The Effects of Trade Liberalization on R&D, Industry Productivity and Welfare When Firms Are Heterogeneous

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Abstract

This paper develops an oligopolistic model of international trade with heterogeneous firms to examine how trade liberalization affects R&D investment, industry productivity and social welfare. We identify three effects of trade liberalization on industry productivity: (i) a direct effect through changes in R&D; (ii) a scale effect due to changes in firm size; and (iii) a selection effect due to inefficient firms leaving the market and efficient firms becoming exporters and expanding their overall market share. We show how these effects operate in the short run when market structure is fixed, and in the long run when market structure is endogenous. Among the robust results that hold for any market structure are that trade liberalization (i) decreases (increases) R&D for high (low) trade costs; (ii) increases firm size if trade costs are high; (iii) induces a reallocation of market shares within the industry; (iv) raises consumer surplus; and (v) raises exports.

JEL classification: F12, F15

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1 Introduction

This paper examines how trade liberalization affects R&D, aggregate industry productivity and social welfare when firms differ in their marginal costs. For this purpose we extend and modify the well-known reciprocal dumping model of trade due to Brander and Krugman (1983) to allow for firm heterogeneity and cost-reducing R&D investment. We identify three channels through which trade liberalization affects productivity and ultimately welfare. First, a reduction in trade costs may alter firms' incentives to undertake cost-reducing R&D. Second, trade liberalization may change firms' scale, thereby affecting their average cost. Third, with heterogeneous firms trade liberalization leads to a reallocation of market shares within the industry. Specifically, it forces inefficient firms to exit the market, but helps efficient firms to enter export markets and/or expand their market share abroad. We study how each of these channels operates and how the different channels interact, both when market structure is exogenous, and when it is endogenous. The case of an exogenous market structure can be interpreted either as a short-run scenario or as a model of an industry facing large sunk entry costs. In both interpretations, firms adjust to trade liberalization by adjusting domestic and foreign sales (possibly to zero) and R&D investment, but there is not entry of new firms. The case of an endogenous market structure represents a long-run scenario, in which profits are driven to zero by free entry and exit of firms. Alternatively, we may interpret this case as representing an industry in which sunk entry costs are small. Firms may still respond to trade liberalization by adjusting output and R&D expenditure. However, part of the adjustment will be in the form of entry and exit.

Recent empirical studies of international trade using firm- and plant-level data have identified apparently robust stylized facts concerning the effects of trade liberalization and about the link between trade and firm productivity (see Tybout (2003) and Wagner (2007) for surveys of the literature). Specifically, trade liberalization tends to (i) reduce mark-ups; (ii) lower domestic sales of import-competing firms; (iii) expand markets for very efficient firms;

(iv) increase efficiency at the plant level; and (v) lead to different adjustment patterns within industries depending on the level of sunk entry costs. Moreover, (vi) firms that export tend to be larger and more productive than firms that do not export. Specifically, the most productive firms in an industry tend to become exporters, while there is only little evidence of exporting making firms more productive.

Existing theoretical studies tend to concentrate on a single channel of adjustment to trade liberalization. At best, they reproduce a few of the stylized facts mentioned above. At worst, they are contradicted by them. For example, traditional new trade theory models with homogeneous firms predict that trade liberalization forces some firms to exit, while surviving firms either do not adjust their output (when the demand elasticity is assumed to be constant) or expand their output. This scale effect figures prominently in older studies of trade liberalization (see, for instance, Cox and Harris, 1985). But it does not consistently show up in the data (Head and Ries, 1999). Heterogeneous firm models focus on the market share reallocation effect of trade liberalization. Typically these studies assume away any output and mark-up adjustment by firms (Melitz, 2003, Baldwin, 2004). Even if they allow for mark-ups to change (Melitz and Ottaviano, 2004), they do not consider any strategic output response by firms. This is curious, especially since these models are intended to reproduce the stylized fact that only the largest and most efficient firms in an industry engage in exporting. But these are exactly the firms for which strategic adjustments should be important and for which therefore the assumption of monopolistic competition is most likely violated. Another unsatisfying feature of the literature, including the heterogeneous firm one, is that firms have no influence at all on their productivity. Rather firm productivity is determined exogenously by a random draw from a fixed probability distribution. Why would firms that anticipate trade liberalization not try to raise their productivity or at least try to improve their chance of drawing a favorable productivity? Doing so would allow them to take advantage of possible export opportunities or to protect themselves from import competition.

The current paper tries to make progress in two areas. First, we introduce R&D investment through which firms can increase their chance of drawing a low marginal cost. Second, we allow firms to adjust to trade liberalization not just through one channel but through three channels: the R&D effect just mentioned as well as the output and market share reallocation effects mentioned in the previous paragraph. Doing so requires setting up a model with the following distinct features. First, firms have to be heterogeneous; they draw their marginal cost from a probability distribution. Second, they can affect this distribution by investing in R&D. Third, firms are potentially large and therefore interact strategically; that is, they play an oligopoly game. Fourth, there has to be free entry and exit of firms, at least when market structure is endogenous.

We are able to incorporate all these features in a surprisingly simple model of international trade. This model is a variant of the reciprocal dumping model (Brander and Krugman, 1983), in which firms first invest in R&D to increase the likelihood of drawing a low marginal cost, then individually learn their marginal cost, and finally decide on market entry and play a Bayesian Cournot game to determine their domestic and foreign sales. The model allows us to derive comparative static effects of a reduction in trade costs on R&D, output, mark-ups, critical values of marginal cost below which firm sell domestically and below which they export. Moreover, we are able to determine how trade liberalization affects aggregate industry productivity and social welfare, both under an exogenous and an endogenous market structure.

