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Technology, Market Structure and the Gains from Trade

Abstract

We study the gains from trade in a model with oligopolistic competition, heterogeneous firms and innovation, and provide a formula to decompose the mechanism. The new insight we provide is that market concentration can be a welfare-relevant feature of market power above and beyond markup dispersion. Trade liberalisation increases foreign competition and reduces the number of active firms in the market, thereby increasing concentration. A more concentrated economy is more efficient due to increasing returns in production. Moreover, higher concentration produces a scale effect on firms' incentives to innovate, which increases welfare via productivity improvements. In the calibrated version of the model we show that a trade-induced increase in concentration contributes substantially to the gains from trade, mostly via its stimulating effect on innovation. Sizeable gains also come from the reduction of the inefficiency produced by trade in identical goods; i.e. through a reduction in reciprocal dumping. Changes in markup dispersion, in contrast, have only negligible effects.

JEL-Codes: F120, F130, O310, O410.

Keywords: gains from trade, heterogeneous firms, oligopoly, innovation, endogenous markups, market concentration.

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1 Introduction

Modern economies are dominated by a few global firms that are large, highly productive, and have substantial market power. The top one percent of US exporters account for more than 80 percent of total US trade (Bernard et al., 2017), and their market power varies both in the cross-sectional and time dimesion (e.g. Hottman et al., 2016; De Loecker and Eckhout, 2020).[1] Large firms are also found to be key players in "innovation-races" to increase their market shares in the global economy (e.g. Bustos, 2011; Aghion et al., 2017). Standard models of international trade with heterogeneous firms, however, do not usually capture the market structure and the strategic nature of competition amongst these large players.

With global markets populated by large players where technology is at the root of firms competitiveness, it is critical to incorporate powerful firms interacting strategically in analysing the effects of globalisation. In this paper we study the welfare gains from trade and their sources in an economy with heterogeneous, oligopolistic, firms where both technology and market structure are endogenously determined. The response of technology and market structure to lowering trade barriers shapes the welfare impact of globalisation.

We build a global economy with two symmetric countries producing the same set of varieties of differentiated goods. Each variety is produced by a small number of domestic and foreign firms competing a la Cournot for market shares. Productivity differs across varieties, but the small number of firms competing head-to-head in each variety has identical productivity. Entry is directed to a particular variety, or product line, and pins down the number of local and foreign firms competing in there. As a consequence, markups differ across varieties and the equilibrium depends critically on the endogenous distribution of market power and the associated degree of market concentration. After entry, firms allocate resources to production and innovation. Since innovation reduces the firms' unit cost, its benefits are larger the larger is the scale of firms' production. Hence, the firms' market size drives their decision to innovate.

Multilateral trade liberalisation has two opposing effects on markups. As trade barriers are reduced, foreign competition intensifies and markups on domestic sales decline. At the same time, the cost of accessing the foreign market falls, which allows firms to increases their markups in the foreign market, as the cost-reduction is not fully passed on to foreign consumers. Abstracting from entry, we show that the former, pro-competitive, effect dominates and firms' average markups – as well as the average markup in each country – decline with trade liberalisation. With free entry, this pro-competitive effect, if strong enough, may lead to an increase in market concentration as the associated reduction in profits induces some firms to exit the market.[2] Higher concentration can offset the direct competition effect of

[1] Mayer and Ottaviano (2007) find that the share of exports attributable to the top one percent of exporters is 59 percent for Germany, 44 percent for France, 42 percent for the UK, 32 percent for Italy, 77 for Hungary, 48 percent for Belgium, and 53 percent for Norway. Freud and Pierola (2015) report that the top five percent of firms account for 30 percent of export across the 32 developing countries in their study.

[2] Due to the integer constraint on the number of firms, there are "bands of inactions" of the free entry condition, with liberalisation scenarios that do not change the equilibrium number of firms.

lower trade barriers on markups, thereby leading to higher markups both on domestic and export sales. Thus, markups can increase not only for the incomplete pass-through on export prices but also for the feedback effect produced by changes in concentration. Moreover, in more concentrated markets, firms are larger and therefore have stronger incentives to innovate. When the effect of foreign competition is weaker, instead, the entry margin does not ignite and trade liberalisation reduces firms' average markups, as well as the economy's aggregate markup, with no noticeable effects on innovation and productivity.

We solve the model numerically and calibrate it to match some relevant firm-level and aggregate statistics of the U.S. economy. In our baseline simulations, the effect of eliminating trade costs entirely has a heterogenous impact. In about half of the product lines the pro-competitive effect dominates, markups decline, and concentration as well as innovation do not change. For the other half, the number of firms in each product line drops, markets become more concentrated and firms become larger and more innovative. The effects on the aggregate economy can be broken down in two phases of liberalisation. In the first phase, when the drop in the trade cost is up to 30% of its benchmark value, the average number of firms declines, markups, concentration and innovation increase. From there to free trade, concentration and innovation do not change further and the average markup of the economy declines.

These results highlight a rich interaction between globalisation and market power. The typical measure of market power, markups, can increase or decrease with liberalisation. Another measure of market power, concentration, can also increase or remain invariant and its changes have important implications for changes in markups. In both cases though, our analysis emphasises that the changes in market power brought about by trade liberalisation originate from stronger competition. Hence, we turn to the central questions of the paper. Are these changes in market power triggered by globalisation beneficial for aggregate economic wellbeing? And what are the key sources of the welfare effects of trade?

We compute the welfare gains from trade and provide a formula that separates transparently their main sources into four channels: increasing returns, innovation, variable markups, and a measure of the inefficiency associated with two-way trade in identical goods. First, *increasing returns* – due to the presence of a fixed operating cost – are stronger in more concentrated markets. Hence, in the liberalisation scenarios where the number of firms drops, welfare increases via increasing returns. Second, concentration increases firm size which in turn raises *innovation*, productivity and welfare. Third, as in Brander and Krugman (1983), two-way trade in identical goods produces losses since firms engaged in independent domestic and foreign Cournot games do not internalise the social cost of trading the same good in the presence of trade costs. The welfare effect of resources wasted due to *reciprocal dumping*, in Brander and Krugman's jargon, has an inverted-U shape relationship with the trade cost. It is zero at when trade is costless, it reduces welfare as the trade cost becomes positive, and it is zero again when the trade cost is prohibitive and firms do not find it profitable to export. Finally, trade can increase welfare by reducing the resource misallocation due to *markup dispersion*.

Going from our benchmark variable trade cost – which is an iceberg cost of 21% – to free trade generates a welfare gain of about a 10% increase in consumption equivalents. Most of this gain is split between the reciprocal dumping and the innovation channel, while the gains from increasing returns is small, and the contribution of markup dispersion is negligible. In the first phase of globalisation, where concentration is increasing, gains from trade are mostly driven by innovation, in the second phase, reciprocal dumping is instead the key driver.

Literature review. Our paper contributes to a long-standing literature on the welfare gains from trade and more closely to the work on the role of variable markups in shaping the size and the channels of these gains. Arkolakis et al. (2019) compute the pro-competitive effect of trade on welfare in a class of models with monopolistic competition, heterogeneous firms, and variable markups obtained via non-CES demand. They show that trade liberalisation reduces domestic markups and increases export markups, via the standard incomplete pass-through channel. Under translog preferences the two effects cancel out, thus the pro-competitive effects are "elusive" and variable markups do not produce any additional welfare gains compared to the standard CES demand system. When preferences are non-homothetic, the incomplete pass-through dominates, and the pro-competitive effect is negative.

More closely related to our paper, Edmond et al. (2015) analyse pro-competitive gains from trade in a quantitative version of a model of firm heterogeneity and Cournot competition (Atkeson and Burstein, 2008), abstracting from innovation. They find large pro-competitive gains from trade, operating via a reduction of the inefficiency produced by markup dispersion. Besides innovation, we depart from their analysis in another important dimension. Their baseline model does not allow for free entry, and their extension to free entry is essentially a quantitative robustness check showing that entry does not produce essential changes in the main results. We provide new theoretical insights of the role of entry in shaping the gains from trade and show that it can be quantitatively relevant. Our findings complement their analysis suggesting that trade-induced competition can produce welfare gains above and beyond those related to markup dispersion, crucially operating via free entry. We also perform a full decomposition of the gains from trade, providing a formula that clearly separates the main sources in a Cournot trade model with innovation.

We build on the model of trade under oligopoly introduced by Brander (1981). Brander and Krugman (1983) introduce free entry to show that trade increases welfare. In a similar framework, Horstman and Markusen (1986) show that under free entry an import tariff leads to inefficient entry. In line with our results, the losses from protectionism come via the increasing returns in production.[3] Since these early contributions two technical challenges hampered the adoption of these models in trade. First the models where not embedded in general equilibrium, so they could not be used to analyse the interactions between product and factor markets that are important in trade. Second, they

[3] As related result can be found in Mankiw and Whinston (1986). In a partial equilibrium, homogenous product, closed economy Cournot oligopoly with fixed entry cost, they show that there is a bias toward excessive entry. The welfare losses due to the excessive entry fall as the fixed cost falls.

did not allow an explicit analysis of entry and exit.[4] Even large oligopolistic markets in the long run experience some churning, but endogenising entry and exit preserving the strategic interaction between firms proves to be hard due to the "integer problem".[5] Neary (2003) provides a solution to the first problem with the "small in the large and large in the small" approach which we follow. Oligopoly trade with free entry and a discrete number of firms is, instead, still an outstanding challenge (Neary, 2010). To the best of our knowledge, besides Edmond et al. (2015), we are not aware of other attempts to tackle this problem. We contribute by explicitly modelling entry and exit, showing that this margin is key in shaping the welfare gains from trade. Our trade model can be viewed as an extension of Brander and Krugman (1983) to heterogeneous firms, general equilibrium and free entry of a discrete number of firms.

We make contact with the recent literature on the welfare effects produced by the innovation response of heterogeneous firms to trade. In a dynamic model with constant markups, Atkeson and Burstein (2010) show that the role of innovation depends on the curvature of the innovation technology and the speed of the transitional dynamics. In most of their key specifications, innovation does not affect the gains from trade, unless strong knowledge spillovers are introduced. Akcigit et al. (2021) build an open economy version of the step-by-step Schumpeterian model with heterogeneous firms and show that the effect of trade on growth and welfare depend on the pre-liberalisation relative productivity distribution of firms (comparative advantage). Using micro and aggregate data to discipline the innovation technology and knowledge spillovers, their calibrated model shows substantial innovation-induced gains from trade. In an endogenous growth model, with variable markups and heterogeneous firms, Impullitti and Licandro (2018) find that by affecting the long-run growth rate of productivity, innovation can double the gains from trade otherwise obtainable in static models. Moreover, under free entry, but ignoring the integer constraint trade liberalisation increases the number of firms and reduces the aggregate markup.

We build on Impullitti and Licandro (2018) but following the insights of Atkeson and Burstein (2010) we cast the model in a static environment, eliminate knowledge spillovers and model free entry respecting the integer constraint. Our key findings suggest that free entry is key in shaping the contribution of innovation to the gains from trade. Trade-induced exit increases the size of surviving firms thereby rising the incentives to innovate. Innovation generates substantial gains from trade even in the absence of knowledge spillovers.[6]

[4] In Brander and Krugman (1983) free entry is only used to eliminate profits and therefore producer surplus from welfare. With consumer surplus alone determining welfare, they show that a trade-induced reduction in markups leads to lower prices and higher welfare. But since entry is not properly modelled and the equilibrium number of firms not derived, they cannot explore the feedback from changes in the number of firms to markups. Horstman and Markusen (1986) treat the number of firms as a continuous variable, a strong assumption in markets with a few powerful firms.

[5] Analytically, free entry with a discrete number of firms forbids the use of infinitesimal calculus on which economic analysis relies heavily. Discrete changes in the number of firms makes computational solutions more challenging as well.

[6] Cavenaile et al. (2020) combines insights from Akcigit et al. (2021) and Impullitti and Licandro (2018) to show that the trade-induced increase in innovation has a feedback effect on competition, shifting the distribution of firms toward product lines with higher technology gap between leader and follower, which also have higher markups. Long et al. (2011) build static model of oligopoly trade and firm heterogeneity in which firms innovate before entering the market, in order to

Finally, our results provide some theoretical insights for the recent empirical evidence in the macroeconomic research on market power. Many studies have found an increasing trend in both markups and several concentration measures for many countries in the last decades (e.g. Autor et al., 2020; De Loecker et al., 2020; De Loecker and Eckhout, 2020; Bajgar et al., 2019; Gutierrez and Philippon, 2018).[7] Our results suggests that globalisation can be a plausible source of the observed dynamics of market power. They highlight the key role of free entry in producing liberalisation scenarios where both markups and concentration move in the same direction. Monopolistically competitive models with variable markups are less well suited to generate a positive relationship between trade liberalisation and markups. Melitz and Ottaviano (2008) predicts that trade reduces markups and has an ambiguous effect on market concentration. Markups in this framework can only increase due to a reallocation across industries with different average markups, while industry and firm-level markups decrease with liberalisation. Mrazova and Neary (2019) show that for a large class of demand functions that they call "subconvex" (less convex than CES) trade reduces markups in monopolistically competitive economies. The opposite happens when the demand is "superconvex", but this class of demand functions are not empirically supported. In Bertoletti and Epifani (2014) where preferences are additively separable, monopolistically competitive models can produce anti-competitive effects of trade, with increasing average markups, but at the cost of generating counterfactual reallocations, with less productive firms growing more than more productive firms, thereby hampering the efficiency effects of trade.

