below the level under incipient trade and soon falls below the autarky level.<sup>16</sup> Thus, we find that the free trade welfare level in the Home country under unilateral liberalisation is lower than its welfare under autarky. There is an exception to this. We have so far confined discussion to levels of  $\eta$  at which both firms are always active. However, at lower  $t$  and higher  $\eta$  the home firm finds it harder to compete with its stronger foreign rival. If the effectiveness of investment,  $\eta$ , is high enough, then welfare is higher at  $t = 0$  than under autarky; however, this only occurs when the Home firm is driven from the market altogether leaving the Foreign firm as a global monopolist.

## 7. Conclusion

In this paper we have developed a reciprocal markets model with international R&D intensive firms. The firms use R&D to commit to higher output and thus maintain and increase market share, both to help them penetrate into foreign markets and defend their market share at home from rivals. We examined how trade liberalisation affects innovation, profits and welfare. We found that, compared to the autarky equilibrium, the two-way trade equilibrium involves higher R&D spending and innovation. The fact that firms commit to R&D to manipulate rival outputs and, as a consequence, choose R&D investment above the level that minimises costs, helps to raise overall welfare when trade is opened up. However, this hurts the firms themselves who are caught up in a prisoner's dilemma. We showed that it is precisely because of this strategic investment behaviour that, unlike in the original RM model, trade may, if the effectiveness of investment is sufficiently high, yield higher welfare than autarky at *any* level of non-prohibitive trade costs.

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<sup>16</sup> This is consistent with Aghion *et al.* (2005) who examined the relationship between product market competition and innovation and found strong evidence of an inverted-U relationship.

Unlike in the original RM-model without R&D investment (Brander and Krugman, 1983), we found that for intermediate degrees of trade liberalisation there exists a range of trade costs at which there are two stable equilibria: in one of the equilibria firms do not export, while there is intra-industry trade in the other. This implies that the path of trade liberalisation is not unique. Like in the original RM-model, the equilibrium with two-way trade is the only one to exist when trade is liberalised sufficiently.

Although we mainly focused on a symmetric set-up, it is straightforward to use our framework to examine a number of asymmetries. We have paid particular attention to the case of trade liberalisation between countries with different market sizes. Focussing on the more interesting case with “large” market size asymmetry, our results show that, as trade costs fall from prohibitively high levels, firms from the larger-sized countries start exporting to the smaller-sized market before (i.e., at higher trade costs than) their counterparts from the smaller-sized country do. Furthermore, firms from the smaller-sized country gain most when trade costs vanish and can hence be expected to support policy initiatives involving complete trade liberalisation. Firms from larger-sized economies, exploiting the advantage of a relatively large home market, tend to gain most from partial trade liberalisation programmes with “intermediate” trade costs and are therefore more likely to oppose radical trade liberalisation schemes.

One natural extension of our model that would be well worth exploring is the issue of mutual forbearance. When large firms compete with each other in more than one market, there is reason to believe that multiplicity of contacts across distinct geographical markets has the potential to foster anti-competitive practices. For instance, facing a process of trade liberalisation, firms may have an incentive to tacitly cooperate in R&D in order to remain in control of their respective domestic markets for longer. Such practices would have important welfare implications and may even lead to perverse trade liberalisation effects. In addition, there is a number of other extensions in which we could allow for more firms and more goods. For instance, it is possible to merge our framework with one in which there are multi-product firms. Extending our model to include these issues provides potentially interesting avenues for future research.