We come up with the following robust results that hold independent of market structure: trade liberalization (i) raises (reduces) aggregate R&D spending if trade costs are low (high); (ii) raises industry productivity if trade costs are high; (iii) increases firm size provided that trade costs are high; (iv) raises social welfare if trade costs are sufficiently low; and (v) leads to a reallocation of market share with inefficient firms leaving the market and efficient firms becoming exporters and expanding their overall market share.

The remainder of the paper is structured as follows. Section 2 introduces the model. Section 3 contains the results both in the case of a fixed market structure and in the case of an endogenous market structure. Section 4 concludes. The Appendix contains proofs.

2 The Model

We consider an oligopolistic trade model with two segmented markets: the home and the foreign market. The oligopolists produce a homogeneous good under constant (but ex-ante unknown) marginal cost. We assume that the marginal cost c is firm-specific and is revealed to the firm (as private information) only after it has incurred a set-up cost $f > 0$. The probability that a firm's marginal cost is less or equal to c is given by the ex-ante cumulative distribution $F(c)$; the support of the density function $f(c)$ is the interval $[0, \bar{c}]$.

Furthermore, a firm may invest an amount $r \geq 0$ in R&D to increase its chances to become a lower-cost firm. Let $G(c)$ denote the respective after-R&D cumulative probability. R&D increases this probability such that

$$G(c) = g(r)F(c), g(0) = 1, g' > 0, g'' \leq 0. \tag{1}$$

Obviously, expression (1) holds true only as long as $G(c) \leq 1$.[1] The cost of R&D is given by

$$\rho(r) : \rho(0) = 0, \rho' > 0, \rho'' \geq 0. \tag{2}$$

A firm of type c plans to sell quantity $y(c)$ domestically and export quantity $x(c)$. Let n be the number of active firms in each country. The demand function in market j is

$$p_j = A - Q_j. \tag{3}$$

[1] Precisely, $G(c) = \min(g(r)F(c), 1)$.

Consider home firm i. It has incurred the entry cost f and the R&D cost $\rho(r)$. Upon learning its cost c_i, its output decision will be $y(c_i)$ for the home market and $x(c_i)$ for the foreign market. This output decision will depend on the expected output of all rival firms. Note that output decisions have to be made under asymmetric information as marginal costs will be revealed only to the individual firm and individual output decisions have to be based on expectations about the rivals' output. The home firm will face $n-1$ domestic rivals, each expected to produce and sell $\widehat{y}$ units in the home market, and n foreign rivals, each expected to sell $\widehat{x}^*$ units in the home market. Define

$$Q_{-i} \equiv (n-1)\widehat{y} + n\widehat{x}^*.$$

The home firm's first-order condition for its domestic sales $y(c_i)$ is

$$p(y(c_i) + Q_{-i}) + y(c_i)p'(y(c_i) + Q_{-i}) - c_i \leq 0, (= 0 \text{ if } y(c_i) > 0) \tag{4}$$

Let us define the critical marginal cost for which $y(c_i)$ becomes zero:

$$\widetilde{c}_y \equiv A - (n-1)\widehat{y} - n\widehat{x}^*. \tag{5}$$

Then the first-order conditions give rise to the decision rule[2]

$$y(c_i) = \begin{cases} 0 & \text{if } c_i \geq \widetilde{c}_y, \\ \frac{1}{2}\left(\widetilde{c}_y - c_i\right) & \text{if } c_i < \widetilde{c}_y, \end{cases} \tag{6}$$

and the profit in the home market is equal to

$$\pi(c_i) = \begin{cases} 0 & \text{if } c_i \geq \widetilde{c}_y, \\ \frac{1}{4}\left(\widetilde{c}_y - c_i\right)^2 & \text{if } c_i < \widetilde{c}_y. \end{cases} \tag{7}$$

Similarly in the foreign market, the home firm faces n foreign rivals, each supplying $\widehat{y}^*$ units, and $n-1$ domestic rivals, each exporting $\widehat{x}$ units. Firm i's first-order condition for its exports $x(c_i)$ is

$$p(x(c_i) + Q^*_{-i}) + x(c_i)p'(x(c_i) + Q^*_{-i}) - t - c_i \leq 0, \ (= 0 \text{ if } x(c_i) > 0), \tag{8}$$

where

$$Q^*_{-i} \equiv n\widehat{y}^* + (n-1)\widehat{x}.$$

[2]See also Cramton and Palfrey (1990), Lemma 5 (p 26 and pp. 41-2).

The critical marginal cost for which $x(c_i)$ becomes zero is given by:

$$\widetilde{c}_x \equiv A - (n-1)\widehat{x} - n\widehat{y}^* - t. \tag{9}$$

Hence the quantity of exports is

$$x(c_i) = \begin{cases} 0 & \text{if } c_i \geq \widetilde{c}_x, \\ \frac{1}{2}\left(\widetilde{c}_x - c_i\right) & \text{if } c_i < \widetilde{c}_x, \end{cases} \tag{10}$$

and the export profit is

$$\pi^*(c_i) = \begin{cases} 0 & \text{if } c_i \geq \widetilde{c}_x, \\ \frac{1}{4}\left(\widetilde{c}_x - c_i\right)^2 & \text{if } c_i < \widetilde{c}_x. \end{cases} \tag{11}$$

Prior to learning its marginal cost, the home firm forms expectations about its sales levels. This expectation coincides with the expected sales levels of all rivals. In what follows, we set $\widehat{y}^* = \widehat{y}$ and $\widehat{x}^* = \widehat{x}$, because the two countries are identical.