2 Economic Environment

We begin providing an overview of the model and then proceed to the description of the economic environment. Consider a static world economy populated by two symmetric countries, home and foreign. In each of these economies there is a (measure one) mass of products of a composite consumption good. Both economies produce the same set of products, implying that trade does not entail any gain from product variety. Each product is produced by a small discrete number of firms. Preferences are CES defined over the set of differentiated products, with an elasticity of substitution larger than one. There is only one factor of production, labor, which is supplied inelastically. Labor is employed in both production and innovation activities. Firms produce each product variety with a production technology that is linear in labor, with labor productivity differing across product lines. Production also requires a fixed operating cost. The initial productivity of all product lines is common knowledge and Pareto distributed on a bounded interval. Furthermore, an R&D technology allows firms to use innovation to increase their own productivity. The R&D technology uses labor as sole

study the effects of trade on innovation. Firm-level innovation is independent of trade costs, and trade affects aggregate innovation only through its effect on the number of firms, which increases with liberalisation, while the opposite happens in our model. See also Lim et al. (2018).

[7] See Syverson (2019) and Philippon (2019) for surveys of literature.

input and faces decreasing returns.

The set of products, as well as the initial productivity of each product, are the same in both countries. Trade is not characterised, consequently, by any form of comparative advantage. Firms can sell in each others' markets upon payment of an iceberg-type trade cost and there are no fixed export costs.[8] In equilibrium, all products are produced and exported by a discrete, finite, number of home and foreign Cournot competitors, competing independently in the home and foreign markets. Two-way trade in identical goods takes place due to the perception that markets are segmented; each firm perceives each country as a separate market and makes separate decisions. The equilibrium markups depend negatively on the number of both home and foreign competitors, with differences in market shares due to the trade cost leading to differences between domestic and export markups. For each product line, the equilibrium number of competitors in each country is given by an entry condition that exhausts any potential gains from entry.[9]

As explained in more detail in Section 3.2, the timing of the Cournot game is the following. First, the initial productivity of all product lines realises. Second, firms enter the market until any further potential gains from entry are exhausted; as a consequence, a finite discrete number of home and foreign firms compete in each product line in both countries. Third, firms conduct R&D in order to increase their labor productivity and decide how much labor to hire, produce and sell to consumers. In their production choice, they behave as Cournot competitors playing a two-way trade in identical goods game as in Brander and Krugman (1983).

Market structure and entry. There is a measure one mass of products indexed by z, $z \in (\underline{\omega}, \bar{\omega})$, the same products being produced in both countries. In each country, there is a large number of potential entrants, entering at zero cost and ready to produce in any product line. In equilibrium, free entry in the home and foreign markets endogenously determines the number of home, n, and foreign firms, n^*, operating in each product line, where n and n^* are natural numbers. All firms, home and foreign, producing in the same product line, z, have the same initial productivity and manufacture the same homogeneous product. They play separate Cournot games in the home and foreign markets. The equilibrium number of home and foreign firms, (n, n^*), governs markups, market shares and innovation across product lines and countries.

Following Atkeson and Burstein (2008) and Edmond et al. (2015), firms enter the Cournot game sequentially for any product line, z. As a result of entry, each product line in equilibrium will be in one of the following three regimes: the $\{(1,0),(0,1)\}$ monopolistic regime with only one home or only one foreign firm producing for both markets; the (n,n) symmetric Cournot regime with n home and n foreign firms, $n \in \{1,2,...\}$; or the $\{(n,n-1),(n-1,n)\}$ asymmetric Cournot regime, $n \in \{2,3,...\}$. In both the monopolistic and the asymmetric Cournot equilibrium, the home economy may have one

[8]As a consequence, selection into export is then excluded from the analysis, even if it could be easily added to the picture.

[9]Due to the integer nature of the number of firms, profits will be non-negative in equilibrium. However, free entry reduces profits to a point where no *additional* firm finds it profitable to enter.

firm more than the foreign economy with a 50% probability. The aggregate equilibrium will then be characterised by a distribution of product lines across the different market regimes.

Technology. The distribution of initial productivity across product lines, z, is assumed to be a bounded Pareto,

$$\mathrm{F}(z) = \frac{1-(\underline{\omega}/z)^{\kappa}}{1-(\underline{\omega}/\bar{\omega})^{\kappa}}, \tag{1}$$

for $z \in (\underline{\omega}, \bar{\omega})$, $0 < \underline{\omega} < \bar{\omega} < \infty$, with $\kappa > 1$. A bounded Pareto has been chosen for the sake of tractability. In order to transform *inital* productivity into *final* productivity, firms need to allocate labor, h, according to the R&D technology

$$\tilde{z} = A\, h^{\eta}\, z, \tag{2}$$

where $\tilde{z}$ denotes final productivity; $\eta \in (0,1)$ and $A > 0$ are constant parameters.

In addition to R&D, firms use labor to cover both variable production costs and a fixed operating cost $\lambda > 0$. A firm producing a product with final productivity $\tilde{z}$, faces the following cost function

$$\ell = \tilde{z}^{\frac{\alpha-1}{\alpha}} q + \lambda, \tag{3}$$

where ℓ represents the amount of labor required to produce q units of output. This technology is similar to the one in Melitz (2003), where an industry with a CES aggregate of differentiated products features different technologies across product lines. The key difference is that in the Melitz model a product is produced by one firm only, while here it is produced by a small, integer number of Cournot competitors. Similar to Melitz (2003), each firm competes horizontally with the many other firms producing imperfectly substitutable varieties with different efficiencies, but in addition it also competes vertically with the few other firms in the same product line.

Preferences. Both economies are populated by a continuum of identical households of measure one. Households are endowed with one unit of labor which is supplied inelastically. Labor is taken as the numéraire. Preferences of the representative household are CES and given by

$$X = \left(\int_{\underline{\omega}}^{\bar{\omega}} x(z)^{\alpha}\, \mathrm{dF}(z) \right)^{\frac{1}{\alpha}}, \tag{4}$$

where $x(z)$ is consumption of product z, and $\mathrm{F}(z)$ is the distribution of products across z.

3 Equilibrium

The representative household maximizes utility subject to its budget constraint. The inverse demand function emerging from this problem is

$$p(z) = \frac{E}{X^{\alpha}}\, x(z)^{\alpha-1}, \qquad \text{with} \;\; E = \int p(z)x(z)\, \mathrm{dF}(z), \tag{5}$$

where $p(z)$ is the price of product z, E is total household expenditure, and X is defined in equation (4).

3.1 Cournot Game

Home and foreign firms behave non-cooperatively maximising profits subject to the inverse demand function in equation (5), for both the domestic and export markets, taking the quantities produced by their competitors as given. In this section, we analyse equilibrium for a given number of firms (n,n^{*}); the endogenous determination of the number of firms is studied in the next section. In the following, when needed, we use the subindices d and f to refer to transactions taking place in the domestic and export markets (the foreign market from the perspective of a home firm), respectively. Variables associated to the foreign economy are denoted with an asterisk superscript. Due to the presence of an iceberg costs, $\tau \geq 1$, q_f denotes foreign consumption of domestic products while the associated production is τq_f. The same applies to domestic consumption of foreign products q_f^{*}, which is associated to foreign production τq_f^{*}.

In the home country, a firm in a product line with initial productivity z solves

$$\pi = \max_{q_d, q_f, h} \underbrace{\frac{E}{X^{\alpha}}\left(\hat{x}+q_d\right)^{\alpha-1}}_{p} q_d + \underbrace{\frac{E}{X^{\alpha}}\left(\hat{x}^{*}+q_f\right)^{\alpha-1}}_{p^{*}} q_f - \big(\underbrace{Ah^{\eta}z}_{\tilde{z}}\big)^{\frac{\alpha-1}{\alpha}}\left(q_d+\tau q_f\right) - \lambda - h, \tag{6}$$

where p and p^{*} represent prices in the home and foreign markets, and $\hat{x}$ and $\hat{x}^{*}$ denote the production of competitors in the domestic and export markets, respectively.[10] The first order conditions for domestic sales, q_d, and exports, q_f, are, respectively,

$$\frac{E}{X^{\alpha}}\left((\alpha-1)x^{\alpha-2}q_d + x^{\alpha-1}\right) = \tilde{z}^{\frac{\alpha-1}{\alpha}}, \tag{7}$$

$$\frac{E}{X^{\alpha}}\left((\alpha-1)x^{*\,\alpha-2}q_f + x^{*\,\alpha-1}\right) = \tau\tilde{z}^{\frac{\alpha-1}{\alpha}}. \tag{8}$$

where $x = \hat{x}+q_d$ and $x^{*} = \hat{x}^{*}+q_d$ represent consumption in the domestic and foreign markets, respectively. The first order condition for R&D labor is

$$h = \hat{\eta}\, \tilde{z}^{\frac{\alpha-1}{\alpha}}\left(q_d+\tau q_f\right) = \hat{\eta}\left(\ell-\lambda\right), \tag{9}$$

[10] We omit the dependence on z to simplify notation.

with $\hat{\eta} = \frac{1-\alpha}{\alpha}\eta$. Since innovation is cost reducing, firms' innovation effort is linearly increasing in firm size. Notice that a reallocation of labor from fixed to variable activities has the effect of proportionally increasing innovation. Using equation (2), actual productivity becomes

$$\tilde{z} = A\left(\hat{\eta}\,\tilde{z}^{\frac{\alpha-1}{\alpha}}\left(q_d+\tau q_f\right)\right)^{\eta} z \quad \Rightarrow \quad \tilde{z} = A^{\frac{1}{1+\hat{\eta}}}\left(\hat{\eta}\,\left(q_d+\tau q_f\right)\right)^{\frac{\eta}{1+\hat{\eta}}} z^{\frac{1}{1+\hat{\eta}}}. \tag{10}$$

Below we will study the properties of the model in the monopolistic regime, the symmetric Cournot regime, and the asymmetric Cournot regime, respectively.

Monopolistic regime. Consider the product lines where only one domestic firm produces for the global market - this is the $(1,0)$ regime.[11] From the first order conditions in equations (7) and (8), the home and foreign prices, respectively, are

$$p(z) = \frac{1}{\alpha}\,\tilde{z}(z)^{\frac{\alpha-1}{\alpha}} \quad \text{and} \quad p^*(z) = \frac{1}{\alpha}\,\tau\,\tilde{z}(z)^{\frac{\alpha-1}{\alpha}}, \tag{11}$$

with home firms charging the monopolistic markup, $1/\alpha$, over marginal costs, for both domestic and foreign markets. From the demand function in equation (5), total consumption in the home and foreign markets, respectively, are

$$x(z)^\alpha = q_d(z)^\alpha = \left(\frac{\alpha E}{X^\alpha}\right)^{\frac{\alpha}{1-\alpha}}\tilde{z}(z) \quad \text{and} \quad x^*(z)^\alpha = q_f(z)^\alpha = \left(\frac{\alpha/\tau E}{X^\alpha}\right)^{\frac{\alpha}{1-\alpha}}\tilde{z}(z). \tag{12}$$

Substituting these into equation (3), firm variable production costs become

$$\ell(z) - \lambda = \left(1+\tau^{\frac{\alpha}{\alpha-1}}\right)\left(\frac{\alpha E}{X^\alpha}\right)^{\frac{1}{1-\alpha}}\tilde{z}(z). \tag{13}$$

A firm's size is therefore increasing in firm's productivity. After substitution of the labor demand above into equation (9), we solve for the R&D effort h. Substituting the solution into the R&D technology in equation (2), we can solve for final productivity $\tilde{z}$. Finally, substituting optimal behavior into the profit function yields

$$\pi(z) = \left(1+\tau^{\frac{\alpha}{\alpha-1}}\right)\alpha^{\frac{\alpha}{1-\alpha}}\left(1-(1+\hat{\eta})\alpha\tau^{\frac{1}{\alpha-1}}\right)\left(\frac{E}{X^\alpha}\right)^{\frac{1}{1-\alpha}}\tilde{z}(z) - \lambda.$$

Thus profits in the $(1,0)$ regime are linear in final productivity $\tilde{z}$, and exceed zero only if $(1+\hat{\eta})\alpha\tau^{\frac{1}{\alpha-1}} < 1$. We will proceed by assuming that η is small enough such that this parameter restriction holds.

[11] The $(0,1)$ regime with only one foreign global monopolists is the mirror image.

Symmetric Cournot regime. In a symmetric equilibrium, i.e. when $n = n^*$, for $n \in \{1,2,3,...\}$, consumption in the home country is given by $x = n(q_d + q_f)$, as symmetry implies $q_f^* = q_f$. Symmetry also implies that domestic and foreign consumption are equal, i.e., $x(z) = x^*(z)$. Adding equations (7) and (8), domestic consumption is given by

$$x(z)^{\alpha} = \left(\frac{\theta_d E}{X^{\alpha}}\right)^{\frac{\alpha}{1-\alpha}} \tilde{z}(z) \quad \text{where} \quad \theta_d = \frac{2n+\alpha-1}{n(1+\tau)}, \tag{14}$$

where θ_d represents the inverse of the markup on domestic sales. As it will become clear below, the equilibrium value of n and (consequently) θ_d depends on z. By construction, prices are given by

$$p(z) = \frac{\tilde{z}(z)^{\frac{\alpha-1}{\alpha}}}{\theta_d} = \frac{\tau\, \tilde{z}(z)^{\frac{\alpha-1}{\alpha}}}{\theta_f}, \tag{15}$$

where $\theta_f = \tau\theta_d$ is the inverse of the markup charged on export sales. As in the standard models with oligopoly trade, a sufficient condition for firms to export is that the autarky markup is larger than the trade cost. For a given n, this condition identifies a trade cost $\bar{\tau} = n/(n+\alpha-1)$ above which a product line in a symmetric equilibrium with n firms is not exported.[12]

The symmetric Cournot equilibrium displays reciprocal dumping as in Brander and Krugman (1983): due to the presence of trade costs, firms charge a lower markup on their export sales, $1/\theta_f$, than on their domestic sales, $1/\theta_d$. As suggested by Brander and Krugman, the crucial element for the existence of two-way trade in identical goods is the "segmented market" perception which posits that each firm perceives each country as a separate market and makes separate decisions for each. The economic intuition is straightforward. The marginal cost of exporting is larger than that of domestic production due to the trade cost. Since firms charge a lower markup on export sales than on domestic sales, they produce a smaller quantity for the export market than for the domestic market. Hence, the perceived marginal revenue is higher for exports than for domestic sales, and can equal the marginal cost of exporting at positive output levels.