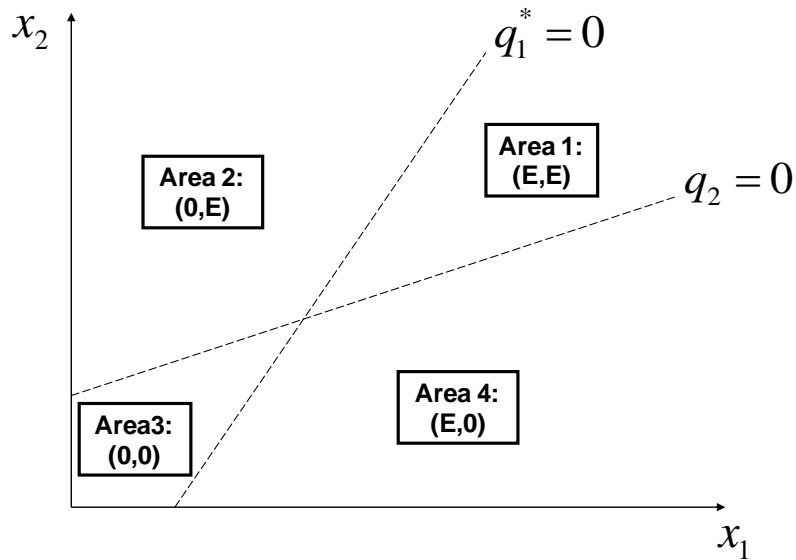
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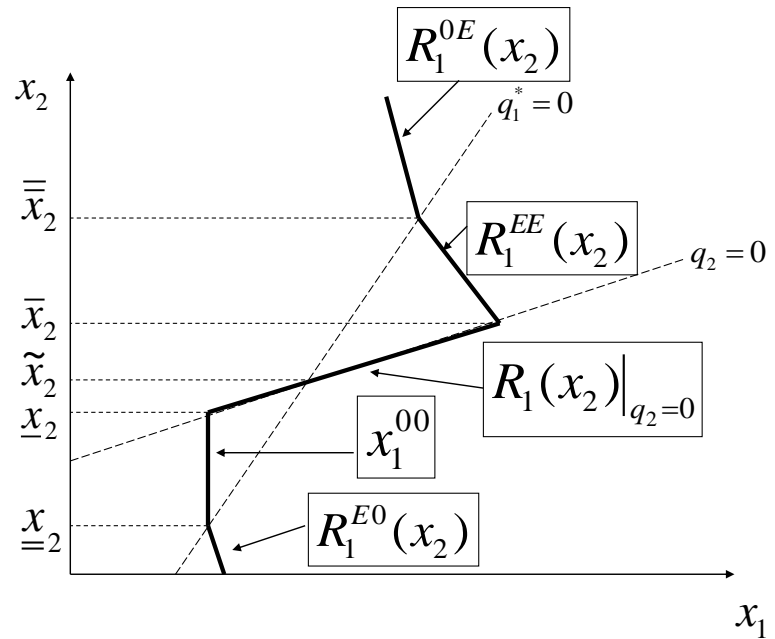
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**Figure 1: Firm 1's reaction function in  $(x_1, x_2)$ -space**  
 $(\tilde{t} < t < \hat{t})$