Lemma 1 *Expected sales are*

$$\begin{aligned} \widehat{y} &= \frac{g(r)}{2}\int_0^{\widetilde{c}_y} F(c)dc, \\ \widehat{x} &= \frac{g(r)}{2}\int_0^{\widetilde{c}_x} F(c)dc. \end{aligned}$$

Proof: See Appendix. □

According to Lemma 1, the expected local and export sales of a firm are determined by a system of only two equations:

$$2\widehat{y} - g(r)\int_0^{A-(n-1)\widehat{y}-n\widehat{x}} F(c)dc = 0, \tag{12}$$

$$2\widehat{x} - g(r)\int_0^{A-(n-1)\widehat{x}-n\widehat{y}-t} F(c)dc = 0. \tag{13}$$

Using (7) and (11) we may write the expected profits as

$$\widehat{\Pi} = \frac{g(r)}{4}\Omega - (f + \rho(r)), \tag{14}$$

where

$$\Omega \equiv \int_0^{A-(n-1)\widehat{y}-n\widehat{x}} [A-(n-1)\widehat{y}-n\widehat{x}-c]^2\, dF(c) + \int_0^{A-(n-1)\widehat{x}-n\widehat{y}-t} [A-(n-1)\widehat{x}-n\widehat{y}-t-c]^2\, dF(c). \tag{15}$$

Prior to learning its marginal cost, each entrant chooses its R&D level according to the following first-order condition:

$$\frac{\partial \widehat{\Pi}}{\partial r} = g'(r)\frac{\Omega}{4} - \rho'(r) = 0. \tag{16}$$

We assume that $\widehat{\Pi}_{rr} \equiv g''(r)\Omega - 4\rho'(r) < 0$. For future convenience, let us denote the optimal level of R&D by $\widehat{r}$ such that

$$g'(\widehat{r})\Omega - 4\rho'(\widehat{r}) = 0. \tag{17}$$

Assumption 1

$$\Omega > 4\rho'(0)$$

guarantees that $\widehat{r} > 0$, *i.e.*, the optimal R&D level is non-zero.

3 The Effects of Trade Liberalization

In this section we examine how trade liberalization in the form of a marginal reduction in t affects the equilibrium of the model. We start with the case of a fixed market structure. That is, we determine how trade liberalization affects expected local sales, expected exports and R&D, holding fixed the number of firms. One may interpret this as a short-run scenario, in which the number of firms has not yet had time to adjust. We then turn to the case of endogenous market structure, where market entry and exit occurs until expected profits are equal to zero. In this case we want to know how trade liberalization affects expected local sales, expected exports, R&D, as well as the equilibrium number of firms.

3.1 Fixed Market Structure

In the case of a fixed market structure the equilibrium $\widehat{y}$, $\widehat{x}$ and $\widehat{r}$ are determined by equations (12), (13) and (17). By totally differentiating these equilibrium conditions we are able to show that:

Proposition 1 *If the number of firms is fixed, trade liberalization (i) increases expected exports; (ii) decreases expected local sales if trade costs are high, and has an ambiguous effect on local sales if trade costs are low; (iii) increases the expected total output of each firm; and (iv) increases (decreases) R&D if trade costs are low (high).*

Proof: see Appendix A.2 □

In order to derive the intuition for these results it is useful to first consider another result, namely the effect of trade liberalization on the reallocation of market shares across firms. For $t = 0$ we obviously have $\widetilde{c}_y = \widetilde{c}_x$: there is only one critical value such that firms with marginal cost draws below this value are active on the integrated home and foreign markets, whereas firms with higher marginal costs do not produce any output. For $t > 0$, we must have $\widetilde{c}_y > \widetilde{c}_x$: only the most efficient firms export, whereas firms with cost draws between $\widetilde{c}_y$ and $\widetilde{c}_x$ only sell on the domestic market. To see how $\widetilde{c}_y$ and $\widetilde{c}_x$ change with t, we can use (5) and (9) to obtain:

$$\begin{aligned} \frac{d\widetilde{c}_y}{dt} &= -(n-1)\frac{d\widehat{y}}{dt} - n\frac{d\widehat{x}}{dt}, \\ \frac{d\widetilde{c}_x}{dt} &= -(n-1)\frac{d\widehat{x}}{dt} - n\frac{d\widehat{y}}{dt} - 1. \end{aligned} \tag{18}$$

We can prove the following result:

Proposition 2 *If the number of firms is fixed,* $\frac{d\widetilde{c}_y}{dt} > 0$ *and* $\frac{d\widetilde{c}_x}{dt} < 0$.

Proof: see Appendix A.2 □

This result implies that as trade costs decline, the threshold cost level $\widetilde{c}_x$ becomes higher, so that firms with marginal cost draws just above the old export threshold level will now be able to export. On the other hand, the threshold cost level $\widetilde{c}_y$ falls, meaning that firms that were just efficient enough to sell on their local market are now forced to exit the market altogether.

We are now in a position to give a complete account of the different parts of Proposition 1. Part (i) is due to the fact that trade liberalization raises the probability that any given firm will be efficient enough to be able to export ($\widetilde{c}_x$ falls), and that those firms that do export increase their shipments abroad. Hence a decline in trade costs raises expected export sales. Part (ii) concerning the effect of trade liberalization on local sales is more complicated, especially when compared with a standard reciprocal dumping model. There are three effects to take into account. First, a reduction in trade costs raises import competition, thereby decreasing local sales. This is just the opposite side of the coin from part (i). Second, as $\widetilde{c}_y$ rises, the likelihood that a given firm will be able to sell on its local market falls. This, too, reduces expected local sales. Third, trade liberalization affects R&D, as indicated by part (iv). For high trade costs, trade liberalization reduces R&D, thereby reducing the expected productivity of firms and hence lowering expected local sales. This reinforces the other two effects and trade liberalization then unambiguously reduces expected local sales. However, if trade costs are low R&D increases with trade liberalization; this raises the expected productivity of firms and hence expected local sales. This effect may dominate the other two.