The ratio of production to consumption in product line z is given by

$$\frac{q_d + \tau q_f}{q_d + q_f} = \frac{(1-n-\alpha)(1+\tau^2)+2n\tau}{(1-\alpha)(1+\tau)} \equiv \mathscr{A} > 1. \tag{16}$$

where the inverse of $\mathscr{A}$ measures losses associated to two-way trade in identical goods. In the following, we will refer to it as the reciprocal dumping inefficiency factor. Notice that $\mathscr{A}^{-1}$ is U-shaped in τ; it is equal to one in the extreme cases of free trade, $\tau = 1$, and at the prohibitive trade costs, $\bar{\tau} = n/(n+\alpha-1)$, and below one for values in between. Intuitively, when variable trade costs are at its prohibitive level, exports, q_f, are zero and the share of production wasted in transportation is

[12] Another way to see this is that θ_f, which is increasing in τ, reaches one at $\tau = \bar{\tau}$; thus at any larger value of τ, the export markup rate turns negative and firms do not find it profitable to export.

zero, implying $\mathscr{A} = 1$. A reduction in variable trade costs induces firms to export by reducing their domestic sales. As a consequence, the waste associated with trade costs becomes positive, and $\mathscr{A}$ rises above one. At the other extreme, without any trade costs the loss is by construction equal to zero, and any increase in trade cost increases $\mathscr{A}$ above one.

Let us define the inverse of the average markup as

$$\theta \equiv \frac{q_d \theta_d + q_f \theta_f}{q_d + q_f} = \mathscr{A}\,\theta_d, \tag{17}$$

which follows from the definition of $\mathscr{A}$ and from $\theta_f = \tau\theta_d$. The variable θ is a quantity-weighted average of the inverse of the markups on domestic and export sales. Under free trade, $\theta = \theta_d = (2n+\alpha-1)/(2n)$, since $\theta_f = \theta_d$ for $\tau = 1$.

Firms' variable production costs are

$$\ell(z) - \lambda = \tilde{z}^{\frac{\alpha-1}{\alpha}} \left(q_d(z) + \tau q_f(z)\right) = \tilde{z}^{\frac{\alpha-1}{\alpha}} \mathscr{A} \left(q_d(z) + q_f(z)\right) = \frac{\mathscr{A}}{n} \left(\frac{\theta_d E}{X^\alpha}\right)^{\frac{1}{1-\alpha}} \tilde{z}(z), \tag{18}$$

where ℓ is labor allocated to the production of goods for both the domestic and export markets. More productive firms produce more, demand more labor and, from equation (9), also invest more in R&D. Substituting optimal h into the R&D technology in equation (2) gives the final productivity $\tilde{z}$.

In a symmetric Cournot equilibrium, from equations (7) and (8), the market shares of home firms in the domestic and export markets, respectively, are

$$s_d = \frac{\tau n - (n+\alpha-1)}{(1-\alpha)(1+\tau)} \quad \text{and} \quad s_f = \frac{n - \tau(n+\alpha-1)}{(1-\alpha)(1+\tau)}, \tag{19}$$

with $s_d \geq s_f$. For $\tau \in \left(1, \frac{n}{n+\alpha-1}\right)$, both shares are in the interval $(0,1)$, and the domestic market share increases monotonically with τ, ranging from 1/2 to 1 as τ moves from unity to the prohibitive level $n/(n+\alpha-1)$. Trade costs protect firms in their domestic markets, raising their market shares at the expenses of the market share of imports. Due to variable trade costs, an increase in substitutability across products raises the market share of domestic firms relative to foreign firms.

Finally, the profit function can be simplified to

$$\pi(z) = \Big(1 - (1+\hat{\eta})\theta\Big) \frac{\theta_d^{\frac{\alpha}{1-\alpha}}}{n} \left(\frac{E}{X^\alpha}\right)^{\frac{1}{1-\alpha}} \tilde{z} - \lambda. \tag{20}$$

Again, profits are linear in final productivity $\tilde{z}$. As in the monopolistic equilibrium, η is assumed to be small enough such that $(1+\hat{\eta})\theta < 1$, for all n observed at equilibrium.

Taking the number of competitors as given, the pro-competitive effect of trade fundamentally operates through the direct effect of a reduction in τ on markups. Trade liberalisation, by boosting competition from abroad, induces a reduction in both domestic and average markups, and it does so despite the associated rise in export markups. The proposition below summarises these properties for the symmetric Cournot equilibrium.

Proposition 1 (Pro-competitive effect of trade). *In a symmetric Cournot equilibrium with* $\tau \in [1, n/(n+\alpha-1)]$ *and given n,* $n \in \{1,2,3,...\}$*, for any firm in a product line z, a reduction in* τ *reduces the domestic markup,* $1/\theta_d$*, increases the export markup,* $1/\theta_f$*, and reduces the average markup,* $1/\theta$*. Changes in* θ_d *and* θ_f *are less than proportional than changes in* τ*.*

Proof: Differentiating with respect to τ, θ_d in equation (14), θ_f implicitly in equation (15), and θ in equations (16) and (17) yields,

$$\frac{\partial \theta_d}{\partial \tau}\frac{\tau}{\theta_d} = -\frac{\tau}{1+\tau} \in (-1,0), \quad \frac{\partial \theta_f}{\partial \tau}\frac{\tau}{\theta_f} = \frac{1}{1+\tau} \in (0,1) \text{ and } \frac{\partial \theta}{\partial \tau} = -\frac{2n(\tau-1)\theta_d^2}{(1-\alpha)(1+\tau)} < 0. \ \square$$

For a given n, trade liberalisation decreases firms' markups on domestic sales since the home market becomes more competitive due to the stronger penetration of foreign firms. In addition, our economy features an incomplete pass-through of the reduction in trade costs onto prices: lower trade costs lead to higher markups on export sales, $1/\theta_f$, because exporters enjoy a cost reduction in their shipments, increasing their market shares. Hence, exporters optimally charge a higher markup, by not passing the whole cost reduction onto foreign consumers. This "pricing to market" mechanism is typical of oligopoly trade models, such as Brander (1981) and Brander and Krugman (1983).

Remarkably, abstracting from free entry (for given n), trade liberalisation decreases firms' average markups on total sales. This suggests that although our economy features incomplete pass-through of the reduction in trade costs onto prices, the increase in export markups is never sufficiently strong to offset the pro-competitive effect on domestic markups. In other words, in an oligopolistic open economy with Cournot competition and CES demand, when the number of firms is kept constant, there is an overall *pro-competitive effect* of trade on markups. Later we will introduce free entry. It is important to notice at this stage, as we can observe in equation (20), that trade liberalisation by reducing the average markup θ moves the profit function down putting pressure on the number of firms to decline.

Asymmetric Cournot regime. We now turn to the case of an asymmetric number of firms. Consistently with the equilibrium refinement in Section 3.2, we study the case of product lines where the home country has one firm more than the foreign country, i.e. the $(n, n-1)$ Cournot equilibrium. Again, notice that the $(n-1, n)$ Cournot equilibrium is its mirror image.

For any product line z in a $(n, n-1)$ equilibrium, after using equation (10) to substitute final productivities $\tilde{z}$ and $\tilde{z}^*$, the system in equations (7) and (8) for both home and foreign firms generate the demand functions $q_d(z)$, $q_f(z)$, $q_d^*(z)$ and $q_f^*(z)$, all depending on E/X^α and n. Consumption in both countries is then given by $x(z) = nq_d(z) + (n-1)q_f^*(z)$ and $x^*(z) = (n-1)q_d^*(z) + nq_f(z)$, and prices are given by the demand function in equation (5), evaluated at these quantities for both the home and foreign economies. To be more precise, the FOCs in equations (7) and (8) can be written as

$$\underbrace{\frac{E}{X^{\alpha}}\, x(z)^{\alpha-1}}_{p(z)}\underbrace{\Big((\alpha-1)s_d(z)+1\Big)}_{\theta_d(z)} = \tilde{z}(z)^{\frac{\alpha-1}{\alpha}}, \tag{21}$$

$$\underbrace{\frac{E}{X^{\alpha}}\, x^*(z)^{\alpha-1}}_{p^*(z)}\underbrace{\Big((\alpha-1)s_f(z)+1\Big)}_{\theta_f(z)} = \tau\, \tilde{z}(z)^{\frac{\alpha-1}{\alpha}}, \tag{22}$$

where $s_d = q_d(z)/x(z)$ and $s_f = q_f(z)/x^*(z)$ are the market shares of home firms in the domestic and export markets, respectively. These equations show the standard result in a Cournot equilibrium that markups positively depend on market shares. The corresponding set of equations for foreign firms are

$$\underbrace{\frac{E}{X^{\alpha}}\, x^*(z)^{\alpha-1}}_{p^*(z)}\underbrace{\Big((\alpha-1)s_d^*(z)+1\Big)}_{\theta_d^*(z)} = \tilde{z}^*(z)^{\frac{\alpha-1}{\alpha}}, \tag{23}$$

$$\underbrace{\frac{E}{X^{\alpha}}\, x(z)^{\alpha-1}}_{p(z)}\underbrace{\Big((\alpha-1)s_f^*(z)+1\Big)}_{\theta_f^*(z)} = \tau\, \tilde{z}^*(z)^{\frac{\alpha-1}{\alpha}}. \tag{24}$$

After substitution of the price equations above into the inverse demand function in equation (5), we obtain

$$x(z)^{\alpha} = \left(\frac{\theta_d(z)E}{X^{\alpha}}\right)^{\frac{\alpha}{1-\alpha}} \tilde{z}(z) \quad \text{and} \quad x^*(z)^{\alpha} = \left(\frac{\theta_d^*(z)E}{X^{\alpha}}\right)^{\frac{\alpha}{1-\alpha}} \tilde{z}^*(z). \tag{25}$$

These equations show the effect of both markups and innovation on household consumption.

To better understand the behaviour of the asymmetric regime, we study the functioning of an economy without innovation by assuming $\tilde{z} = \tilde{z}^* = z$, which allows us to obtain closed-form solutions. From equations (21) to (24), it is easy to show that the inverses of the domestic markups at the home and foreign economies are

$$\theta_d = \frac{2n+\alpha-2}{n(1+\tau)-\tau} \; > \; \theta_d^* = \frac{2n+\alpha-2}{n(1+\tau)-1}, \quad \forall z. \tag{26}$$

Since trade is costly, and there is one more local firm in the home economy, the domestic market is more competitive in the home country than in the foreign country, implying that the domestic markup is lower. The associated market shares are

$$s_d = \frac{1-\theta_d}{1-\alpha}, \quad s_f = \frac{1-\tau\,\theta_d^*}{1-\alpha}, \quad s_d^* = \frac{1-\theta_d^*}{1-\alpha} \quad \text{and} \quad s_f^* = \frac{1-\tau\,\theta_d}{1-\alpha}, \quad \forall z.$$

Since foreign firms are in smaller in numbers, they have larger market shares in their domestic markets, charging larger domestic markups. Hence, in asymmetric regimes, there is markup heterogeneity both between and within product lines.

Trade liberalisation has the same effects on the domestic and export markups as in the symmetric equilibrium.

Proposition 2 *In an asymmetric Cournot equilibrium without innovation, for any product line z and any $n \in \{2,3,...\}$, a reduction in τ reduces the markup of both home and foreign firms in their domestic markets, but increases them in the export markets.*

Proof: Differentiate θ_d and θ_d^* in equation (26) with respect to τ gives

$$\frac{\partial \theta_d}{\partial \tau}\frac{\tau}{\theta_d} = -\frac{\tau}{\frac{n}{n-1}+\tau} \in (-1,0), \quad \text{and} \quad \frac{\partial \theta_d^*}{\partial \tau}\frac{\tau}{\theta_d^*} = -\frac{\tau}{\frac{n-1}{n}+\tau} \in (-1,0),$$

$$\frac{\partial \theta_f}{\partial \tau}\frac{\tau}{\theta_f} = \frac{1}{1+\tau\frac{n}{n-1}} \in (0,1) \quad \text{and} \quad \frac{\partial \theta_f^*}{\partial \tau}\frac{\tau}{\theta_f^*} = \frac{1}{1+\tau\frac{n-1}{n}} \in (0,1). \quad \square$$

Thus, the pro-competitive effect on domestic markups and the incomplete pass-through on the export markup stated in Proposition 1 for the symmetric equilibrium also holds for the asymmetric equilibrium.[13]

3.2 Entry and Equilibrium Refinement

This section provides a refinement strategy to single out a unique Cournot equilibrium for any product z, with $z \in (\underline{\omega}, \bar{\omega})$. The refinement strategy has been designed to ensure a symmetric treatment, and expected outcome, of the two countries in equilibrium. The resulting outcome is essentially a version of the equilibrium concept in Atkeson and Burstein (2008) and Edmond et al. (2015), adapted to our economy with symmetric countries and firms with identical initial productivity within each product line. Similarity to those papers, there are potentially many (n, n^*) constellations that satisfy the equilibrium condition. Thus, to single out a unique allocation we proceed with the refinement below.