**(a) Trading regimes**

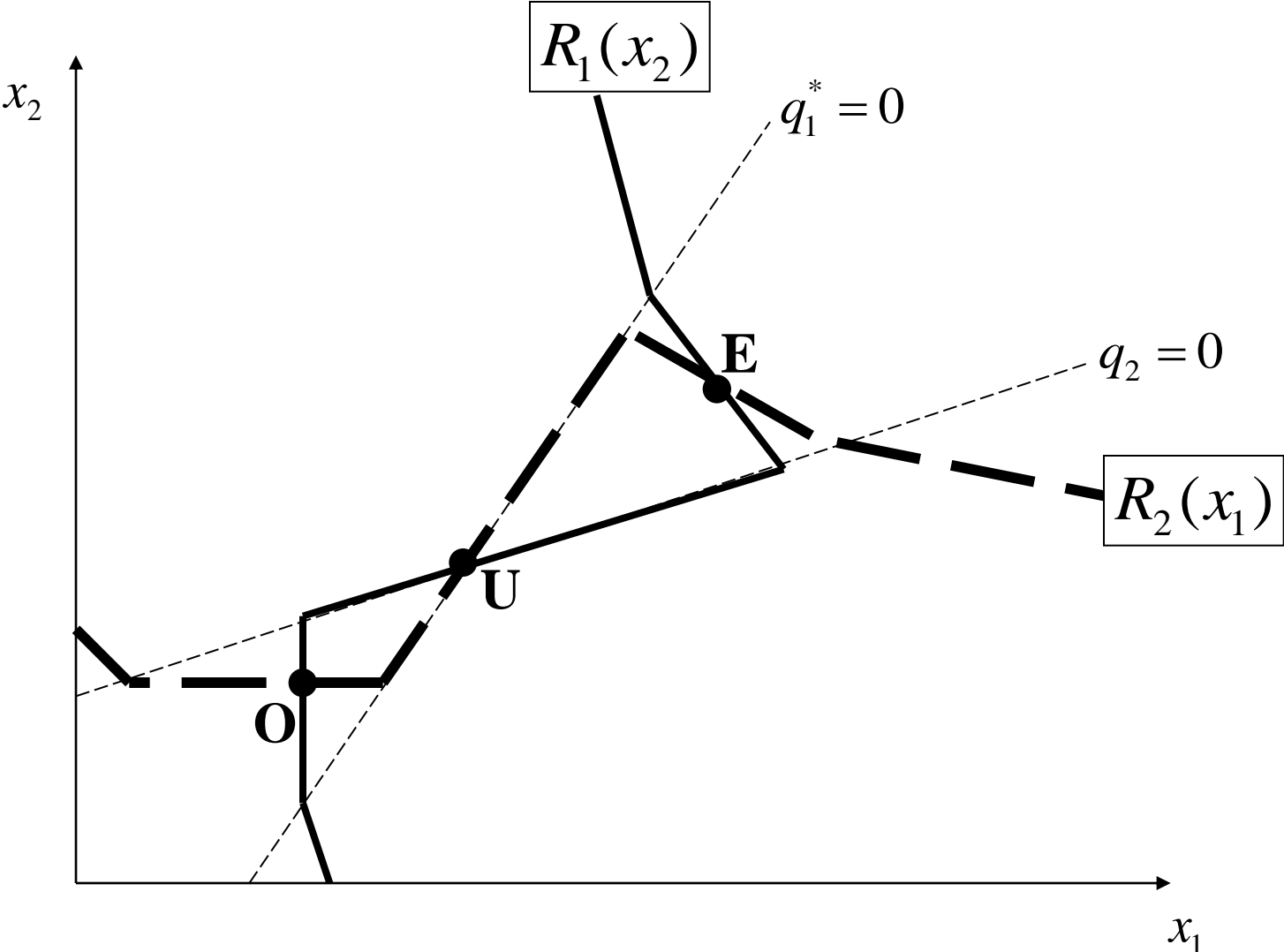


**(b) Innovation reaction function**



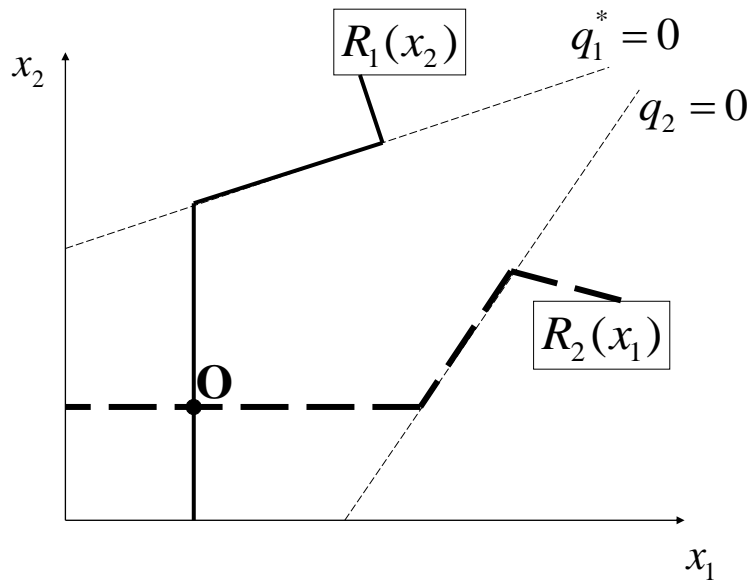


*Figure 2: Equilibria for trade costs  $\tilde{t} < t < \hat{t}$*

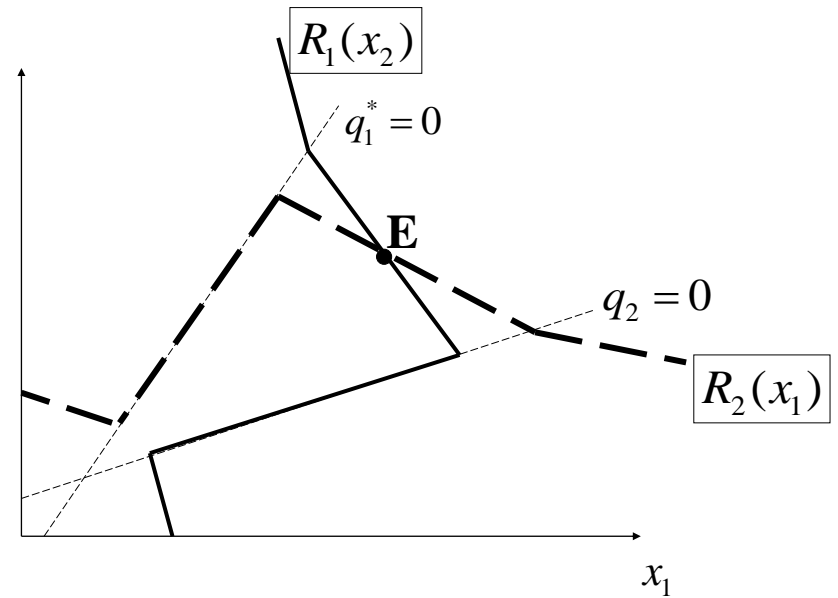


**Figure 3: Equilibria for prohibitive and low trade costs**

(a)  $t \geq \hat{t}$

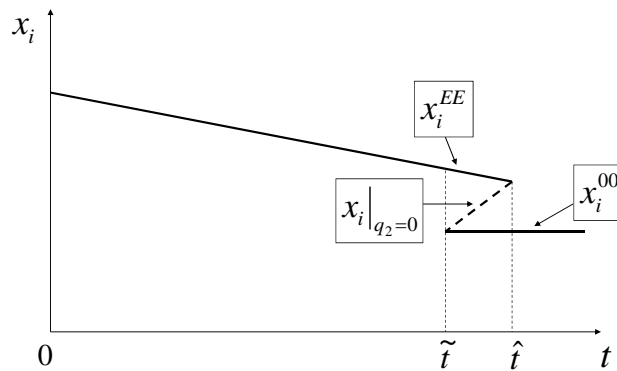


(b)  $t \leq \tilde{t}$

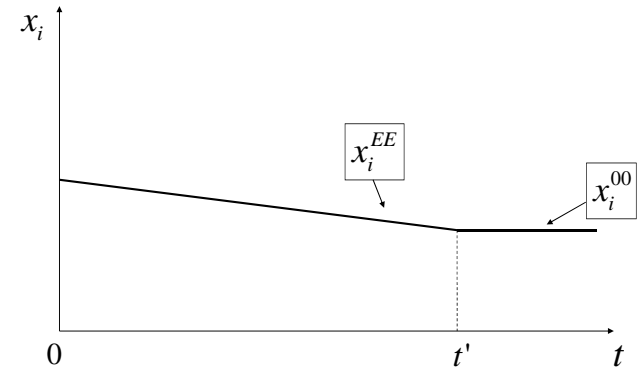