Next, consider how R&D changes with t. To understand why there is a non-monotonic relationship between R&D and trade liberalization, as indicated by part (iv) of Proposition 1, consider a marginal reduction in trade costs starting from the prohibitive level. There are three effects to take into account. First, the probability that a given firm will now be able to access the export market is very small; only when it draws a very low marginal cost will it be able to do so. Second, since it still benefits from considerable protection, the probability that trade liberalization will force it to exit the market is small. Third, the probability that the firm will face import competition in its local market is relatively high because the probability that at least one foreign rival firm will export is much higher than the probability that a given firm will be able to export. All three effects imply that the marginal benefit from undertaking R&D decreases with trade liberalization if t is high. When trade costs are low, we have the opposite effect. First, trade liberalization further improves access to export markets, thereby increasing the marginal benefit of R&D. Second, import competition at home forces less efficient firms to exit, which gives an incentive to increase R&D to avoid this fate.

Propositions 1 and 2 indicate that trade liberalization has three distinct effects on industry productivity: (i) a scale effect like in reciprocal dumping: as firm size increases the fixed cost is spread over higher expected output; (ii) a selection effect: less efficient firms exit, more efficient firms gain access to the export market and raise exports and total output; and (iii) a direct effect due to higher R&D investment at least for low trade costs: firms invest more in R&D to be better positioned to take advantage of export opportunities and to avoid being pushed from the market by tougher import competition.

Finally, we want to know how trade liberalization affects consumers and social welfare. Since expected output increases with trade liberalization it follows that consumer surplus rises unambiguously. To determine how social welfare is affected, we have to take two additional effects into account, namely the change in domestic firms' expected profits and the trade cost itself. Recall that in the reciprocal dumping model there exists a u-shaped relationship between social welfare and the trade cost. That is, as the trade cost falls from the prohibitive level, social welfare at first declines, since the effect on prices (and hence consumer surplus and profits) is only a second-order effect, whereas the trade cost that is now incurred is a first-order effect. As trade is liberalized further, social welfare eventually increases as the trade cost becomes sufficiently small. We obtain the same result for low trade costs. However, in our model the welfare effect of trade liberalization may not be negative for close to prohibitive trade costs. The reason for this is that as trade costs are lowered from the prohibitive level only the most efficient firms are able to export, whereas the least efficient active firms are forced to exit the market. In other words, the selection effect of trade liberalization provides an additional boost to productivity and hence welfare that is not present in the conventional reciprocal dumping model. The following Proposition summarizes these results:

Proposition 3 *If the number of firms is fixed, trade liberalization raises (i) industry productivity; (ii) expected consumer surplus; and (iii) expected social welfare provided that the trade cost is sufficiently low.*

Proof: see Appendix. □

3.2 Endogenous Market Structure

Now consider the case of an endogenous market structure. Free entry and exit of firms ensures that expected profits (14) are zero, which implies that

$$\frac{\Omega}{4} = \frac{\rho(r) + f}{g(r)}. \tag{19}$$

Using (19), we may rewrite the first-order condition for R&D (16) as:

$$\frac{g'(\widehat{r})}{g(\widehat{r})} = \frac{\rho'(\widehat{r})}{\rho(\widehat{r}) + f}. \tag{20}$$

Expression (20) clearly shows that the optimal R&D level per firm depends only on g and ρ. This has the following consequence:

Proposition 4 *Firm-level R&D does not depend on trade costs if market structure is endogenous.*

According to Proposition 4, firm entry and exit eliminates any effect of trade liberalization on R&D per firm. This does not, however, mean that trade liberalization has no effect on aggregate R&D, since the equilibrium number of firms may change. To determine the effects of trade liberalization, we may treat R&D expenditures as a fixed cost and use equations (12), (13) and (19) to solve for the remaining endogenous variables $(n, \widehat{x}, \widehat{y})$. Since $\widehat{r}$ does not change, we may rewrite these equations as

$$2\widehat{y} - \int_0^{A-(n-1)\widehat{y}-n\widehat{x}} G(c)dc = 0, \tag{21}$$

$$2\widehat{x} - \int_0^{A-(n-1)\widehat{x}-n\widehat{y}-t} G(c)dc = 0, \tag{22}$$

$$\begin{aligned} &\int_0^{A-(n-1)\widehat{y}-n\widehat{x}} \left[A-(n-1)\widehat{y}-n\widehat{x}-c\right]^2 dG(c) \quad + \\ &\int_0^{A-(n-1)\widehat{x}-n\widehat{y}-t} \left[A-(n-1)\widehat{x}-n\widehat{y}-t-c\right]^2 dG(c) - 4(f+\rho(r^*)) \quad = \quad 0. \end{aligned} \tag{23}$$

Total differentiation of these equations yields the following comparative static results:

Proposition 5 *If market structure is endogenous, trade liberalization (i) increases expected exports and decreases expected home production of each firm; (ii) increases (decreases) the number of firms and hence aggregate R&D if trade costs are low (high); (iii) increases the expected size of each firm if trade costs are high.*

Proof: see Appendix A.3

Before providing explanations for these results, let us verify that the selection effect operates in the same way as under a fixed market structure. We obviously still have $\widetilde{c}_y = \widetilde{c}_x$ for $t = 0$, and $\widetilde{c}_y > \widetilde{c}_x$ for $t > 0$. In the derivatives of $\widetilde{c}_y$ and $\widetilde{c}_x$ with respect to t we obtain an additional effect, since the number of firms changes:

$$\begin{aligned} \frac{d\widetilde{c}_y}{dt} &= -(n-1)\frac{d\widehat{y}}{dt} - n\frac{d\widehat{x}}{dt} - (\widehat{y}+\widehat{x})\frac{dn}{dt}, \\ \frac{d\widetilde{c}_x}{dt} &= -(n-1)\frac{d\widehat{x}}{dt} - n\frac{d\widehat{y}}{dt} - (\widehat{y}+\widehat{x})\frac{dn}{dt} - 1. \end{aligned} \tag{24}$$

Still we can prove that the selection effect is equivalent to the one in the fixed market structure case. That is, trade liberalization eliminates the least efficient firms from the domestic market, whereas more efficient firms are able to export.