Let $\pi(z,n,n^*)$ denote the profit function for a home firm producing product z when facing $n-1$ domestic competitors and n^* foreign competitors.[14] Analogously, let $\pi^*(z,n^*,n)$ denote the profit function for a foreign firm producing product z when facing n^*-1 domestic competitors and n foreign competitors. We proceed as follows:

1. For any given product, z, one firm from each country has the opportunity to enter the market. If at the $(1,1)$ symmetric equilibrium

$$\pi(z,1,1) = \pi^*(z,1,1) > 0,$$

[13] The numerical analysis support this result even in the full model with innovation.

[14] That is, there are n home firms and n^* foreign firms in the market.

at least $(n,n^*) = (1,1)$ firms will enter, and we proceed to step two. However, if

$$\pi(z,1,0) > 0 > \pi(z,1,1) \quad \text{and} \quad \pi^*(z,1,0) > 0 > \pi^*(z,1,1),$$

a symmetric $(1,1)$ Cournot equilibrium does not exist. We then flip a coin. If head, the home firm enters the market, otherwise the foreign firm enters. This gives rise to a $(1,0)$ or $(0,1)$ equilibrium in the global monopoly, and the refinement ends.[15]

2. If $(n,n^*) = (1,1)$ firms have entered in step 1 above, then if at the $(2,2)$ symmetric equilibrium

$$\pi(z,2,2) = \pi^*(z,2,2) > 0,$$

at least $(n,n^*) = (2,2)$ firms will enter, and we proceed to step three. However, if

$$\pi(z,2,1) > 0 > \pi(z,2,2) \quad \text{and} \quad \pi^*(z,2,1) > 0 > \pi^*(z,2,2),$$

a symmetric $(2,2)$ Cournot equilibrium does not exist. We then flip a coin. If head, an additional home firm enters the market, otherwise a foreign firm enters. This gives rise to a $(2,1)$ or a $(1,2)$ equilibrium with a global oligopoly with three firms, and the refinement ends.

Lastly, if

$$\pi(z,2,1) < 0 \quad \text{and} \quad \pi^*(z,2,1) < 0,$$

only a symmetric Cournot $(1,1)$ equilibrium exists with a global duopoly, and the refinement ends.

3. More generally, if $(n,n^*) = (n-1,n-1)$ firms have already entered,then if at the (n,n) symmetric equilibrium

$$\pi(z,n,n) = \pi^*(z,n,n) > 0,$$

at least (n,n) firms will enter, and we proceed to step $n+1$. However, if

$$\pi(z,n,n-1) > 0 > \pi(z,n,n) \quad \text{and} \quad \pi^*(z,n,n-1) > 0 > \pi^*(z,n,n),$$

a symmetric (n,n) Cournot equilibrium does not exist. We then flip again a coin. If head, an additional home firm enters the market, otherwise a foreign firm enters. This gives rise to a $(n,n-1)$ or $(n-1,n)$ equilibrium with $2n-1$ oligopolistic firms, and the refinement ends.

[15] Of course, $\pi(z,1,0) < 0$ is also a possibility in which case no firm will produce product z at equilibrium.

Finally, if

$$\pi(z,n,n-1) < 0 \quad \text{and} \quad \pi^*(z,n,n-1) < 0,$$

only a symmetric $(n-1,n-1)$ Cournot equilibrium exist, which gives rise to a global oligopoly with $2(n-1)$ symmetric firms, and the refinement ends.

This is a similar equilibrium concept to Atkeson and Burstein (2008) and Edmond et al. (2015), however due to firm homogeneity within varieties and symmetric countries, our refinement strategy is slightly different. We let the marginal firms to be randomly selected instead of letting "the most productive firms enter first". The outcome of this refinement is indeed a Nash equilibrium, and all varieties are exported by (potentially) several combinations of firms from the two countries. As in Brander and Krugman (1983) and in the free-entry version of Edmond et al. (2015), all active firms export.

3.3 General Equilibrium

Conditional on E/X^{α}, Section 3.2 uses the profit functions derived in Section 3.1 to determine the type of equilibrium corresponding to any product line z. With "equilibrium type", we refer the number of domestic and foreign firms (n,n^*) belonging to the set $\{(1,0),(0,1),(1,1),(2,1),...\}$. Knowing the pair (n,n^*) associated to any z, for all $z \in (\underline{\omega},\bar{\omega})$, Section 3.1 determines actual productivities $\{\tilde{z}(z),\tilde{z}^*(z)\}$, labor demands $\{\ell(z),\ell^*(z)\}$, consumed quantities $\{x(z),x^*(z)\}$, produced quantities $\{q_d(z),q_f(z),q_d^*(z),q_f^*(z)\}$, and prices $\{p(z),p^*(z)\}$. All these functions depend on E/X^{α}. Plugging the solution above into the labor market clearing condition, we solve for the equilibrium value of E/X^{α}.

3.4 Welfare Decomposition

In this section, we suggest a decomposition of the welfare gains that takes into account the main dimensions of the problem discussed in the previous sections. As we saw above, product lines can be in a symmetric or an asymmetric equilibrium.[16] From equations (15), (21) and (22), the price equations can be generally written as

$$p(z) = \mu_d(z)\tilde{z}(z)^{\frac{\alpha-1}{\alpha}} \quad \text{and} \quad p^*(z) = \mu_d^*(z)\tilde{z}^*(z)^{\frac{\alpha-1}{\alpha}},$$

where $\mu_d(z) = 1/\theta_d(z)$ and $\mu_d^*(z) = 1/\theta_d^*(z)$ are the markups of home and foreign firms in their respective local markets.

[16]In all our simulations, no product line is in the monopolistic regime. So we focus our decomposition on these two general cases.

When substituting the price equations above into the inverse demand function in equation (5), equilibrium consumption in the home and foreign economies, respectively, are given by

$$x(z) = \left(\frac{E}{X^{\alpha}}\right)^{\frac{1}{1-\alpha}} \mu_d(z)^{\frac{1}{\alpha-1}} \tilde{z}(z)^{\frac{1}{\alpha}} \quad \text{and} \quad x^*(z) = \left(\frac{E}{X^{\alpha}}\right)^{\frac{1}{1-\alpha}} \mu_d^*(z)^{\frac{1}{\alpha-1}} \tilde{z}^*(z)^{\frac{1}{\alpha}}. \tag{27}$$

Substituting these expression into the preferences in equation (4), we obtain

$$\begin{aligned} X^{\alpha} &= \left(\frac{E}{X^{\alpha}}\right)^{\frac{\alpha}{1-\alpha}} \left(\frac{1}{2}\int_{\underline{\omega}}^{\bar{\omega}} \left(\mu_d(z)^{\frac{\alpha}{\alpha-1}} \tilde{z}(z) + \mu_d^*(z)^{\frac{\alpha}{\alpha-1}} \tilde{z}^*(z)\right) \mathrm{d}F(z)\right) \\ &= \left(\frac{E}{X^{\alpha}}\right)^{\frac{\alpha}{1-\alpha}} \bar{\mu}_d^{\frac{\alpha}{\alpha-1}} \bar{z} \underbrace{\left(\frac{1}{2}\int_{\underline{\omega}}^{\bar{\omega}} \left(\left(\frac{\mu_d(z)}{\bar{\mu}_d}\right)^{\frac{\alpha}{\alpha-1}} \frac{\tilde{z}(z)}{\bar{z}} + \left(\frac{\mu_d^*(z)}{\bar{\mu}_d}\right)^{\frac{\alpha}{\alpha-1}} \frac{\tilde{z}^*(z)}{\bar{z}}\right) \mathrm{d}F(z)\right)}_{=\mathscr{D}_1^{\frac{\alpha}{\alpha-1}}}, \end{aligned} \tag{28}$$

where average productivity and average domestic markups are respectively defined as

$$\bar{z} = \frac{1}{2}\int_{\underline{\omega}}^{\bar{\omega}} \left(\tilde{z}(z) + \tilde{z}^*(z)\right) \mathrm{d}F(z) \quad \text{and} \quad \bar{\mu}_d = \frac{1}{2}\int_{\underline{\omega}}^{\bar{\omega}} \left(\mu_d(z) + \mu_d^*(z)\right) \mathrm{d}F(z).$$

In the first line of equation (28), we use the property of the refinement strategy that asymmetric equilibria are $(n, n-1)$ or $(n-1, n)$ with probabilities $1/2$ and $1/2$, and the property that both countries are symmetric. To simplify notation, we use the property that when a product is in an asymmetric $(n, n-1)$ equilibrium in the home country, the same product is in an $(n-1, n)$ equilibrium in the foreign country. This allows us to use asterisks to refer to the $(n-1, n)$ equilibria in the home market, which by symmetry are equal to $(n-1, n)$ equilibria in the foreign market.

For a given total expenditure E, the component $\mathscr{D}_1$ measures the efficiency cost of markup dispersion resulting in a misallocation of labor across the production lines. Notice that if there is no markup dispersion, i.e. if $\mu_d(z) = \mu_d^*(z) = \bar{\mu}_d$ for all z, then $\mathscr{D}_1 = 1$. As we show below, markup dispersion also affects E, implying that $\mathscr{D}_1$ is a partial measure of the total efficiency costs of markup dispersion.

Using the production technology in equation (3), the labor demand of domestic and foreign firms producing in the product line z are, respectively,

$$\ell(z) = \tilde{z}(z)^{\frac{\alpha-1}{\alpha}} \mathscr{A}(z)\left(q_d(z) + q_f(z)\right) + \lambda \quad \text{and} \quad \ell^*(z) = \tilde{z}^*(z)^{\frac{\alpha-1}{\alpha}} \mathscr{A}^*(z)\left(q_f^*(z) + q_d^*(z)\right) + \lambda,$$

where, as in equation (16),

$$\mathscr{A}(z) = \frac{q_d(z) + \tau q_f(z)}{q_d(z) + q_f(z)} \quad \text{and} \quad \mathscr{A}^*(z) = \frac{q_d^*(z) + \tau q_f^*(z)}{q_d^*(z) + q_f^*(z)}.$$

The reciprocal dumping inefficiency factors $\mathscr{A}^{-1}$ and $\mathscr{A}^{*-1}$, both in the interval $(0,1]$, measure the inefficiencies emerging from two-way trade in identical goods.[17]

The contribution of products with initial productivity z to total labor demand (including research labor) is

$$\tilde{\ell}(z)\mathrm{d}F(z) = \left(\frac{1+\hat{\eta}}{2}\left(n(z)\mathscr{A}(z)\big(q_d(z)+q_f(z)\big)\tilde{z}(z)^{\frac{\alpha-1}{\alpha}} + \right.\right.$$

$$\left.\left. + \; n^*(z)\mathscr{A}^*(z)\big(q_d^*(z)+q_f^*(z)\big)\tilde{z}^*(z)^{\frac{\alpha-1}{\alpha}}\right) + \tilde{n}(z)\lambda\right)\mathrm{d}F(z)$$

where $\tilde{n}(z) = 1/2\big(n(z)+n^*(z)\big)$ is the average number of firms with initial productivity z. The factor $1+\hat{\eta}$ originates from using equation (9) to express research labor as a proportion $\hat{\eta}$ of variable production labor.

The labor market clearing condition is

$$\int_{\underline{\omega}}^{\bar{\omega}} \tilde{\ell}(z)\mathrm{d}F(z) = 1,$$

where the right hand side represents the total labor supply (normalized to one by assumption). Let us conjecture that $\tilde{z}(z)/\tilde{z}^*(z) = a^{\frac{\alpha}{1-\alpha}}$, where a is an unknown constant which is independent of z. In the case of a symmetric equilibrium $a=1$. This conjecture is verified in all our simulations.Then,

$$\tilde{\ell}(z) = \frac{1+\hat{\eta}}{2}\Big(\underbrace{n(z)\mathscr{A}(z)q_d(z) + a\,n^*(z)\mathscr{A}^*(z)q_f^*(z)}_{=\,\tilde{A}(z)x(z)} + \underbrace{n(z)\mathscr{A}(z)q_f(z) + a\,n^*(z)\mathscr{A}^*(z)q_d^*(z)}_{=\,a\tilde{A}^*(z)x^*(z)}\Big)\,\tilde{z}(z)^{\frac{\alpha-1}{\alpha}} + \tilde{n}(z)\lambda.$$

Substituting this expression into the labor market clearing condition and rearranging terms gives

$$\frac{1}{2}\int_{\underline{\omega}}^{\bar{\omega}}\Big(\tilde{\mathscr{A}}(z)x(z) + a\tilde{\mathscr{A}}^*(z)x^*(z)\Big)\tilde{z}(z)^{\frac{\alpha-1}{\alpha}}\mathrm{d}F(z) = \mathscr{L},$$

where $\mathscr{L} = (1-\bar{n}\lambda)/(1+\hat{\eta})$ measures total variable production labor and $\bar{n} = \int \tilde{n}(z)\mathrm{d}F(z)$ is the average number of domestic firms. Using equation (27) to substitute for $x(z)$ and $x^*(z)$, and rearranging terms

$$\left(\frac{E}{X^{\alpha}}\right)^{\frac{1}{1-\alpha}}\int_{\underline{\omega}}^{\bar{\omega}}\frac{1}{2}\Big(\tilde{\mathscr{A}}(z)\mu_d(z)^{\frac{1}{\alpha-1}}\tilde{z}(z) + \tilde{\mathscr{A}}^*(z)\,\mu_d^*(z)^{\frac{1}{\alpha-1}}\tilde{z}^*(z)\Big)\,\mathrm{d}F(z) = \mathscr{L}. \tag{29}$$