# Figure 4: Innovation, profits and consumer surplus under trade liberalisation

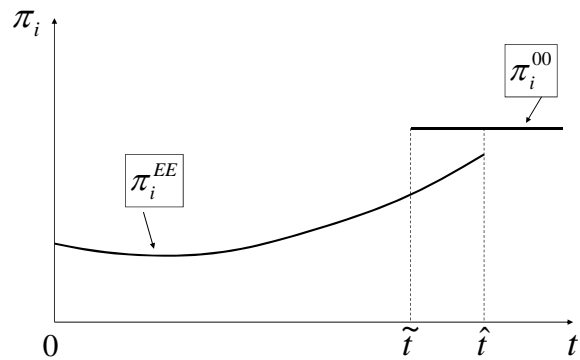
**(a) Innovation**



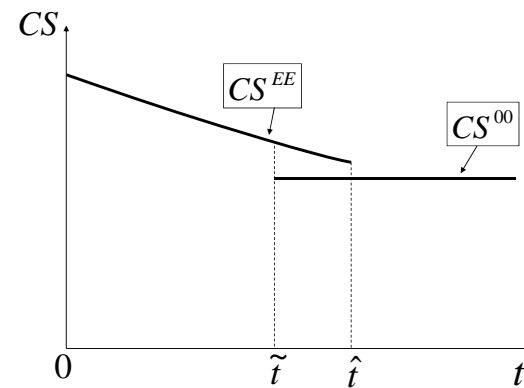
**(b) Innovation in benchmark**



**(c) Profits**

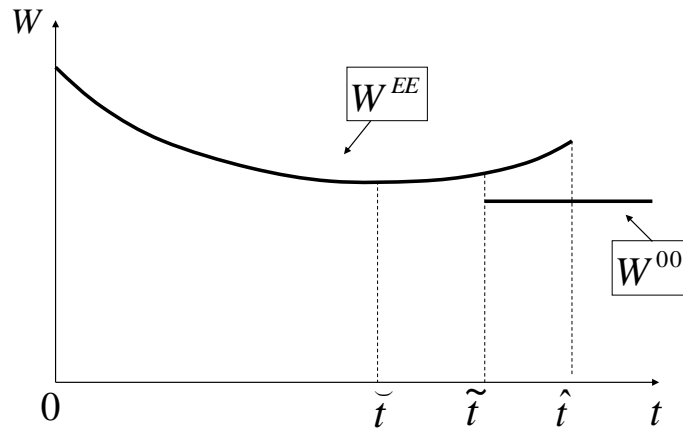


**(d) Consumer surplus**

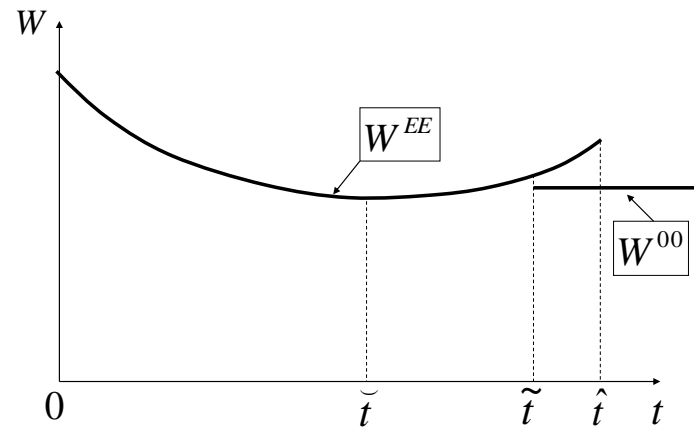


*Figure 5: Welfare under trade liberalisation*

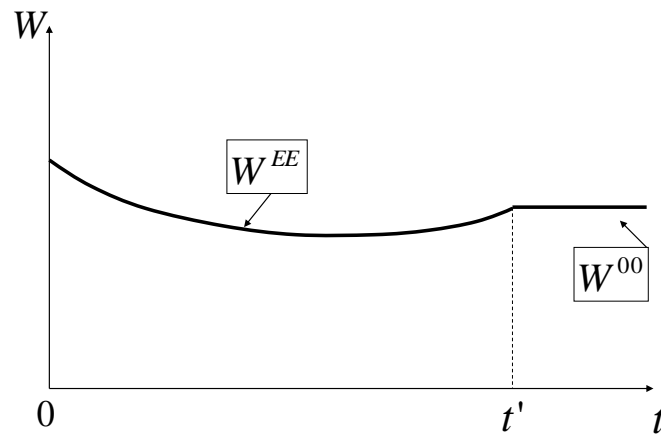
**(a)** With high  $\eta$



**(b)** With low  $\eta$

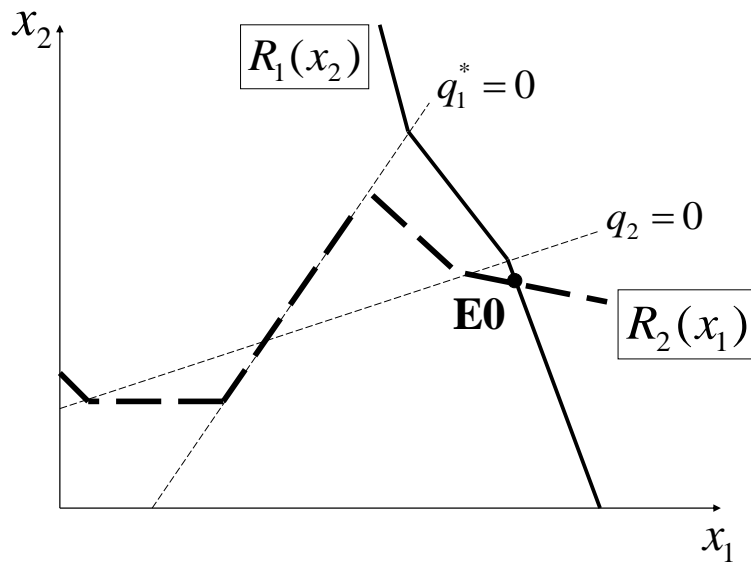