Proposition 6 *If the number of firms is endogenous,* $\frac{d\widetilde{c}_y}{dt} > 0$ *and* $\frac{d\widetilde{c}_x}{dt} < 0$*.*

Proof: see Appendix A.3 □

We can now discuss the reasons for the different parts of Proposition 5. To gain intuition for part (i) recall that with a fixed market structure the effect of trade liberalization on local sales was ambiguous for low trade costs, because trade liberalization induced firms to raise their R&D spending. Since this effect is absent here, the impact of trade liberalization is straightforward: the probability that a given firm exports rises as do sales of each exporting firm abroad. Increased competition from abroad reduces local sales, as does the selection effect. The intuition for part (ii) is similar to the effect of trade liberalization on R&D under a fixed market structure, except that now it is the number of firms that adjusts while R&D expenditures per firm remain constant. The reason why for high trade costs trade liberalization reduces the number of firms and therefore also aggregate R&D is that the increased likelihood of import competition reduces expected domestic sales, while high trade costs prevent firms from compensating the loss of domestic market share by raising their exports. The increase in firm size for high trade costs, stated in part (iii), simply comes from the fact that the number of firms goes down.

The effect of trade liberalization on expected firm size remains ambiguous for low trade costs. Unlike in the case of a fixed market structure, increased exports may not longer compensate for declining domestic sales. This is in part due to the interaction between firm size and the number of firms. We are able to show:

Proposition 7 *If the expected size of each firm decreases with trade liberalization, the number of firms will increase.*

Proof: see Appendix A.3

Finally consider the effects of trade liberalization on industry productivity and social welfare. The selection effect unambiguously raises industry productivity when trade is liberalized. The scale effect goes in the same direction provided that trade costs are high, since in this case we obtain fewer but larger firms; however, it may not operate, since output per firm may decrease as the number of firms rises. Since R&D per firm remains unchanged trade liberalization hence raises industry productivity at least for high trade costs.

The effect of trade liberalization on social welfare is equal to the effect on consumer surplus, since profits are zero due to free entry. We are able to prove that welfare unambiguously increases with trade liberalization. These results are summarized in the following Proposition:

Proposition 8 *If market structure is endogenous, trade liberalization raises (i) expected social welfare; and (ii) industry productivity provided that trade costs are high.*

Proof: see Appendix A.3

4 Conclusions

In this paper we developed a model of international trade with oligopolistic competition to explore the effects of trade liberalization on R&D, industry productivity, production patterns and social welfare. In this setting, we were able to identify a number of robust results concerning the effects of trade liberalization—robust in the sense that these results hold for both fixed and endogenous market structures and hence should be observed across different industries independent of whether their entry cost is large or small. Specifically, we find that trade liberalization (i) raises (reduces) aggregate R&D spending if trade costs are low (high); (ii) raises industry productivity if trade costs are high; (iii) increases firm size provided that trade costs are high; (iv) raises social welfare if trade costs are sufficiently low; and (v) leads to a reallocation of market share with inefficient firms leaving the market and efficient firms becoming exporters and expanding their overall market share.

How does our model match up with the stylized facts of trade liberalization summarized in the introduction? Note that our model reproduces the stylized fact that trade liberalization (i) reduces mark-ups; (ii) lowers domestic sales of import-competing firms (at least provided that trade costs are high or that market structure is endogenous); (iii) expands markets for very efficient firms; (iv) increases efficiency at the plant level (at least for low trade costs or endogenous market structure); and (v) leads to different adjustment patterns within industries depending on the level of sunk entry costs. In addition, in our model (vi) firms that export tend to be larger and more productive than firms that do not export.

If one takes both these stylized facts and our model at face value, then the endogenous market structure version of the model appears to provide a better fit for the stylized facts than the one where market structure is fixed. Note that we leaves out here fact (v), which deals with the fact that the level of sunk cost and hence market structure drives adjustment patterns. The endogenous market structure model provides an explanation for why empirical studies of trade liberalization seem to fail to find a scale effect (see Head and Ries, 1999); this effect only consistently shows up if trade costs are high to start with. Moreover, it may provide a partial explanation for why empirical studies typically only find that firm productivity causes exporting but not vice versa: in our model, trade liberalization leads to higher exports but does not induce individual firms to increase their R&D.

Our model also makes a methodological contribution to the literature. Specifically it shows how one can model firm heterogeneity in a simple way without resorting to the assumption of monopolistic competition, and how one can endogenize firm productivity by allowing for R&D. Note that monopolistic competition models rest on the implicit assumption that there are so many small (and hence sufficiently homogeneous) firms in the industry that strategic effects can be ignored. This is completely at odds with the idea of firm heterogeneity, because the most productive firms in an industry will have market power and will exercise their market power on international markets. Another distinctive feature of our model is the assumption that productivity is in part determined by the outcome of R&D and that both the productivity draw and R&D investment are private information and do not become common knowledge. This assumption seems to be more realistic than the conventional assumption made in the literature that productivity is exogenous and that each firm's productivity draw is revealed to every potential rival before output decisions are made.

