

# R&D in the Network of International Trade: Multilateral versus Regional Trade Agreements \*

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## Abstract

This paper argues that different types of trade liberalization – multilateral versus regional – may lead to different R&D and productivity levels of firms. Trade agreements between countries are modelled with a network: nodes represent countries and links indicate trade agreements. In this framework, the multilateral trade agreement is represented by the *complete* network, while the overlap of regional trade agreements is represented by the *hub-and-spoke* system. Trade liberalization, which increases the network of trade agreements, reinforces the incentives for R&D through the creation of new markets (scale effect) but it may also dampen these incentives through the emergence of new competitors (competition effect). As a result, productivity gains of regionalism versus those of multilateralism depend heavily on the relative number of regional trade agreements signed by countries. A *core* economy, signing relatively large number of trade agreements within the regional system, has higher R&D and productivity than a country in the multilateral system. But a *periphery* economy in the regional system has lower productivity gains than a country in the multilateral agreement.

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# 1 Introduction

In the era of unprecedented proliferation of regional trade agreements and simultaneous developments in the WTO, assessments of the relative economic benefits of multilateralism versus those of regionalism take on special significance. The existing literature has compared multilateral and regional trade arrangements in terms of welfare benefits, trade volumes, GDP levels and GDP growth rates.<sup>1</sup> However, to the best of my knowledge, no research has been done on the issue of potential variations in the impact of multilateral and regional trade liberalization on countries' *R&D* and *productivity*. The aim of this paper is to fill this gap and compare R&D and productivity of countries belonging to different types of trade systems – multilateral versus regional.

The existence of a link between trade liberalization and countries' R&D\productivity is confirmed by substantial empirical evidence. Bustos (2010) finds that during the period of trade liberalization between Argentina and Brazil, companies in sectors benefiting from a comparatively higher reduction in Brazil's tariffs increased their spending on purchases of technology goods. Likewise, Treffer (2004) observes that the U. S. tariff concessions caused a boost in labor productivity of the Canadian firms in the most impacted, export-oriented group of industries. Similar patterns are shown by Bernard et al. (2006) for the U. S., by Topolova (2004) for India, by Aw et al. (2000) for Korea and Taiwan, by Alvarez and Lopez (2005) for Chile, and by Van Biesebroeck (2005) for sub-Saharan Africa.<sup>2</sup> Additionally, the positive effect of trade liberalization on productivity is substantiated by extensive theoretical work.<sup>3</sup>

What is missing in the literature is the evaluation of the impact on R&D and productivity of different types of trade liberalization – multilateral versus regional. In this paper I address this question by examining a simple theoretical model. The model has firms that compete in output and can improve their productivity by investing in costly R&D, where R&D is viewed broadly as

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<sup>1</sup>For an extensive research of theoretical models on this subject see Panagariya (2000). The empirical works are summarized in De la Torre and Kelly (1982), Srinivasan et al. (1993), and Frankel (1997). Other theoretical and empirical works include Krueger (1999), Bagwell and Staiger (1999a, b), Bhagwati (1993), Kowalczyk and Wonnacott (1992), Deltas et al. (2006), Goyal and Joshi (2006), Diao et al. (2003).

<sup>2</sup>The evidence on industry-level productivity improvements is presented in Baggs et al. (2002) for Canada, in Pavcnik (2002) for Chile, in Muendler (2004) for Brazil, in Bernard et al. (2006) for the U. S., in Del Gatto et al. (2006) for Europe, and in Alcalá and Ciccone (2004) for a range of countries.