**(c)** Simultaneous-move benchmark

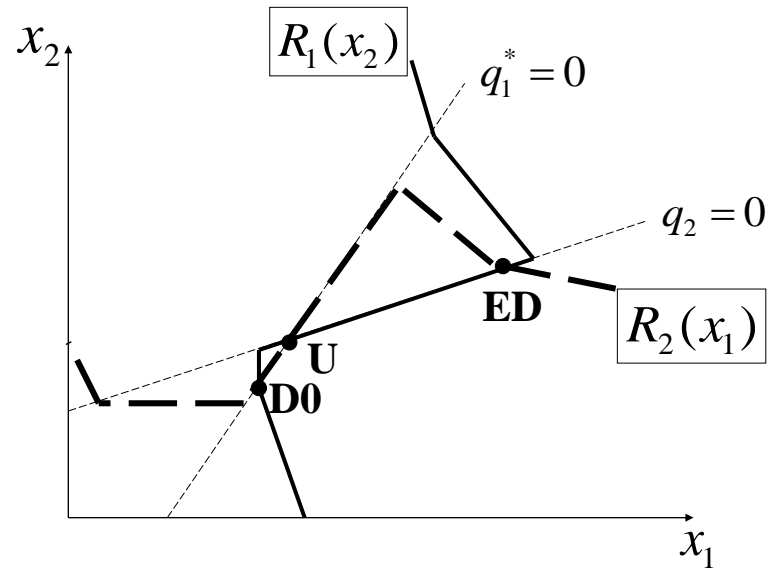


**Figure 6: Equilibria with market size asymmetries for intermediate trade costs**

**(a) Large market size asymmetry**



**(b) Small market size asymmetry**



**Table 1: Firm 1's innovation best response function for  $\tilde{t} < t < \hat{t}$**

Firm 2's innovation level ( $x_2$ )	Firm 1's best response ( $R_1(x_2)$ )
$x_2 > \bar{\bar{x}}_2$	$R_1^{0E}(x_2)$
$x_2 = \bar{\bar{x}}_2 = A - 2t(1 - (4/3)\eta)$	$R_1^{0E}(x_2) = R_1^{EE}(x_2)$
$\bar{x}_2 < x_2 < \bar{\bar{x}}_2$	$R_1^{EE}(x_2)$
$x_2 = \bar{x}_2 = \frac{1-2\eta}{1-(4/3)\eta}t - \frac{1-(8/3)\eta}{2(1-(4/3)\eta)}A$	$R_1^{EE}(x_2) = R_1(x_2) _{q_2=0}$
$\underline{x}_2 < x_2 < \bar{x}_2$	$R_1(x_2) _{q_2=0}$
$x_2 = \underline{x}_2 = -\frac{1-\eta}{2-\eta}A + t$	$R_1(x_2) _{q_2=0} = x_1^{00}$
$\underline{\underline{x}}_2 < x_2 < \underline{x}_2$	$x_1^{00}$
$x_2 = \underline{\underline{x}}_2 = \frac{2+\eta}{2-\eta}A - 2t$	$x_1^{00} = R_1^{E0}(x_2)$
$x_2 < \underline{\underline{x}}_2$	$R_1^{E0}(x_2)$