Finally, we use equation (28) to substitute for $(E/X^{\alpha})^{\frac{1}{1-\alpha}}$ and obtain

$$X = \bar{\mathscr{A}}^{-1}\,\bar{z}^{\frac{1-\alpha}{\alpha}}\,\mathscr{D}\,\mathscr{L}, \tag{30}$$

[17] Notice that at a symmetric (n,n) equilibrium $\mathscr{A}(z) = \mathscr{A}^*(z) = \mathscr{A}$ which is independent of z and has the closed-form expression in equation (16).

where

$$\bar{\mathscr{A}} = \frac{1}{2}\int_{\underline{\omega}}^{\bar{\omega}} \left(\tilde{\mathscr{A}}(z)\,\frac{\tilde{z}(z)}{\bar{z}} + \tilde{\mathscr{A}}^*(z)\,\frac{\tilde{z}^*(z)}{\bar{z}}\right)\mathrm{d}F(z).$$

The first factor in equation (30) is a measure of the average reciprocal dumping inefficiency. The second factor measures the contribution of average productivity $\bar{z}$, which is the channel through which welfare benefits from innovation. The third factor measures the welfare effect of markup dispersion. This is defined as $\mathscr{D} = (\mathscr{D}_2/\mathscr{D}_1)^{\frac{1}{1-\alpha}}$ with

$$\mathscr{D}_2 = \int_{\underline{\omega}}^{\bar{\omega}} \frac{1}{2}\left(\frac{\tilde{\mathscr{A}}(z)}{\bar{\mathscr{A}}}\left(\frac{\mu_d(z)}{\bar{\mu}_d}\right)^{\frac{1}{\alpha-1}}\frac{\tilde{z}(z)}{\bar{z}} + \frac{\tilde{\mathscr{A}}^*(z)}{\bar{\mathscr{A}}}\left(\frac{\mu_d^*(z)}{\bar{\mu}_d}\right)^{\frac{1}{\alpha-1}}\frac{\tilde{z}^*(z)}{\bar{z}}\right)\,\mathrm{d}F(z).$$

That is, $\mathscr{D}_2$ measures the general equilibrium efficiency costs of markup dispersion operating through expenditures, E. Notice that if there is no markup dispersion, i.e. if $\mu_d(z) = \mu_d^*(z) = \bar{\mu}_d$ for all z, then $\mathscr{D}_2 = 1$. Consequently, the $\mathscr{D}$ factor is a measure of the inefficiencies associated to markup dispersion which include all general equilibrium feedbacks. Finally, the factor $\mathscr{L}$ measures labor allocated to variable production activities. This factor channels the presence of fixed costs, which reduces labor available for variable production as well as R&D. Notice that $\mathscr{L}$ is inversely proportional to the number of firms, as more firms operate in the economy more labor resources a wasted on fixed costs. It also reflects the tradeoff between allocating labor to production or R&D. For simplicity we refer to this as the increasing returns channel.

It is important to notice that the average markup, $\bar{\mu}_d$, is not present in the decomposition in equation (30). Since there is no alternative use of labor than the composite good X, a change in the average markup cannot divert the use of labor to other purposes.[18] The only possible channel through which the average markup may operate is through the entry condition. A reduction in markups makes production less profitable, reducing the number of firms and then fixed product costs, increasing variable production labor. This indirect effect of competition operating through the entry conditions is captured by the factor $\mathscr{L}$.

4 Numerical analysis

We discipline the model's predictive scope using US data before numerically exploring its key properties. In particular, we calibrate the seven parameters α, λ, $\bar{\omega}$, $\underline{\omega}$, κ, τ, and η, to reproduce some key US firm-level and aggregate statistics.[19] We target an R&D-to-sales ratio of 10%, which is the

[18]In Impullitti and Licandro (2018), since the composite good is competing with a homogeneous good for the use of labor, a reduction in markups reallocates labor from the production of the homogeneous good to the composite good, improving efficiency and generating welfare gains.

[19]In our model firms operating in the same product line have the same production technologies and produce perfectly substitutable goods. Although the model is highly stylized, an empirical counterpart of a product line could be, for example, smart phones. In this line a few top-end powerful firms share the domestic and the global market and operate with similar productivities. To get a sense of the empirical mapping, in NAICS industry classification, our smart phone example belongs

average in 1993-2013 in Foster et al. (2020).[20] We also target an export to sales ratio of 14% as found in Bernard et al. (2007)). Using Compustat data for 2012, Edmond et al. (2019) find an average markup of 26%, and they also report the sales distribution. We target both.

The efficiency of the R&D technology A is a scale parameter which does not affect the equilibrium, but merely controls the link between the actual productivity $\tilde{z}$ and the initial level z. We set A to 3.0375 in order for the difference between the actual productivity $\tilde{z}$ and the initial level z to be on average 1%, roughly matching the US long run TFP annual growth rate (Penn World tables).[21] We normalize population size to 1.

Table 1: Summary of calibration targets.

Calibration target	Data	Model	Source
R&D to sales ratio	17%	16.7%	Foster et al. (2020)
Export to sales ratio	14%	13.8%	Bernard et al. (2007)
Average markup	34.6%	29.8%	Edmond et al. (2020)
Fraction of firms with relative sales			Edmond et al. (2020)
≤ 1	87.7%	72%	
≤ 2	94.2%	94%	
≤ 5	97.9%	99.4%	
≤ 10	99.0%	99.9%	

Notes. This table lists the empirical targets and their corresponding model moments.

The calibrated parameters are jointly determined and do not correspond one-by-one to a specific target. Table 1 shows the model fit and Table 2 summarizes the calibrated parameters. Albeit stylized, the model provides a decent fit for all the targeted statistics. Relative sales are defined as the average sales of firms in a given size class and industry relative to the average sales of all firms in that industry. The data suggest that about 94% of all firms sell less than twice the industry average, about 98% sell less than five times the average and about 99% sell less than ten times the average. The model fits this distribution well.

to sector 334220, "Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing". This sector includes a large set of products ranging from Airborne radios to cellular phones, from smart phones to televisions (more than 30 different and quite broadly defined types of products). A product line in our model cannot be NAICS 334220, since we have a small number of firms (up to three in the calibration) competing tightly in the production of highly substitutable goods: Iphone 7 competes with Samsung Galaxy s7, but not with Sony Smart TV SD9. Hence, if we think about our product lines as sectors, there would not be a clear empirical counterpart for them, not even at the 6-digit level. For this reason, we interpret our model as a model of heterogeneous firms and target firm-level moments in the data.

[20] Foster et al. (2020) combine the Survey of Industrial Research and Development (SIRd), Business Research and Development and Innovation Survey (BRDIS), and the Longitudinal Business Database (LBD). De Ridder (2020) finds similar results with Computstat; a 9% R&D intensity over 2000-2015.

[21] It is possible to interpret our static model as a special case of a dynamic model. Hence, it is useful to have the productivity jump mimicking the long-run growth rate in the data.

Table 2: Summary of calibrated parameters.

Parameter	Interpretation	Value
α	Elasticity of substitution	0.394
λ	Fixed cost of production	0.010
$\bar{\omega}$	Upper bound of the Pareto distribution	15
$\underline{\omega}$	Lower bound of the Pareto distribution	0.8
κ	Shape of the Pareto distribution	2.217
τ	Iceberg trade cost	1.21
η	Elasticity of the innovation function	0.1345

Notes. This table lists the calibrated parameters and their values. The parameters are jointly determined to minimize the distance between the empirical moments in Table 1 and the model counterparts.

4.1 Equilibrium properties

Since our model is quite stylized, the scope of the numerical analysis that follows is mostly to explore and understand the rich set of economic forces shaping the key outcomes rather than performing a comprehensive quantitative analysis. Hence, we will focus more on the theoretical insights produced by the simulations than on the quantitative results which are specific to our simple model and calibration strategy.

Cross-sectional properties. Figure 1 illustrates for the home economy the behavior of the key endogenous variables as a function of the initial productivity z. Three different market regimes are observed. First, for $z \in (0.8, 1.0725)$ markets are at the asymmetric $\{(2,1),(1,2)\}$ equilibrium. They represent 47.88% of product lines and around 28% of total consumption as measured by X. Second, for intermediary values of z, $z \in (1.0725, 13.73)$, markets are at the symmetric $(2,2)$ equilibrium, representing 52.09% of product lines and around 72% of consumption. Finally, the most productive varieties are at a symmetric $(3,3)$ equilibrium, representing a tiny fraction of both firms and consumption.

As can be observed in Figure 1, size, innovation and profits are monotonically increasing in productivity, conditional on belonging to the same regime.[22] As profits become sufficiently high, however, free entry attracts more competitors, and there is a switch of regime to one with a larger number of firms. At this higher productivity level, size, innovation and profits immediately jump down, but start raising again as productivity z increases.

Markups are constant within each regime, but declines when the number of firms increases.[23] The domestic markup of home firms is larger in the $(1,2)$ relative to the $(2,1)$ equilibrium, because they face less competition in the domestic market. Entry plays a critical role determining markups. For high

[22] Notice that in the asymmetric regime, depending on the domestic economy being in the $(2,1)$ or the $(1,2)$ equilibrium, there are two possible domestic markups. Firms size, innovation and profits also show two slightly different values.

[23] Since market shares are the same for all firms in each product line, as stated in equations (14) and (15), markups are equal across product lines at a symmetric Cournot equilibrium.

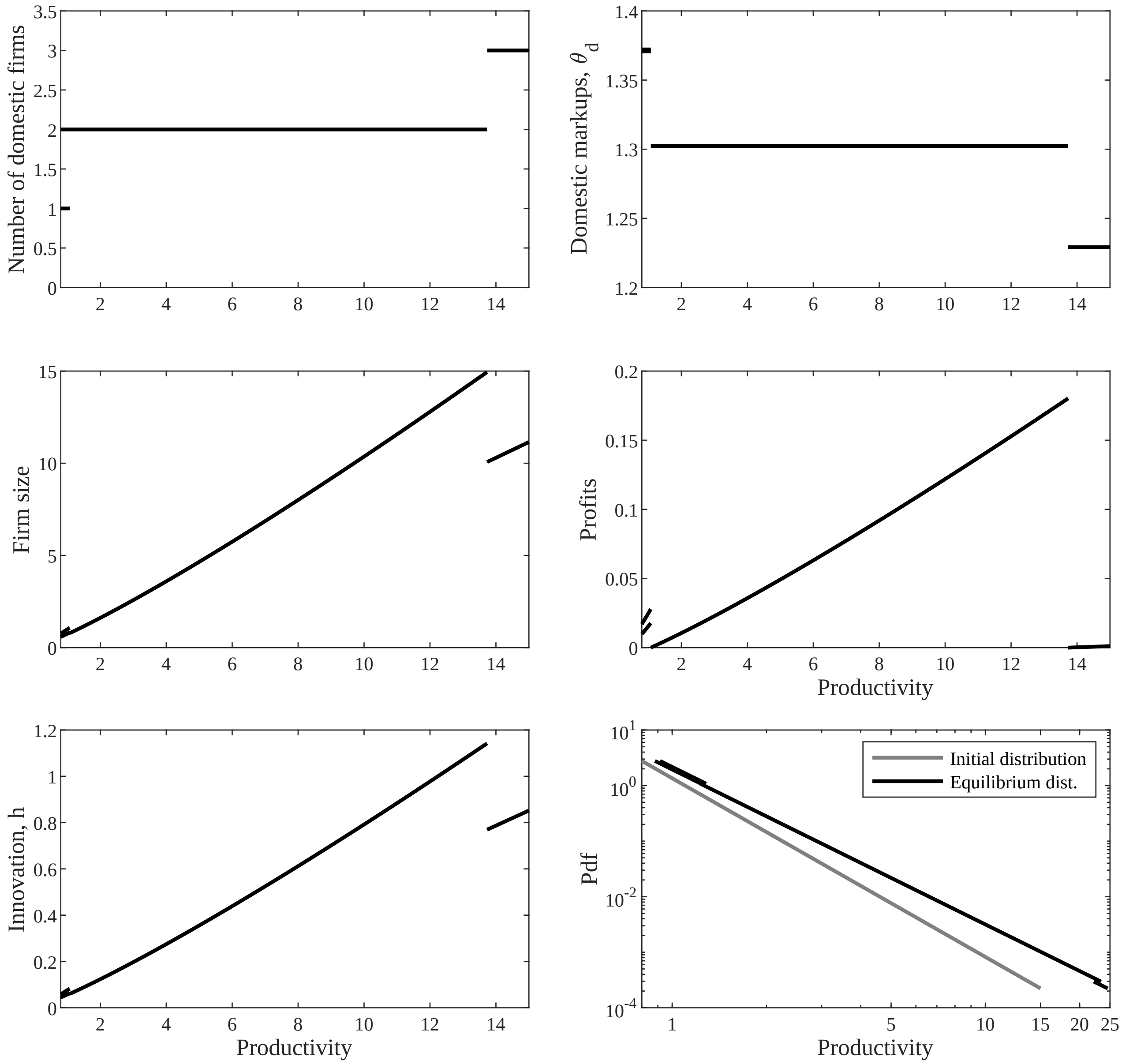

Figure 1: Cross-sectional equilibrium outcomes

Notes. Equilibrium outcomes for firms in the home country. *Productivity* refers to the initial draw z.

productive varieties, since the prospects of profits are larger, free entry entails stronger competition and lower markups.