<sup>3</sup>The theoretical models identify several channels through which international trade affects productivity at the industry and/or at the firm level: the improved allocation of resources through specialization (Grossman and Helpman (1991), Eckel and Neary (2010)), the knowledge spillovers effect (Rivera-Batiz and Romer (1991), Devereux and Lapham (1994)), the reallocation of economic activities from less to more productive firms (Melitz (2003), Bernard et al. (2007), Yeaple (2005)), the exploitation of economies of scale (Helpman (1981), Krugman (1980)), the pro-competitive effect of trade openness (Aghion et al. (2005), Peretto (2003), Licandro and Navas-Ruiz (2011)), and others. See World Trade Report 2008 for the survey.

any activity aimed at reducing the marginal cost of production.<sup>4</sup>

Since R&D is undertaken by individual firms, the return to R&D and hence, firm's incentives to innovate depend crucially on firm's market size, that is, the aggregate size of the market served by the firm. Specifically, as the cost of R&D is assumed to be independent of the amount produced, a larger market increases the benefits of innovation. The two major mechanisms through which trade affects firm's market size are the *scale* and the *competition* effect. The scale effect of trade is associated with the expansion of the overall market and therefore, it is indubitably positive. The competition effect is due to the increased number of competitors in the market and its sign is a priori ambiguous. It depends on which of two components of the competition effect, positive or negative, prevails. The negative component is associated with the immediate reduction in the market share of a firm as the number of competitors grows. The positive component is explained by a reduction in price markups and associated boost in demand as competition increases.<sup>5</sup> The interaction of these two components as well as the interaction of the scale and the overall competition effect depend on specific features of trade arrangements. The focus of this paper is on the *structural* features of trade arrangements, multilateral and regional, and on the impact they have on the resulting outcome of the scale and competition effect on firm's market size and R&D.

I model trade agreements between countries with a network. Nodes represent countries and a link between the nodes indicates the existence of a trade agreement. In every country, there is a single firm producing one good. The good is sold domestically and in markets of the trade partner countries subject to oligopolistic Cournot competition. There is, therefore, an intra-industry trade between countries which are directly linked in the network. In order to focus entirely on the role of the network structure and position of a country in the network, I abstract from differences in country size and take the trading relationship as a binary one where countries trade if they have a link and otherwise they do not. The network of trade agreements is regarded as exogenous; so, the issue of incentives that drive the formation of particular trade arrangements is left beyond the analysis.

The advantage of modelling trade agreements with a network is that it enables distinction between various types of trade systems. In particular, it allows me to focus on such differences between trade systems as the degree of countries' trade involvement (the number of trade agree-

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<sup>4</sup>Examples include developing new production technology, training of employees, internal re-organization of resources and factors of production.

<sup>5</sup>In fact, the ambiguity of the overall competition effect on market size and innovation has been a concern in the literature (Licandro and Navas-Ruiz (2011), Aghion et al. (2005)).

ments signed) and the nature of market interaction between countries (which countries trade and compete with each other, in which markets, the number of traders in each market, etc). Given the focus of this paper on the interaction between the scale and competition effects of trade liberalization within different types of trade systems, capturing exactly these differences is key.

I consider two classes of network structures associated with the multilateral and the regional scenarios of trade liberalization. The first class is symmetric, or regular, networks. It incorporates the case of a *complete* network structure – a network where any one country is directly linked to every other country. The complete network in this model represents the multilateral trade agreement. The second class of networks is asymmetric networks with two types of nodes: high and low degree nodes. This class of networks captures the basic characteristics of the so-called *hub-and-spoke* trade system, where some countries (hubs) have relatively large number of direct trade partners as compared to other countries (spokes), which are mainly involved in trade agreements with hubs. According to a number of contributions on regional trade agreements, the hub-and-spoke trade arrangement has become a typical outcome of the regional trade liberalization.<sup>6</sup> In the paper, I consider various architectures within the hub-and-spoke class of networks. I compare them with each other and with the multilateral trade network.

The modelling approach in this paper is closely related to the common approach in the strand of literature on R&D *co-operation* between firms in oligopoly. This strand of literature is well represented by the seminal papers, D’Aspremont and Jacquemin (1988) and Goyal and Moraga (2002). They consider a framework of Cournot competition, where at a pre-competitive stage firms can exert a cost-reducing effort. The typical element of this approach is that the rationale of co-operation between firms is the existence of R&D spillovers, which creates an externality. Co-operation is intended to internalize such an externality. Another related strand of literature is oligopoly models of international trade. They examine implications of strategic interaction between firms in the context of Cournot and Bertrand competition for positive and normative aspects of international trade, motives for trade, gains from trade, etc. Classic references include Brander (1981), Brander and Krugman (1983), Weinstein (1992), Yomogida (2008), Dixit and Grossman (1986), Neary (1994, 2002, 2009), and Eckel and Neary (2010).