Appendix

A.1 Proof of Lemma 1

Expected output for the home market is

$$E\left[y(c)\right] = \widehat{y} = g(r)\int_0^{\widetilde{c}_y} y(c)dF(c) = \frac{g(r)}{2}\int_0^{\widetilde{c}_y}\left[\widetilde{c}_y - c\right]dF(c) \qquad \text{(A.1)}$$

and expected exports to the foreign market are

$$E\left[x(c)\right] = \widehat{x} = g(r)\int_0^{\widetilde{c}_x} x(c)dF(c) = \frac{g(r)}{2}\int_0^{\widetilde{c}_x}\left[\widetilde{c}_x - c\right]dF(c). \qquad \text{(A.2)}$$

Let us evaluate the integral on the right-hand side of (A.1) by parts. Let $\phi(c) \equiv [\widetilde{c}_y - c]$. Then

$$\begin{aligned}\int_0^{\widetilde{c}_y}\left[\widetilde{c}_y - c\right]dF(c) &= \int_0^{\widetilde{c}_y}\phi(c)F'(c)dc \\ &= \left[\phi(\widetilde{c}_y)F(\widetilde{c}_y) - \phi(0)F(0)\right] - \int_0^{\widetilde{c}_y}\phi'(c)F(c)dc \\ &= \int_0^{\widetilde{c}_y}F(c)dc\end{aligned}$$

because $\phi(\widetilde{c}_y) = F(0) = 0$ and $\phi'(c) = -1$. A similar analysis leads to the expected export level. □

A.2 Proofs of Propositions 1 and 2

Differentiate (12), (13) and (17) totally, we get

$$\begin{bmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33}\end{bmatrix}\begin{bmatrix} dr \\ d\widehat{x} \\ d\widehat{y}\end{bmatrix} = \begin{bmatrix}\beta_1 \\ \beta_2 \\ \beta_3\end{bmatrix} dt$$

where

$$\alpha_{11} \equiv -\frac{2g'\widehat{y}}{g}, \qquad \alpha_{12} \equiv gnF(\widetilde{c}_y), \qquad \alpha_{13} \equiv 2 + g(n-1)F(\widetilde{c}_y),$$
$$\alpha_{21} \equiv -\frac{2g'\widehat{x}}{g}, \quad \alpha_{22} \equiv 2 + g(n-1)F(\widetilde{c}_x), \quad \alpha_{23} \equiv gnF(\widetilde{c}_x),$$
$$\alpha_{31} \equiv \widehat{\Pi}_{rr}, \quad \alpha_{32} = -\frac{4g'}{g}((n-1)\widehat{x} + n\widehat{y}), \quad \alpha_{33} = -\frac{4g'}{g}((n-1)\widehat{y} + n\widehat{x}),$$
$$\beta_1 = 0, \qquad \beta_2 = -gF(\widetilde{c}_x), \qquad \beta_3 = \frac{4g'}{g}\widehat{x}.$$

Expanding along the first column yields the determinant

$$\begin{aligned}\Delta \; &= \frac{8g'}{g^2} \underbrace{\left(\widehat{x}^2[(2n-1)(1-gF(\widetilde{c}_y)) - 1] + \widehat{y}^2[(2n-1)(1-gF(\widetilde{c}_x)) - 1] + 4n\widehat{x}\widehat{y}\right)}_{\equiv \Delta_1} \\ &\quad + \widehat{\Pi}_{rr} \underbrace{\left(g^2n^2F(\widetilde{c}_x)F(\widetilde{c}_y) - (2 + g(n-1)F(\widetilde{c}_y))(2 + g(n-1)F(\widetilde{c}_x))\right)}_{\equiv \Delta_2}\end{aligned}$$

Since $gnF(\widetilde{c}_x) < 2+g(n-1)F(\widetilde{c}_x)$ and $gnF(\widetilde{c}_y) < 2+g(n-1)F(\widetilde{c}_y)$, $\Delta_2 < 0$ and hence $\widehat{\Pi}_{rr}\Delta_2 > 0$. Thus, $\Delta > 0$ will hold true if we can show that $\Delta_1 > 0$. We will show that $\Delta_1 > 0$ by contradiction. We observe first that $\Delta_1 > 0$ if $(2n-1)(1-gF(\widetilde{c}_y)) - 1 \geq 0$ and $(2n-1)(1-gF(\widetilde{c}_x)) - 1 \geq 0$. Thus, $\Delta_1 < 0$ requires that $(2n-1)(1-gF(\widetilde{c}_y))-1 < 0$ and/or $(2n-1)(1-gF(\widetilde{c}_x))-1 < 0$. Since $gF(\widetilde{c}_y) \geq gF(\widetilde{c}_x)$, $(2n-1)(1-gF(\widetilde{c}_x)) - 1 \geq (2n-1)(1-gF(\widetilde{c}_y)) - 1$, and we have to consider two possible cases:

Case 1: $(2n-1)(1-gF(\widetilde{c}_x)) - 1 > 0, (2n-1)(1-gF(\widetilde{c}_y)) - 1 < 0$

In this case,

$$\Delta_1 > \widehat{x}^2[(2n-1)(1-gF(\widetilde{c}_y))-1]+4n\widehat{x}\widehat{y} = \widehat{x}(\widehat{x}[(2n-1)(1-gF(\widetilde{c}_y))-1]+4n\widehat{y}) > 0$$

because $\widehat{y} > \widehat{x}$ and $4n > -(2n-1)(1-gF(\widetilde{c}_y)) + 1$.

Case 2: $(2n-1)(1-gF(\widetilde{c}_x)) - 1 < 0, (2n-1)(1-gF(\widetilde{c}_y)) - 1 < 0$

First observe that for zero trade costs, $\widehat{x} = \widehat{y}$, $F(\widetilde{c}_x) = F(\widetilde{c}_y)$ and

$$\Delta_1 = 2\widehat{y}^2(2n-1)(2-gF(\widetilde{c}_y)) > 0$$

Hence, $\Delta_1 < 0$ warrants the existence of a critical $\bar{x} < \widehat{y}$ such that

$$\bar{x}^2[(2n-1)(1-gF(\widetilde{c}_y))-1]+\widehat{y}^2[(2n-1)(1-gF(\widetilde{c}_x))-1]+4n\bar{x}\widehat{y}=0.$$