Since more productive firms innovate more, innovation generates an equilibrium distribution of productivity that is more skewed than the distribution at entry. In particular, the top-right panel of Figure 1 suggests that the slope of the (log-log) *equilibrium* distribution, which is shaped by the innovation choice, is indeed flatter.

Trade liberalisation: Cross-section. In order to gain intuition in how trade barriers affect the equilibrium, we consider the effect on the key cross-sectional outcomes of moving the iceberg cost, τ, from its benchmark value of 1.21 to 1.1. The results are shown in Figure 2.

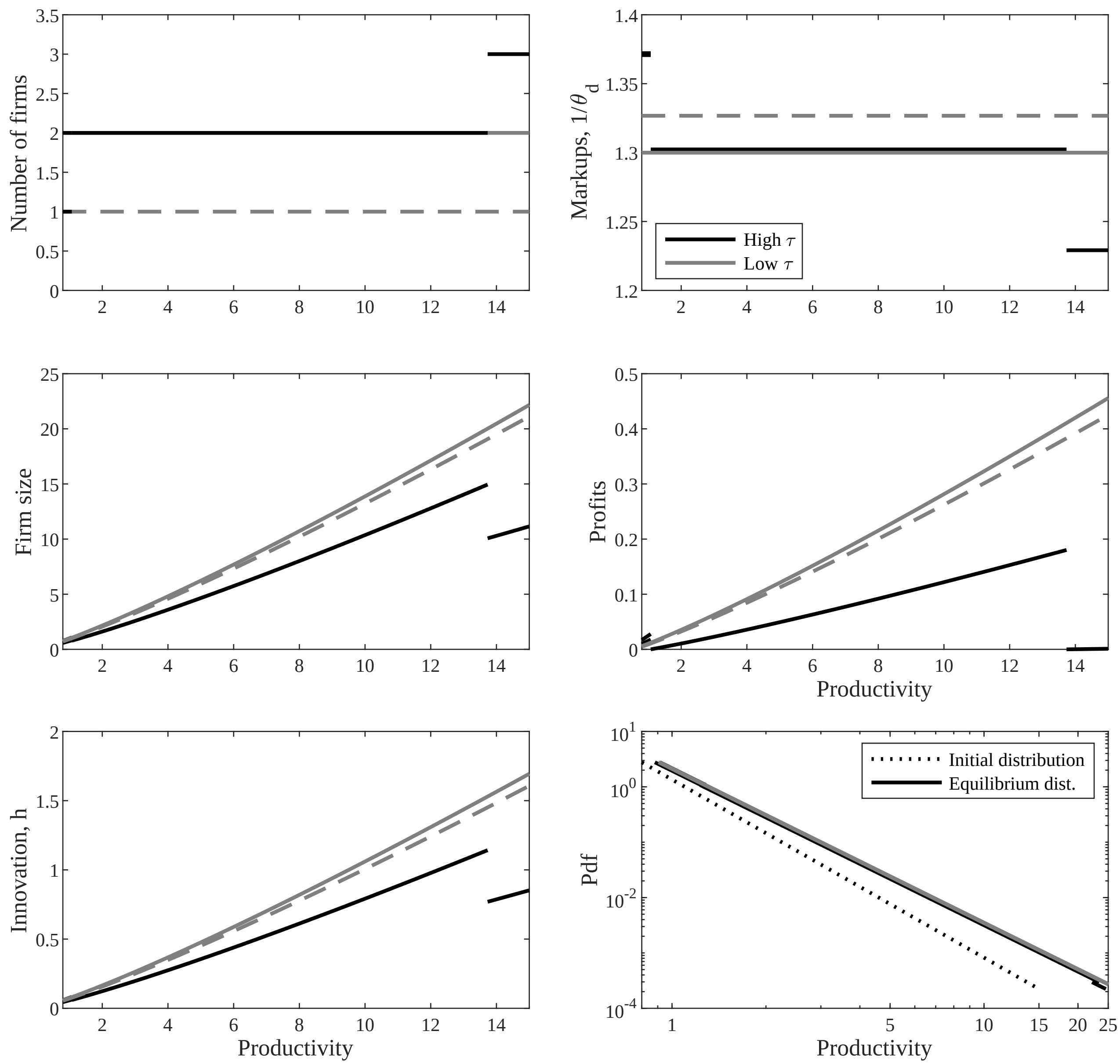

Figure 2: Trade liberalisation: cross-sectional outcomes

Notes. The black solid line replicates Figure 1. The grey lines show the equilibrium outcome at a lower trade cost, $\tau = 1.1$. *Productivity* refers to $\tilde{z}$. The solid grey line refers to the home country and the dashed grey line to the foreign country.

Reducing trade costs leads to an increase in competition. The more competitive environment lowers profits and induces a reduction in the number of firms through the entry condition. Indeed, all markets in a symmetric $(2,2)$ or $(3,3)$ equilibrium move to the asymmetric $\{(2,1),(1,2)\}$ equilibrium, with half of the product lines having two home firms and one foreign firm, and the other half having one home firm and two foreign firms. There are two opposing forces underpinning this result. First, as shown in Proposition 1 for symmetric equilibria and in Proposition 2 for asymmetric equilibria, for a given number of firms, the pro-competitive effect on the domestic markup dominates the anti-competitive effect on the export markup, therefore firms' average markups declines. Absent any exits in the market, the reduction in average markups leads to a fall in profits.[24] If profits turn negative, firms exit the market, and the equilibrium number of firms declines. The markups of the surviving firms – both in the domestic and the export market – are then higher than before the reduction in trade costs. This is the *concentration effect* of trade which, as we show below, is the key driver of most of our results

In those product lines that pre-liberalisation were at the $(2,2)$ and $(3,3)$ symmetric equilibria, the reduction in the number of firms produced by trade liberalisation undoes the pro-competitive effect derived in Proposition 1 in the absence of entry. In fact, due to the lower number of firms, not only does the export markup experience a stronger increase but, remarkably, there is a strong pressure for domestic markups to increase as well.[25] In product lines where the number of firms does not change, instead, the standard opposite effect of trade on the domestic and export markups stated in Proposition 2 (for an asymmetric equilibrium) attains. In fact, for the least productive varieties that stay in the asymmetric $\{(2,1),(1,2)\}$ regime, trade liberalisation reduces domestic markups and increases export markups.

Increased market concentration, results in an increase in the size of the surviving firms (left-central panel). Since innovation is cost-reducing, a larger firm-size implies stronger incentives to innovate, thereby raising labor allocated to R&D (left-bottom panel), and consequently firms' equilibrium productivity, $\tilde{z}$. The equilibrium distribution slightly moves to the right (right-bottom panel). Larger markups, larger size and higher productivity prompt larger profits, more than counterbalancing the reduction induced by foreign competition. As results of market concentration, trade liberalisation also induces an increase in profits in those product lines with a decline in the number of competitors (right-central panel).

Thus, taking stock, a more globalized economy is populated by *bigger*, *fewer*, more *innovative* and more *profitable* firms. The concentration effect is a novel result related to the introduction of free entry in a Cournot model of international trade. While the pro-competitive effect on domestic markups and the incomplete pass-through mechanism driving the increase in export markup is common to existing Cournot trade models (e.g. Brander and Krugman, 1983; Atkeson and Burstein, 2008) and monopolistic competitive models with variable markups (e.g. Arkolakis et al., 2019), the increase in concentration and its feedback effect on both domestic and export markups is a unique property of our model which, as we will see later, plays an important role for the gains from trade.

[24]In Appendix B we illustrate the relationship between trade liberalisation, markups and profits more in dept.

[25]In appendix B we show that trade liberalisation increases export markups more in product lines that experienced a reduction in the number of firms.

Trade liberalisation: Aggregate effects. Figure 3 shows the path of several key aggregate variables when moving from the benchmark trade cost to free trade. The figure illustrates the percentage change in each variable.

Trade liberalisation shows two distinct phases; in the first, trade costs are reduced by up to 30%, after which the second phase takes over taking the economy toward free trade. In the initial phase, the concentration effect of trade dominates, and the most pronounced changes in the key variables take place. The economy features markets at the asymmetric $\{(2,1),(1,2)\}$-equilibrium as well as markets at the symmetric $(2,2)$-equilibrium. For small reductions in trade costs, the economy also features a tiny fraction of markets at the $(3,3)$-equilibrium which vanishes very quickly as trade barriers shrink. All along the first phase of trade liberalisation, the pro-competitive effect induces a decline in the average number of firms triggering the concentration effect of trade. A more concentrated market with fewer and larger firms, increases innovation as well as productivity.

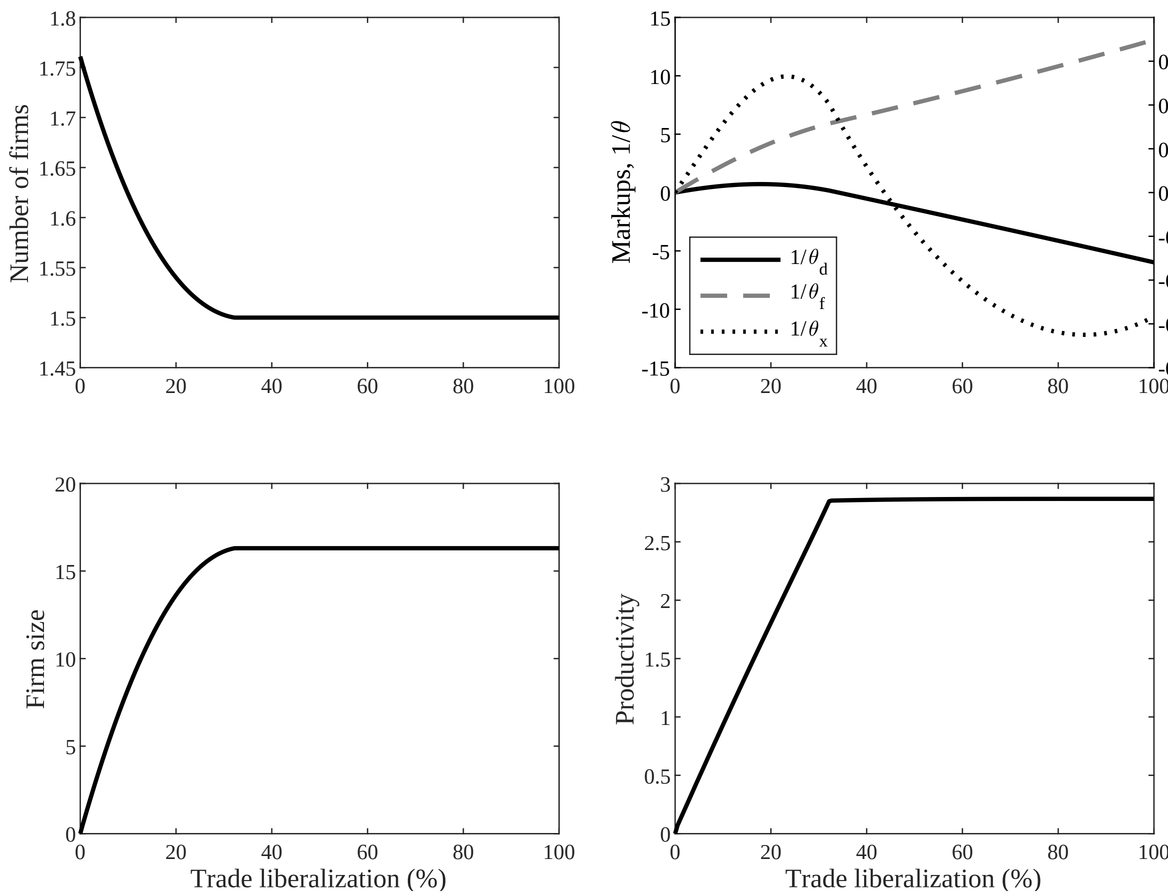

Figure 3: Trade liberalisation: aggregate outcomes

Notes. The figure plots the average number of firms, the average domestic and export markup (left scale), the average markup (right scale), the average firms size and productivity. All graphs illustrate the percentage change in each variable relative to the benchmark.

For any additional trade liberalisation, the economy is in the second phase where all markets are at the $\{(2,1),(1,2)\}$-equilibrium with a constant average number of firms and a stable average productivity. Due to the integer nature of the number of firms, changes in τ may have no further effect on the number of competitors, making the economy behave as if the number of firms was constant. When the number of firms does not change, the firm size is invariant, as reductions in trade costs simply reshuffle the composition of production toward more exports. Consequently, when the concentration effect of trade does not operate, a constant average firm size implies a constant innovation effort and constant average productivity.

As in the cross-sectional analysis above, the movement in markups can be interpreted combining the results in Proposition 1 and 2 with free entry. In the second phase of the liberalisation process – when the reduction in τ is larger than 30% – the number of firms remains constant and markups behave as described in Proposition 2. The domestic markup declines with trade liberalisation due to the pro-competitive effect of trade. The export markup raises due to the standard incomplete pass-through channel. For most of this phase the former dominates and the aggregate markup declines, albeit only slightly. In the initial phase, the pro-competitive effect of trade induces market concentration which leads to an even stronger increase in the export markup than in the second phase where the number of firms is constant. Notably, the increase in concentration more than compensates the pro-competitive effect of a lower trade cost, and the domestic markup increases as well. Since both markups rise, in our initial phase of liberalisation, trade increases the aggregate markup.