Similarly to models with R&D co-operation, in this model firms compete in a Cournot fashion choosing individual R&D efforts and production levels in a two-stage non-cooperative game.

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<sup>6</sup>The concept of hub-and-spoke trade arrangement was first introduced in Lipsey (1990) and Wonnacott (1990). It was further developed in Lipsey (1991), Wonnacott (1991, 1996), Kowalczyk and Wonnacott (1991, 1992), Baldwin (2003, 2005), De Benedictis et al. (2005), and others.

However, in contrast to D’Aspremont and Jacquemin (1988), Goyal and Moraga (2002) and the related literature, I concentrate on the effects on R&D of market access and competition faced by firms within various types of trade agreements, rather than on the role of R&D collaboration or spillovers. Furthermore, as the subject of study in this paper is international relations with competition in each country, it is natural to consider that firms compete in several separate markets and every market is accessible only to those firms which have a trade agreement with that market. Instead, D’Aspremont and Jacquemin (1988) and Goyal and Moraga (2002) have standard oligopolistic competition in one central market. Clearly, the difference in market access and competition faced by firms as introduced in this paper results in heterogeneity between firms in terms of their market size, a feature which is absent from the previous models on R&D co-operation. The same feature of firms’ heterogeneity distinguishes this work from oligopoly models of trade, where firms are identical in terms of their aggregate market size.<sup>7</sup>

The primary result of the paper is that the impact of trade liberalization on firm’s R&D depends crucially on the features of trade agreements and on the position of the country in the network of trade agreements. I show that for the *same number of direct trade partners*, the R&D effort of a hub in the regional trade system is higher than that of a country in the multilateral agreement. On the other hand, the R&D effort of a spoke is lower than that of a hub and lower than the R&D effort of a country in the multilateral agreement, even if a country in the multilateral agreement has the same number of direct trade partners as a spoke.<sup>8</sup> Further, I find that the *aggregate* R&D investment within the multilateral trade agreement exceeds that in the *star* – the simplest representative of the hub-and-spoke trade system.<sup>9</sup>

Other important findings of the paper concern the *change* in R&D investments by firms as the network of trade agreements expands and the specific of this change in the multilateral and regional trade system. Consistent with the empirical evidence, I find that an increase in the number of direct trade partners enhances innovation of a firm in the multilateral system and of a hub in the regional system. New direct trade partners also improve R&D of a spoke provided that the markets of new trade partners are not ”overcrowded” with competing firms. Remarkably, in

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<sup>7</sup>A common assumption in this literature is that firms from all countries trade either on a single ”world market”, where the demand for good and competition between firms are increased compared to their autarky levels, or they trade in ”segmented markets”, perceiving markets of different countries as separate, but so that *all* firms have access to *all* markets and compete with each other.

<sup>8</sup>The same relative effects are found for the *welfare* and the *real income* values of countries in the stylized 3-country model by Deltas et al. (2005) and by Kowalczyk and Wonnacott (1992).

<sup>9</sup>Formally, the *star network* is a network in which there is a central country (hub) which is directly linked to every other country (spoke), while none of the other countries have a direct link with each other. The star in the present model is essentially a set of bilaterals of a hub with spokes, where each spoke has a trade agreement only with the hub.

the multilateral trade system this increase in R&D is accompanied by a decrease in firm's profit. I show that this has to do with the fact that both changes are caused by a price-reducing effect of competition, positive for R&D but negative for profits. Furthermore, while multilateral trade liberalization promotes R&D via price-reducing effect of competition, regional trade liberalization promotes R&D via a combination of positive scale and price-reducing competition effects. Also, while in the process of multilateral trade liberalization, a new country becomes a direct trade partner of *all* member countries and has an equally positive impact on their R&D, in case of regional trade liberalization, a new country becomes only a *two-links-away trade partner* for some countries and depresses their R&D. As a result, expansion of the trade network always promotes R&D of a firm in the multilateral system but in the regional, hub-and-spoke system, an impact of a new *direct* trade partner on firm's R&D is often positive, while an impact of *two-links-away* trade partner is negative.