Solving for quadratic equation yields the two solutions

$$\bar{x}_{1,2}=\frac{-4n\widehat{y}\pm\sqrt{8n^2\widehat{y}^2-4[(2n-1)(1-gF(\widetilde{c}_y))-1][(2n-1)(1-gF(\widetilde{c}_x))-1]\widehat{y}^2}}{(2n-1)(1-gF(\widetilde{c}_y))-1}$$

Note carefully that $(2n-1)(1-gF(\widetilde{c}_y))-1 \in [-1,0]$ so that $\bar{x}$ is larger than the numerator in absolute terms. The negative solution is irrelevant as it implied $\bar{x} > 4n\widehat{y}$ which violates $\bar{x} < \widehat{y}$. The positive solution fulfills $\bar{x} < \widehat{y}$ only if

$$\sqrt{8n^2\widehat{y}^2-4[(2n-1)(1-gF(\widetilde{c}_y))-1][(2n-1)(1-gF(\widetilde{c}_x))-1]\widehat{y}^2} > (4n-1)\widehat{y}.$$

However,

$$\sqrt{8n^2\widehat{y}^2-4[(2n-1)(1-gF(\widetilde{c}_y))-1][(2n-1)(1-gF(\widetilde{c}_x))-1]\widehat{y}^2} < \sqrt{8n^2\widehat{y}^2}=2\sqrt{2}n\widehat{y}<(4n-1)\widehat{y},$$

so that no solution exists in the relevant range and $\Delta_1 > 0$ holds also for that case.

We get

$$\frac{dr}{dt}=\frac{8g'}{g\Delta}\left(gn(\widehat{y}F(\widetilde{c}_x)-\widehat{x}F(\widetilde{c}_y))-\widehat{x}(2-gF(\widetilde{c}_y))\right),$$

$$\frac{dr}{dt}<0 \text{ at } t=0 \Leftrightarrow \widehat{x}=\widehat{y} \Leftrightarrow F(\widetilde{c}_x)=F(\widetilde{c}_y), \frac{dr}{dt}>0 \text{ at } x=0,$$

$$\frac{d\widehat{x}}{dt}=-\frac{8g'^2}{g^2\Delta}(\widehat{x}^2(2+g(n-1)F(\widetilde{c}_y))+(n\widehat{y}-\widehat{x})g\widehat{y}F(\widetilde{c}_x))+\frac{\widehat{\Pi}_{rr}}{\Delta}gF(\widetilde{c}_x)(2+g(n-1)F(\widetilde{c}_y))<0,$$

$$\frac{d\widehat{y}}{dt}=\frac{8g'^2}{g^2\Delta}\left(F(\widetilde{c}_x)[(n-1)g\widehat{y}^2F(\widetilde{c}_x)+g\widehat{x}(n\widehat{x}F(\widetilde{c}_y)+\widehat{y}F(\widetilde{c}_x)]-2\widehat{x}\widehat{y}\right)-\frac{\widehat{\Pi}_{rr}}{\Delta}g^2nF(\widetilde{c}_x)F(\widetilde{c}_y),$$

$$\frac{d\widehat{y}}{dt}(\widehat{x}=0)=\frac{8g'^2}{g^2\Delta}(n-1)g\widehat{y}^2F(\widetilde{c}_x)-\frac{\widehat{\Pi}_{rr}}{\Delta}g^2nF(\widetilde{c}_x)F(\widetilde{c}_y)>0,$$

$$\frac{d\widehat{y}}{dt}(\widehat{x}=\widehat{y}) = -2\widehat{y}^2(2-ng(F(\widetilde{c}_x)+F(\widetilde{c}_y)))\frac{8g'^2}{g^2\Delta} - \frac{\widehat{\Pi}_{rr}}{\Delta}g^2 nF(\widetilde{c}_x)F(\widetilde{c}_y) \text{ is ambiguous;}$$

$$\frac{d\widehat{q}}{dt} = -\frac{8g'^2}{g^2\Delta}(2\widehat{x}\widehat{y}(1-gF(\widetilde{c}_x))-\widehat{x}^2(2-gF(\widetilde{c}_y))-g\widehat{y}^2F(\widetilde{c}_x))+\frac{\widehat{\Pi}_{rr}}{\Delta}(g(2-gF(\widetilde{c}_y))) < 0,$$

$$\frac{dQ}{dt} = n\frac{d\widehat{q}}{dt} < 0.$$

As for the critical values of marginal costs, $d\widetilde{c}_y/dt$ can be rewritten as

$$\frac{d\widetilde{c}_y}{dt} = -(n-1)\frac{d\widehat{q}}{dt} - \frac{d\widehat{x}}{dt}$$

which is clearly positive. Differentiating $d\widetilde{c}_x/dt$ yields

$$\frac{d\widetilde{c}_x}{dt} = \frac{2}{g^2}\left(2g^2\widehat{\Pi}_{rr} + g^3(n-1)\widehat{\Pi}_{rr}F(\widetilde{c}_y) - 8g'^2\widehat{y}(n\widehat{x}+(n-1)\widehat{y})\right) < 0.$$

The welfare effect of integration consists of the effect on aggregate expected profits and consumer surplus. Totally differentiating (14) yields

$$\begin{aligned}\frac{d\widehat{\Pi}}{dt} &= \frac{g(r)}{4}\left(\frac{\partial\Omega}{\partial\widehat{y}}\frac{d\widehat{y}}{dt} + \frac{\partial\Omega}{\partial\widehat{x}}\frac{d\widehat{x}}{dt}\right) \\ &= -(n-1)\frac{d\widehat{q}}{dt}\widehat{q} + \frac{d\widehat{y}}{dt}\widehat{x} - \frac{d\widehat{x}}{dt}\widehat{y} - \widehat{x},\end{aligned}$$

taking into account that $\partial\widetilde{\Pi}/\partial r = 0$. Let $\widehat{CS} \equiv (n\widehat{q})^2/2$ denote expected consumer surplus. Its change with t is

$$\frac{d\widehat{CS}}{dt} = n^2\widehat{q}\frac{d\widehat{q}}{dt} < 0.$$

Since $d\widehat{q}/dt < 0$, expected consumer surplus rises with integration, *i.e.*, a decrease in t. The total expected welfare change is determined as

$$\frac{d\widehat{W}}{dt} = \frac{d\widehat{CS}}{dt} + n\frac{d\widehat{\Pi}}{dt} = n\left(\underbrace{\frac{d\widehat{q}}{dt}\widehat{q}}_{-} + \underbrace{\frac{d\widehat{y}}{dt}\widehat{x}}_{+/-} - \underbrace{\frac{d\widehat{x}}{dt}\widehat{y}}_{+} \underbrace{-\widehat{x}}_{-}\right).$$