Taking stock, the model has a rich set of implications for the relationships between trade, markups and concentration. Under some liberalisation scenarios trade increases both markups and concentration, under others markups decline while concentration does not change.[26] Notably, changes in concentration, rather than changes in markups are the key drivers of the innovation and productivity effects of trade and, as we see next, of the overall welfare gains.

4.2 Gains from trade structure

This section measures welfare gains from trade following a reduction in variable trade costs, τ, away from its benchmark level towards free trade, and decomposes these gains into their main sources.[27] Based on the analysis in Section 3.4, welfare at equilibrium can be decomposed into

$$X(\tau) = \bar{\mathscr{A}}(\tau)^{-1}\bar{z}(\tau)^{\frac{1-\alpha}{\alpha}}\mathscr{D}(\tau)\mathscr{L}(\tau), \tag{30}$$

where the dependence on τ is made explicit. The last term of this expression, $\mathscr{L}(\tau)$, represents total labor allocated as a variable factor to the production of consumption goods. The increasing returns channel of the gains from trade operates via this term. The other three terms measure the average productivity of variable production labor, decomposed into the reciprocal dumping inefficiency factor $\bar{\mathscr{A}}^{-1}$; the contribution of innovation through average productivity $\bar{z}$; and the effect of markup

[26] This results provide new insights in the recent debate on the dynamics of market power. Suggesting that globalisation can be at the root of the increase in markups and concentration observed in many countries in recent decades.

[27] In our framework, changes in aggregate consumption X are a compensating variation measure of welfare gains.

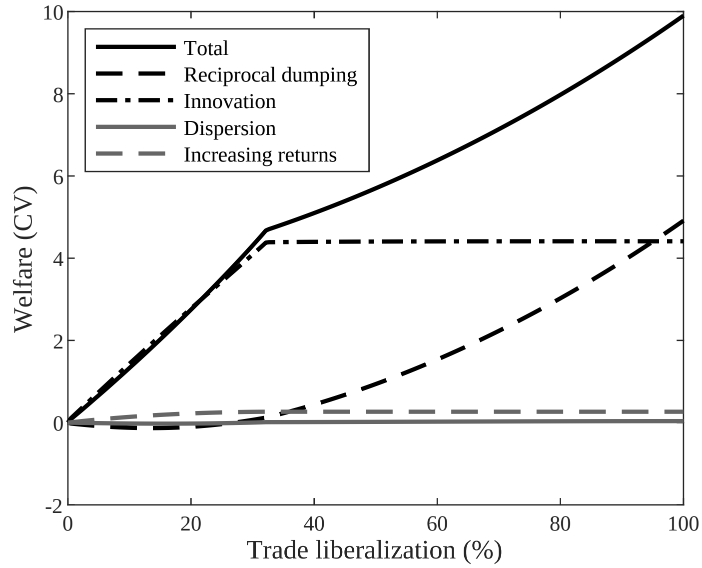

Figure 4: Gains from trade: Decomposition.

dispersion as measured by $\mathscr{D}$.

For each variable in (30), Figure 4 depicts the contribution of each channel – measured as a compensating variation – to total welfare, for a trade liberalisation ranging from 0% to 100%.[28] Moving from the benchmark to free trade produces a 10% increase in welfare. Removing the inefficiencies inherent to two-way trade in identical good, as measured by $\bar{\mathscr{A}}^{-1}$, explains slightly around 50% of these gains. The other 50% is almost completely accounted for by gains associated to innovation; as explained below, these gains are a direct result of the concentration effect of trade. Increasing returns and reductions in markup dispersion have only small and negligible welfare effects, respectively.

Figure 4 further reveals that the welfare gains from trade liberalisation follow two clearly differentiated phases. As we saw above, all along the first liberalisation phase the number of firms declines and concentration increases. The rise in market concentration induces an increase in firm size, boosting the incentives to innovate. The surge in innovation, in turn, boosts average productivity which accounts for most of the gains from trade in this phase. Further liberalisation does not affect the number of firms. The allocation of labor across product lines and between production activities – variable production, fixed production costs, and innovation – remains unchanged as well, and changes in τ only affect the allocation of production between domestic and export markets. Welfare gains from trade are then driven by the efficiency gains associated with the reduction of the reciprocal dumping distortion induced by two-way trade in identical products.[29]

In our benchmark calibration, markups do not seem to play an important role for the gains from trade. What is then the role of competition in shaping the welfare gains from trade? Trade liberalisation

[28]Given that (30) is linear in logs, percentage changes of $x(\tau)$ relative to the benchmark equilibrium are approximated by the difference between $\log\big(x(\tau)\big)$ and $\log\big(x(1.21)\big)$, $\tau = 1.21$ representing the benchmark, where $x = \{\bar{\mathscr{A}}^{-1}, \bar{z}, \mathscr{D}, \mathscr{L}\}$.

[29]Indeed, as it can be seen in Figure 4, the slope of the total welfare gains from trade liberalisation equals to the slope of the reciprocal dumping factor $\bar{\mathscr{A}}^{-1}$.

increases foreign competition. The increase in competition lowers domestic markups, and profits fall. In our first liberalisation phase, reduced profits leads to firm exit and increases market concentration. Thus, the pro-competitive effect of trade induces market concentration which, in turn, increase welfare via innovation. Market concentration also favours the efficient allocation of labor by reducing the distorsion associated to fixed production costs. What about markups? Changes in the level of the aggregate markup does not matter for welfare, since given the simple nature of our model, a reduction in the average markup is not allocative for labor.[30] Markup dispersion instead, generates a misallocation that trade can reduce. This can be an important source of the gains from trade, as shown in , but in our benchmark calibration the gains associated with it are negligible.

In conclusion, the quantitative magnitude of the channels in our welfare decomposition is related to the simple structure of our economy and the specific calibration, but the key message of this exercise is that entry and concentration can be key transmission channels of the pro-competitive gains from trade, above and beyond variable markups. Globalisation can increase firms' market power, both in terms of markups and concentration, and lead to a more competitive and more efficient economy.

Sensitivity. Here we explore how welfare gains from trade are affected by local changes in the elasticity of substitution across product lines α, the elasticity of research labour in the R&D technology η, the tail parameter of the Pareto distribution κ, and fixed production costs λ. The main conclusion we can extract from Table 3 is that any change in the environment triggering a larger *concentration effect* of trade also induces a rise in welfare gains. The reason is that more concentration leads to a larger contribution of both productivity gains, through innovation, and reduced fixed production costs by freeing labor to variable production activities.

Table 3: Sensitivity of welfare gains.

	Benchmark	$\bar{\alpha}$	$\underline{\alpha}$	$\bar{\eta}$	$\underline{\eta}$	$\bar{\kappa}$	$\underline{\kappa}$	$\bar{\lambda}$	$\underline{\lambda}$
Total	9.90	12.3	8.59	8.90	11.5	9.95	9.85	9.58	10.3
Reciprocal dumping	50%	31%	60%	54%	38%	49%	49%	52%	47%
Innovation	47%	65%	38%	44%	58%	48%	47%	45%	49%
Increasnig returns	2.7%	4%	1.2%	1.5%	4.1%	2.8%	2.6%	2.5%	2.8%
Dispersion	0.3%	.03%	0.5%	0.4%	0.1%	0.4%	0.4%	0.4%	0.3%

Notes. This table illustrates the welfare gains from reducing the iceberg cost, τ, from 1.21 to 1 under eight different parameterizations. The total gains and the decomposition are calculated according to equation (30). The decomposition is expressed as a percentage of the respective total gain. A parameter denoted $\bar{x}$ ($\underline{x}$) indicates an increase (decrease) of that parameter's value by 5% relative to benchmark.

A higher elasticity of substitution across varieties, α, leads to larger overall gains from trade, substantially boosting the contribution of the innovation channel, and marginally that of the fixed cost

[30]In Impullitti and Licandro (2018), for example, a reduction in markups affects welfare by reallocating labor from the homogenous to the differentiated good, reducing the distortions generated by oligopolistic competition.

channel. An increase in the research labor elasticity, η, instead has the opposite effect, reducing the total gains via a lower contribution of the innovation and the fixed cost channels. As in the the early literature on innovation and endogenous market structure (e.g. Dasgupta and Stiglitz, 1980; Sutton, 1991), the relationship between trade (market size), the number of firms and innovation is shaped by the characteristics of demand and innovation technology. High substitutability across products implies that markups and profits are less sensitive to changes in the number of firms, so the entry margin is less successful in restoring the free-entry condition, and we therefore observe a large drop in the number of firms following liberalisation. A more productive product line can accomodate more firms. So when foreign competition strikes, a strong innovation response can tame the effect of trade on the number of firms. A more efficient R&D technology implies that innovation is more effective in restoring free-entry and, as a consequence, a smaller adjustment to the number of firms is needed.[31] Although innovation is more efficient, the smaller concentration effect of trade, and the related smaller increase in firm size, dominate, reducing the welfare gains. These two exercises confirm the crucial role of competition in boosting welfare via its effect on concentration.

Changes in the dispersion of the initial productivity draw, controlled by parameter κ, have negligible effects. While an increase in the size of the fixed cost, λ, reduces the total gains, though by a small amount. This latter result materializes as both both the productivity and the increasing returns channel are weakened. This may appear surprising, but occurs as a higher fixed cost is also associated with fewer firms, even at the benchmark. As a consequence, the drop in the average number of firms produced by trade liberalisation is smaller. There is simply less room for the concentration effect of trade liberalisation to operate. A lower concentration effect in turn implies a smaller increase in firm size, and a smaller efficiency gains via the fixed cost channel. The latter channel is weaker because the smaller reduction in the number of firms more than compensate the effect of the larger fixed cost.

5 Discussion

In this final section, we provide a discussion of our results in relation to the outcomes of the recent literature on the gains from trade with a particular attention to the role of firm-level responses. Arkolakis et al. (2012) (ACR) show that in a class of models that satisfy three macro-level restrictions, the gains from trade are related to two sufficient statistics: the domestic trade share, and the trade elasticity. Furthermore, these gains are independent of the different microeconomic details of the model. The restrictions are: (i) balanced trade; (ii) aggregate profits as a constant share of aggregate revenues; and (iii), a CES demand system with a constant elasticity of trade with respect to variable trade costs. Among other results, they show that the standard intra-industry trade model of Krugman (1980), as well as its heterogeneous firm version of Melitz (2003) with an unbounded Pareto distribution, meet these restrictions. Therefore, a given increase in the domestic trade share produces the same gains in

[31] When the economy moves from benchmark to free trade, the drop in the average number of firms is 17% in the benchmark calibration, 37% with higher elasticity of substitution and 8% with higher innovation efficiency.

both models. Our oligopolistic model exists outside the ACR's class since it violates restrictions (*ii*) and (*iii*). The integer constraint implies that inframarginal firms make positive profits, which vary with trade costs. Moreover, while we do have a CES demand system, the elasticity of trade to trade cost is not constant.

Although our model is outside the ACR class, it is useful to ask whether once the changes in the trade elasticity are properly taken into account, the ACR formula provides a good approximation of the gains from trade in our economy. To accomplish this, we follow ACR, which show that in a large class of models the gains from trade can be expressed as

$$GFT = \frac{1}{\sigma} log \left(\frac{\lambda_d}{\lambda_d^{'}} \right),$$

where λ_d and $\lambda_d^{'}$ are the share of expenditures on domestic goods before and after the change in the trade cost, respectively, and σ is the trade elasticity defined as

$$\sigma = \frac{\mathrm{d} log \frac{1-\lambda_d}{\lambda_d}}{\mathrm{d} log \tau}.$$

Table 4 shows the gains from trade computed with the ACR formula and the associated trade elasticity, which we calculate using our model. The ACR gains of moving from the benchmark trade cost to 35% reduction (our first phase of liberalisation), gives rise to a welfare gain equal to about 3.7 percent consumption equivalents. Our model, in contrast, suggests gains of 4.8 percent. Moreover, moving from a 35% trade liberalisation to entirely free trade, the gains are 4.8 percent in ACR and about 5 percent in our model.

Table 4: Gains from trade using ACR

Trade liberalisation	0 to 35%	35% to 100%	0 to 100%
Trade elasticity	4.53	4.46	4.46
GFT: Model	4.83	5.06	9.90
GFT: ACR	3.74	4.84	8.65

Notes. We use ex-post elasticity in the computation of the ACR gains.

The model predicts larger gains from trade in the first phase of liberalisation, where the concentration effect takes place, while the full liberalisation scenario suggests that the ACR formula provides a good approximation of the gains from trade in our economy. As observed by Edmond et al. (2015) – who perform a similar exercise for their economy – one could expect the ACR formula to provide a good approximation for the gains from trade, as important aspects of markup variation are captured by the trade elasticity, and thus key features of variable markups are embedded in this formula. Indeed it does. The micro details of the model are important, however, as they are used to compute the the appropriate trade elasticity which is an endogenous object.[32]

6 Conclusion

This paper proposes an exploration of the gains from trade in an economy where technology and market structure respond to changes in openness. It presents a general equilibrium model of trade with heterogeneous firms under oligopolistic competition with free entry and innovation. Our results highlight the key role of free entry in shaping the reallocations produced by trade as well as the welfare implications. Trade liberalisation increases competition putting downward pressure on firms' profitability. Lower profit margins force some firms out of the market. Market shares and market power are reallocated toward the surviving firms, and the post-liberalisation economy is more concentrated and may feature higher markups. The increase in concentration generates welfare gains via two channels. First, welfare improves via increasing returns at the firm level. Second, the increase in market size brought about by trade-induced concentration increases innovation and productivity.