To complete the analysis I study welfare implications of trade liberalization within the multilateral system and within a simple star. I find that as soon as trade costs are not too high, multilateral trade liberalization improves the social welfare of every country, while regional trade liberalization improves the welfare of the hub but reduces the welfare of spokes. Moreover, numerical simulations suggest that for the same number of trade partners, welfare of a hub in the star exceeds welfare of a country in the multilateral agreement;<sup>10</sup> yet, total welfare benefits in the multilateral system are higher than total welfare benefits in the star, at least in case of relatively low trade costs.

The paper is organized as follows. Section 2 presents the model and describes the two-stage game between firms. Sections 3 and 4 describe the solution of the second and of the first stage of the game, respectively. Section 5 discusses the scale and the competition effects of trade liberalization on firms' innovation decisions. The joint action of these two effects within the multilateral and the hub-and-spoke trade systems is studied in Scenario 1 and Scenario 2 of trade liberalization. These scenarios are compared in Section 6. Then section 7 examines the welfare effects of multilateral and regional trade liberalization. The results suggest some policy implications which are discussed in Section 8. Finally, Section 9 concludes.

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<sup>10</sup>The same result is obtained in the stylized 3-country model by Deltas et al. (2006) and by Kowalczyk and Wonnacott (1992).

## 2 The model

### 2.1 Network of regional trade agreements

Consider a setting with  $N$  countries where some countries are participants of one or more trade agreements within a certain industry. I model trade agreements between countries with a network: countries are the nodes of the network and each link indicates the existence of a trade agreement between the two linked countries. If two countries have negotiated a trade agreement, then each offers the other a privileged access to its domestic market, with lower tariffs and restrictions on trade. On the other hand, for countries that did not sign a trade agreement, tariffs are regarded as trade-prohibitive. So in fact, only countries that are directly linked in the network can trade. These conditions allow me to focus entirely on the role of the network structure and thus, isolate the impact on R&D of the type of trade arrangement.<sup>11</sup>

For any  $i \in 1 : N$ ,  $N_i$  denotes the set of *neighbors* of country  $i$ , that is, countries with which  $i$  has a trade link in the network. These are *direct trade partners* of  $i$ . Let  $|N_i|$  be the cardinality of set  $N_i$ , or degree of  $i$  in the network. Also, let  $N_i^2$  be the set of direct trade partners of direct trade partners of  $i$ , different from  $i$ . In other words,  $N_i^2$  is the set of *two-links-away trade partners* of  $i$ . Notice that some countries may simultaneously be direct and two-links-away trade partners of  $i$ . Let  $|N_i^2|$  be the cardinality of set  $N_i^2$ .

This model takes the network of trade agreements as exogenously given. Besides, since the trade agreement between any two countries is reciprocal, all links in the network are undirected and no multiple links exist.

### 2.2 Demand and cost structure

In every country, there is a single firm producing one good. The firm in country  $i$  can sell its good in the domestic market and in the markets of those countries with which  $i$  has a trade agreement.

<sup>12</sup> Let the output of firm  $i$  (from country  $i$ ) produced for consumption in country  $j$  be denoted by  $y_{ij}$ . Then the total output of firm  $i$  is given by  $y_i = \sum_{j \in N_i \cup \{i\}} y_{ij}$ . Each firm  $i$  exporting its

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<sup>11</sup>The same conditions are imposed in the network formation model of trade by Goyal and Joshi (2006). Alternatively, one could consider the qualitatively identical framework, where countries that do not have a trade agreement can also trade but the overall benefits and costs of this trade are the same for all countries. Then what matters, what distinguishes the countries is the costs and benefits of trade with their trade agreement partners.