For $t = 0 \Leftrightarrow \widehat{y} = \widehat{x} \Leftrightarrow d\widehat{y}/dt = d\widehat{x}/dt$, we find

$$\frac{d\widehat{W}}{dt}(t=0) = n\left(\underbrace{\frac{d\widehat{q}}{dt}\widehat{q}}_{-} \underbrace{-\widehat{x}}_{-}\right) < 0,$$

whereas the marginal welfare effect at the prohibitive trade cost level, *i.e.*, for $\widehat{x} = 0$, is ambiguous:

$$\frac{d\widehat{W}}{dt}(\widehat{x}=0) = n\left(\underbrace{\frac{d\widehat{q}}{dt}}_{-}\widehat{q} - \underbrace{\frac{d\widehat{x}}{dt}}_{+}\widehat{y}\right).$$

A.3 Proofs of Propositions 4 - 6

Differentiating (3.2), (22) and (23) totally, we get

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} dn \\ d\widehat{x} \\ d\widehat{y} \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} dt$$

where

$$\begin{aligned} a_{11} &\equiv (\widehat{x}+\widehat{y})G(\widetilde{c}_y), & a_{12} &\equiv nG(\widetilde{c}_y), & a_{13} &\equiv 2+(n-1)G(\widetilde{c}_y), \\ a_{21} &\equiv (\widehat{x}+\widehat{y})G(\widetilde{c}_x), & a_{22} &\equiv 2+(n-1)G(\widetilde{c}_x), & a_{23} &\equiv nG(\widetilde{c}_x), \\ a_{31} &\equiv -4(\widehat{x}+\widehat{y})^2, & a_{32} &= -4((n-1)\widehat{x}+n\widehat{y}), & a_{33} &= -4((n-1)\widehat{y}+n\widehat{x}), \\ b_1 &= 0, & b_2 &= -G(\widetilde{c}_x), & b_3 &= 4\widehat{x}. \end{aligned}$$

The determinant is

$$\Delta = 8(\widehat{x}+\widehat{y})[\widehat{x}(2-G(\widetilde{c}_y)) + \widehat{y}(2-G(\widetilde{c}_x))] > 0.$$

We then get

$$\frac{dn}{dt} = \frac{n(\widehat{y}G(\widetilde{c}_x) - \widehat{x}G(\widetilde{c}_y)) - (2-G(\widetilde{c}_y))\widehat{x}}{\Delta},$$

$$\frac{dn}{dt} < 0 \text{ at } t=0 \Leftrightarrow \widehat{x}=\widehat{y} \Leftrightarrow G(\widetilde{c}_y) = G(\widetilde{c}_x), \frac{dn}{dt} > 0 \text{ at } \widehat{x}=0,$$

$$\frac{d\widehat{x}}{dt} = -\frac{8\widehat{y}(\widehat{x}+\widehat{y})G(\widetilde{c}_x)}{\Delta} < 0,$$

$$\frac{d\widehat{y}}{dt} = \frac{8\widehat{x}(\widehat{x}+\widehat{y})G(\widetilde{c}_y)}{\Delta} > 0.$$

Define $\widehat{q} \equiv \widehat{x}+\widehat{y}$ as the size of a firm:

$$\frac{d\widehat{q}}{dt} = \frac{(\widehat{x}+\widehat{y})(\widehat{x}G(\widetilde{c}_y) - \widehat{y}G(\widetilde{c}_x))}{\Delta},$$

$$\frac{d\widehat{q}}{dt} = 0 \text{ at } t = 0 \Leftrightarrow x = y \Leftrightarrow G(\widetilde{c}_y) = G(\widetilde{c}_x), \frac{d\widehat{q}}{dt} < 0 \text{ at } \widehat{x} = 0.$$

Note that

$$\frac{d\widehat{q}}{dt} > 0 \Leftrightarrow \widehat{y}G(\widetilde{c}_x) - \widehat{x}G(\widetilde{c}_y) < 0 \Rightarrow \frac{dn}{dt} < 0.$$

The effect on consumption is

$$Q = n\widehat{q},$$

$$\frac{dQ}{dt} = -\frac{8\widehat{x}(\widehat{x}+\widehat{y})(2-G(\widetilde{c}_y))}{\Delta} = -\frac{\widehat{x}(2-G(\widetilde{c}_y))}{\widehat{x}(2-G(\widetilde{c}_y))+\widehat{y}(2-G(\widetilde{c}_y))} < 0.$$

Furthermore, using these results for (24) yields

$$\begin{aligned} \frac{d\widetilde{c}_y}{dt} &= \frac{2\widehat{y}}{2(\widehat{x}+\widehat{y}) - \widehat{x}G(\widetilde{c}_y) - \widehat{y}G(\widetilde{c}_x)} > 0, \\ \frac{d\widetilde{c}_x}{dt} &= -\frac{2\widehat{x}}{2(\widehat{x}+\widehat{y}) - \widehat{x}G(\widetilde{c}_y) - \widehat{y}G(\widetilde{c}_x)} < 0. \end{aligned}$$

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