A new formula to decompose the welfare gains from trade is presented. Besides increasing returns and innovation, trade affects welfare via two other channels. The waste produced by two-way trade in identical goods – the reciprocal dumping inefficiency – and the misallocation due to markup dispersion. A calibrated version of the model suggests that innovation and the reciprocal dumping inefficiency are the quantitatively dominant sources of the gains from trade.

For simplicity and to highlight the role of strategic interaction, we have assumed that oligopolistic firms competing in the same product line produce perfectly substitutable goods. Removing this assumption and introducing imperfect substitutability within each Cournot game, as in Atkeson and Burstein (2008) and Edmond et al. (2015), implies that the reduction of the number of firms produced by trade negatively impacts welfare via a lower product variety. Moreover, vertical differentiation eliminates the inefficiency due to reciprocal dumping. We leave these generalisations to future research.

The challenges in modelling, and solving, a framework with free entry that respects the integer constraint have restricted the adoption of oligopolistic market structures in international trade. At the same time, considering free entry while ignoring the integer problem – an easy shortcut to make this class of models operative – has been received with skepticism.[33] On the one hand, defining firms on a continuous measure seems to contradict the idea that each market is characterized by a few powerful firms, and therefore undermines the possibility that they interact strategically. On the other

[32] The small changes in the ex-post elasticity also contribute to the similarity of gains from trade in the model and using the ACR formula. Repeating the exercise with the ex-ante elasticity produces larger differences, because the big change in the elasticity happens in the first phase of liberalisation, when the concentration effect is at play. The elasticity is 14.7 at the benchmark trade cost and drops to 4.53 with a 35% reduction in the trade cost. In this case, the alignment of the results of the two ways of computing the gains from trade can be obtained used the average elasticity.

[33] Another option to introduce oligopolistic firms in trade models avoiding the entry problem is to use a mixed market structure. Within each industry a monopolistically competitive fringe of firms competes with a small number of oligopolists. Entry and exit is limited to the monopolistically competitive firms, while there is no entry/exit of oligopolists (e.g. Parenti, 2018; Graziano, 2020).

hand, some have advanced the idea that "free entry ignoring the integer problem is not a distinctive market structure", as its implications are similar to those of monopolistic competition or even to perfect competition (Neary, 2010).[34] In the previous version of this paper, Impullitti et al. (2017) we present the same model but ignoring the integer constraint. Strategic interaction among firms operates via the same mechanisms as in the current version, suggesting that the first problem might be mostly quantitative. Moreover, although the calibration and the quantitative results differ, the role of free entry in shaping the gains from trade is similar. Trade increases competition, pushes firms out of the market thereby increasing concentration. Concentration produces welfare gains via innovation and increasing returns. These preliminary observations suggest that a more systematic assessment of the cost and benefits of respecting the integer constraint is needed to expand the adoption of this class of models in international trade.

[34]For example, Brander and Krugman (1983) show that, as in the standard model of trade under monopolistic competition (Krugman, 1980), trade liberalisation cannot decrease welfare.

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A Computational details

Define $\Delta = E/X^{\alpha}$, $x = nq_d + n^* q_f^*$ and $x^* = nq_f + n^* q_d^*$. Then given Δ, and for any z, n, and n^*, optimality is given by six first order conditions

$$\Delta\Big((\alpha-1)x^{\alpha-2}q_d + x^{\alpha-1}\Big) = \Big(Ah^{\eta}z\Big)^{\frac{\alpha-1}{\alpha}}, \tag{A.1}$$

$$\Delta\Big((\alpha-1)x^{*\alpha-2}q_f + x^{*\alpha-1}\Big) = \tau\Big(Ah^{\eta}z\Big)^{\frac{\alpha-1}{\alpha}} \tag{A.2}$$

$$\Delta\Big((\alpha-1)x^{*\alpha-2}q_d^* + x^{*\alpha-1}\Big) = \Big(Ah^{*\eta}z\Big)^{\frac{\alpha-1}{\alpha}}, \tag{A.3}$$

$$\Delta\Big((\alpha-1)x^{\alpha-2}q_f^* + x^{\alpha-1}\Big) = \tau\Big(Ah^{*\eta}z\Big)^{\frac{\alpha-1}{\alpha}}, \tag{A.4}$$

$$h = \hat{\eta}\left(Ah^{\eta}z\right)^{\frac{\alpha-1}{\alpha}}\left(q_d + \tau q_f\right), \tag{A.5}$$

$$h^* = \hat{\eta}\left(Ah^{*\eta}z\right)^{\frac{\alpha-1}{\alpha}}\left(q_d^* + \tau q_f^*\right), \tag{A.6}$$

in the six unknowns $\{q_d, q_f, q_d^*, q_f^*, h, h^*\}$.

Profits are then given by

$$\pi(n, n^*, z; \Delta) = \Delta x^{\alpha-1}q_d + \Delta x^{*\alpha-1}q_f - \Big(Ah^{\eta}z\Big)^{\frac{\alpha-1}{\alpha}}\Big(q_d + \tau q_f\Big) - \lambda - h, \tag{A.7}$$

$$\pi^*(n^*, n, z; \Delta) = \Delta x^{*\alpha-1}q_d^* + \Delta x^{\alpha-1}q_f^* - \Big(Ah^{*\eta}z\Big)^{\frac{\alpha-1}{\alpha}}\Big(q_d^* + \tau q_f^*\Big) - \lambda - h^*. \tag{A.8}$$

And market clearing implies

$$1 = \int_z (q_d + \tau q_f + h + \lambda n)dF(z), \tag{A.9}$$

$$1 = \int_z (q_d^* + \tau q_f^* + h^* + \lambda n^*)dF(z). \tag{A.10}$$

To solve the model we heavily exploit symmetry across countries, and proceed according to

1. Guess for a value of Δ.

2. Find the values of $z \in [\underline{\omega}, \bar{\omega}]$ for which the economy switches equilibrium type. In particular,

   (a) For $n = 1, 2, \ldots$ we find $\{z_{(n,n)}\}_{n=1}$ as the values that satisfy $\pi(n, n, z_{(n,n)}; \Delta) = 0$. Any value $z_{(n,n)} \notin [\underline{\omega}, \bar{\omega}]$ is discarded.

   (b) Subsequently, for $n = 0, 2, \ldots$, we find $\{z_{(n+1,n)}\}_{n=0}$ as the values that satisfy

$$\pi(n+1, n, z_{(n+1,n)}; \Delta) \times \pi(n, n+1, z_{(n+1,n)}; \Delta) = 0,$$

and

$$\pi(n+1,n,z_{(n+1,n)};\Delta) \geq 0, \quad \pi(n,n+1,z_{(n+1,n)};\Delta) \geq 0.$$

Again, any value $z_{(n+1,n)} \notin [\underline{\omega}, \bar{\omega}]$ is discarded. Moreover, any value $z_{(n+1,n)} > z_{(n+1,n+1)}$ is discarded as well.

(c) The number of firms at the end-points, $z = \underline{\omega}$ and $z = \bar{\omega}$, is then found by following section 3.2.

(d) Lastly, we combine $\{z_{(n,n)}\}_{n=1}$ and $\{z_{(n+1,n)}\}_{n=0}$ to an ascending vector, $\mathscr{Z}$, along with their associated number of firms. To give an example, in the benchmark, $\mathscr{Z}$, is given by

$$\mathscr{Z} = \{z_{(2,1)}, z_{(2,1)}, z_{(2,2)}, z_{(3,3)}, z_{(3,3)}\},$$

where the first and last element corresponds to $z = \underline{\omega}$ and $z = \bar{\omega}$, respectively. Notice too that $z_{(3,2)}$ and $z_{(4,3)}$ are not in this set as in the computations $z_{(3,2)} > z_{(3,3)}$, and $z_{(4,3)} > \bar{\omega}$.

3. In between each element of $\mathscr{Z}$ we construct a grid for z containing 100 equidistant points, and solve equations (A.1)-(A.6) at each gridpoint.

4. We use numerical integration to evaluate the market clearing condition in equation (A.9). If labor demand exceeds (falls short of) supply we adjust Δ upwards (downwards) using the Bisection method, and return to step 1.

All root finding operations uses Newton's method with an analytic Jacobian. The first order conditions are solved to a precision of $1e(-9)$. All functional approximations throughout the paper are using linear interpolation, and all numerical integrations use a global adaptive quadrature.

B Trade liberalisation, markups and profits

In this appendix, we first show the effects of the liberalisation exercise in Figure 2, on the export markups. Figure B.1 show that the export markup increase in for all firms after liberalisation, but the change in stronger in those product lines experiencing a reducing in the number of firms.

Next, in order to see the link link between trade liberalisation, markups, and profits more clearly, we zero in on the response of one firm. The black solid lines in the right panel of figure B.2 show equilibrium profits for a firm at product line $z = 3$, for trade costs ranging from the benchmark, labeled as a 0 percent liberalisation, to free trade, labeled as 100 percent. The grey lines illustrate the off equilibrium paths when entry/exit is prohibited. The right panel show the corresponding pattern for markups; both in the domestic market and in the foreign. As can be seen from the graph, a market in this product line experiences a shift in the equilibrium type at a trade liberalisation of about 25 percent,

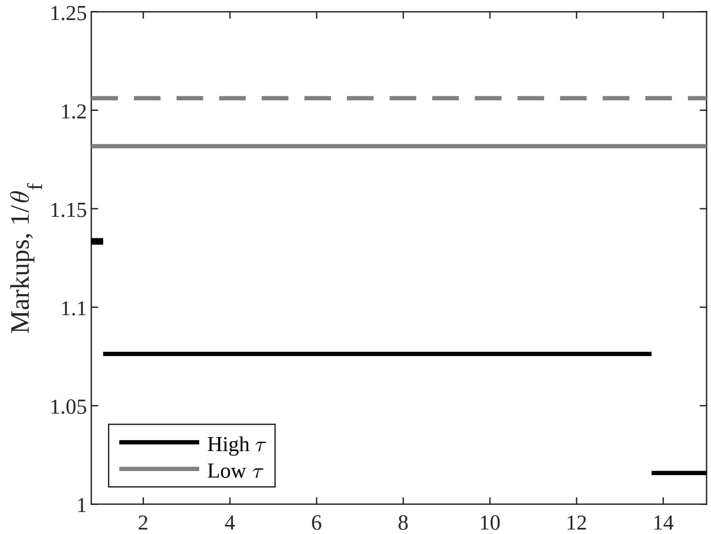

Figure B.1: Trade liberalisation: export markups

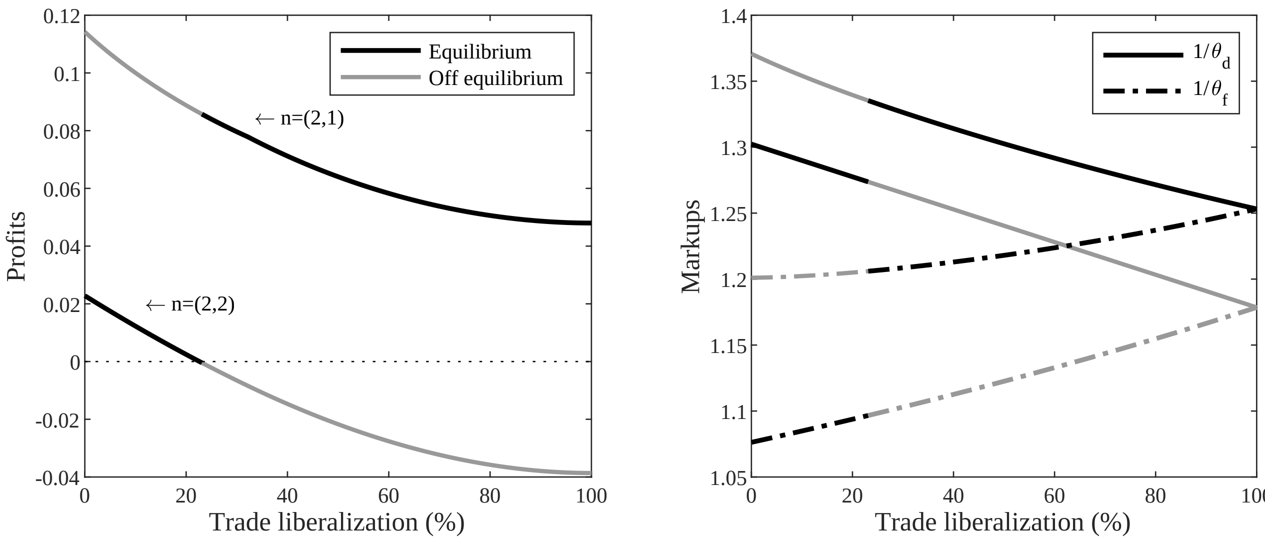

Figure B.2: Trade liberalisation: Off equilibrium outcomes

Notes. The graph shows the profits (left panel) and markups (right panel) for a product line with $z = 3$. The equilibrium outcome is in black, while the off equilibrium outcome is in grey. Both panels show the results for a home firm in either the symmetric $(2,2)$ equilibrium, or the asymmetric $(2,1)$ equilibrium.

moving from the symmetric $(2,2)$ equilibrium to the asymmetric $\{(2,1),(1,2)\}$ equilibrium.[35] The results are as described above: absent exit, competition pushes profits down to negative territory. The domestic markup falls, while the markup in the foreign market increases. Because of negative profits, however, one firm will exit the market. In the new equilibrium, markups shift up, exceeding the

[35] The graph shows the effect of a product line moving to the $(2,1)$ equilibrium. This is to conserve space and enhance transparency of the graph. However, the result when the product line instead moves to the $(1,2)$ equilibrium is very similar.

previous values. As a result, profits increase. While not illustrated in the graph, the remaining firms are bigger and substantially more innovative.