<sup>12</sup>Implicitly this suggests that there is no free entry of domestic firms which gives rise to oligopolistic market structure. This is of course relevant for some but not all industries.

good to country  $j \in N_i \cup \{i\}$  faces an inverse linear demand in country  $j$  given by:

$$p_j = a - b \left( y_{ij} + \sum_{k \in N_j \cup \{j\}, k \neq i} y_{kj} \right) \quad (2.1)$$

where  $a, b > 0$  and  $\sum_{k \in N_j \cup \{j\}} y_{kj} \leq a/b$ .  $a$  is set to be constant, identical for all countries, so that market sizes of all countries are the same. This does not only simplify the analysis but also brings attention to the role of trade network structure, our main point of interest.

Let  $\tau$  denote the trade costs faced by *every* firm per unit of exports to *any* of its direct trade partners. These costs include tariffs on unit of export, transportation costs, etc.<sup>13</sup> The total trade costs faced by firm  $i$  are equal to:

$$t_i(\{y_{ij}\}_{j \in N_i}) = \tau \sum_{j \in N_i} y_{ij} \quad (2.2)$$

In addition, each firm can invest in R&D. The R&D effort of a firm helps lower its marginal cost of production. The cost of production of firm  $i$  is, therefore, a function of its output level,  $y_i$ , and the amount of research,  $x_i$ , that it undertakes. I assume that the cost function of each firm is linear and given by:

$$c_i(y_i, x_i) = (\alpha - x_i)y_i \quad (2.3)$$

where  $0 \leq x_i \leq \alpha \forall i \in 1 : N$ . In the following, I will also assume that  $a$  is sufficiently large relatively to  $\alpha$  and the costs of trade between countries. Namely, let

**Assumption 1**  $a > \alpha(1 + \max_{i \in 1:N} |N_i|) + 2\tau$

This assumption ensures that the demand for the good is high in all markets relative to costs of production and exporting, so that in equilibrium, all firms produce strictly positive amount of the good and invest strictly positive amount in R&D. The R&D effort is costly. The cost of effort  $x_i \in [0, \alpha]$  of firm  $i$  is

$$z_i(x_i) = \delta x_i^2, \quad \delta > 0 \quad (2.4)$$

Under this specification, the cost of the R&D effort is an increasing function and reflects the existence of diminishing returns to R&D expenditures. The parameter  $\delta$  measures the curvature of this function. In the following, it is regarded as sufficiently large so that the second order conditions of firms' optimization problem hold and equilibria can be characterized in terms of the

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<sup>13</sup>The analysis carries over in a setting where  $\tau = 0$ . The assumption of zero trade costs is standard in the literature on the formation of the network of trade agreements. See, for example, Furusawa and Konishi (2007), Goyal and Joshi (2006), and Mauleon et al. (2006).



first-order conditions and are interior.<sup>14</sup>

### 2.3 Two-stage game

Firms choose the level of R&D activities and the subsequent production plan via interaction in a two-stage non-cooperative game.<sup>15</sup> At the first stage, each firm chooses a level of its R&D effort. The R&D effort of a firm determines its marginal cost of production. Given this cost, at the second stage, a firm chooses production quantities  $\{y_{ij}\}_{i \in 1:N, j \in N_i \cup \{i\}}$  for every market where it sells its good. Each firm chooses the profit-maximizing quantity for each market separately, using the Cournot assumption that the other firms' outputs are given.

Notice the specific nature of interaction between firms in this game. First, firms compete with each other not in one but in several separate markets. Secondly, since only directly linked countries trade, a firm competes only with its direct and two-links-away trade partners. Furthermore, any direct trade partner of firm  $i$  competes with  $i$  in its own market and in the market of firm  $i$ , while any two-links-away trade partner of  $i$ , who is not simultaneously its direct trade partner, competes with  $i$  only in the market(s) of their common direct trade partner(s). This two-links-away radius of interaction between firms does not mean however that R&D and production choices of firms are not affected by other firms. As soon as the network of trade agreements is connected,<sup>16</sup> firms that are further than two links away from firm  $i$  affect R&D and production decisions of  $i$  indirectly, through the impact they have on R&D and production choices of their own trade partners and trade partners of their partners, etc.

The model uses standard subgame perfect Nash equilibrium as a solution concept. It is found using backward induction. Each stage is considered in turn.

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<sup>14</sup>Admittedly, the restrictions imposed on parameters of the demand and cost functions define a special setting. Yet, they are standard in the models with linear-quadratic specification of the objective function (profit function in this case).

<sup>15</sup>One-shot game, with simultaneous choice of R&D and production plan, delivers results which are only *quantitatively* different. The derivations for this alternative model are available from the author upon request.

<sup>16</sup>The network is connected if there exists a path between any pair of nodes.

### 3 Solving the second stage

At the second stage, each firm  $i \in 1 : N$  chooses a vector of its production plans  $\{y_{ij}\}_{j \in N_i \cup \{i\}}$  so as to maximize its profit, conditional on R&D efforts  $\{x_i\}_{i \in 1 : N}$ . The profit of firm  $i$  is

$$\begin{aligned} \pi_i &= \sum_{j \in N_i \cup \{i\}} \left( a - by_{ij} - b \sum_{k \in N_j \cup \{j\}, k \neq i} y_{kj} \right) y_{ij} - (\alpha - x_i)y_i - \delta x_i^2 - \tau \sum_{j \in N_i} y_{ij} = \\ &= \sum_{j \in N_i \cup \{i\}} \left( -by_{ij}^2 - b \sum_{k \in N_j \cup \{j\}, k \neq i} y_{kj}y_{ij} \right) + (a - \alpha + x_i)y_i - \delta x_i^2 - \tau \sum_{j \in N_i} y_{ij} \end{aligned} \quad (3.1)$$

Notice that function  $\pi_i$  is additively separable and quadratic in output levels  $\{y_{ij}\}_{j \in N_i \cup \{i\}}$  of firm  $i$ . This leads to linear first-order conditions and guarantees the existence and uniqueness of the solution of each firm's maximization problem.<sup>17</sup> Simple algebra results in the Nash-Cournot equilibrium production levels  $\{y_{ij}\}_{i \in N, j \in N_i \cup \{i\}}$  of every firm  $i$  for consumption in country  $j$ :<sup>18</sup>

$$y_{ii} = \frac{1}{b(|N_i| + 2)} \left( a - \alpha + (|N_i| + 1)x_i - \sum_{j \in N_i} x_j + |N_i|\tau \right) \quad (3.2)$$

$$y_{ij} = \frac{1}{b(|N_j| + 2)} \left( a - \alpha + (|N_j| + 1)x_i - \sum_{k \in N_j \cup \{j\}, k \neq i} x_k - 2\tau \right), \quad j \in N_i \quad (3.3)$$

Two observations are in order. First, the equilibrium output of firm  $i$  in country  $j \in N_i \cup \{i\}$  is increasing in firm's own R&D effort and decreasing in R&D efforts of  $i$ 's rivals in market  $j$ . That is, the higher the equilibrium R&D effort of  $i$  and the lower the equilibrium effort of every  $k \in N_j \cup \{j\}$ ,  $k \neq i$ , the higher the share of market  $j$  gained by  $i$ .

Second, the presence of non-negative trade costs  $\tau$  gives any firm  $i$  the competitive advantage over its rivals on the domestic market and implies at least as high production of  $i$  for the domestic market as for the markets of its direct trade partners. Indeed, as soon as  $x_i = x_j$  for some  $j \in N_i$ , the equilibrium level of production for market  $i$  of firm  $i$  is at least as high as that of firm  $j$ . Similarly, if for some  $j \in N_i$   $|N_i| = |N_j|$  and  $\sum_{k \in N_i, k \neq j} x_k = \sum_{k' \in N_j, k' \neq i} x_{k'}$ , the equilibrium level of production of firm  $i$  for the domestic market is at least as high as its production for market  $j$ .

<sup>17</sup>Since  $b > 0$ , the second order conditions hold.

<sup>18</sup>Notice that since  $x_k \leq \alpha$ ,

$$\sum_{k \in N_j \cup \{j\}} y_{kj} = \frac{|N_j| + 1}{b(|N_j| + 2)}(a - \alpha) + \frac{1}{b(|N_j| + 2)} \sum_{k \in N_j \cup \{j\}} x_k - \frac{|N_j|}{b(|N_j| + 2)}\tau \leq \frac{|N_j| + 1}{b(|N_j| + 2)}a - \frac{|N_j|}{b(|N_j| + 2)}\tau < \frac{a}{b}$$

In addition, since  $0 \leq x_k \leq \alpha$  and Assumption 1 holds,

$$y_{kj} \geq \frac{1}{b(|N_j| + 2)}(a - \alpha - |N_j|\alpha - 2\tau) = \frac{1}{b(|N_j| + 2)}(a - (\alpha + \alpha|N_j| + 2\tau)) > 0 \quad \forall k \in 1 : N \quad \forall j \in N_k \cup \{k\}$$

## 4 Solving the first stage

At the first stage, firms choose R&D efforts. Plugging expressions (3.2)–(3.3) for output levels into the profit function (3.1) of firm  $i$ , we obtain the function of the R&D effort levels  $\{x_k\}_{k \in N_j \cup \{j\}}$ . Simple algebra results in:

$$\begin{aligned}
\pi_i = & \left[ \frac{1}{b} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} - \delta \right] x_i^2 + \frac{2}{b} \left[ (a - \alpha - 2\tau) \sum_{j \in N_i} \frac{|N_j| + 1}{(|N_j| + 2)^2} + \right. \\
& + (a - \alpha + |N_i|\tau) \frac{|N_i| + 1}{(|N_i| + 2)^2} \left. \right] x_i - \frac{2}{b} \sum_{j \in N_i} \left[ \frac{|N_i| + 1}{(|N_i| + 2)^2} + \frac{|N_j| + 1}{(|N_j| + 2)^2} \right] x_i x_j - \\
& - \frac{2}{b} \sum_{j \in N_i} \sum_{k \in N_j, k \neq i} \frac{|N_j| + 1}{(|N_j| + 2)^2} x_i x_k + f(\{x_k\}_{k \in N_i \cup N_i^2}) \tag{4.1}
\end{aligned}$$

where  $f(\{x_k\}_{k \in N_i \cup N_i^2})$  is a function of R&D efforts of  $i$ 's competitors in different markets which does not distort  $i$ 's equilibrium effort:

$$\begin{aligned}
f(\{x_k\}_{k \in N_i \cup N_i^2}) = & \frac{1}{b} \sum_{j \in N_i} \frac{1}{(|N_j| + 2)^2} \left( a - \alpha - 2\tau - \sum_{k \in N_j \cup \{j\}, k \neq i} x_k \right)^2 + \\
& + \frac{1}{b} \frac{1}{(|N_i| + 2)^2} \left( a - \alpha + |N_i|\tau - \sum_{j \in N_i} x_j \right)^2
\end{aligned}$$

The profit function (4.1) of firm  $i$  is quadratic in its own R&D effort  $x_i$ . Besides, if  $\delta$  is sufficiently high, so that the R&D cost function  $z_i$  is sufficiently steep, the profit function of firm  $i$  is concave in  $x_i$ . To be more precise, for a given network of trade agreements, as soon as

$$\delta > \frac{1}{b} \max_{i \in N} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} \tag{4.2}$$

the second order conditions hold and the profit maximizing R&D efforts of all firms can be found as a solution to the system of linear first-order conditions:

$$\begin{aligned}
\left[ -\frac{1}{b} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} + \delta \right] x_i + \frac{1}{b} \sum_{j \in N_i} \left[ \frac{|N_i| + 1}{(|N_i| + 2)^2} + \frac{|N_j| + 1}{(|N_j| + 2)^2} \right] x_j + \\
+ \frac{1}{b} \sum_{j \in N_i} \sum_{k \in N_j, k \neq i} \frac{|N_j| + 1}{(|N_j| + 2)^2} x_k = \frac{1}{b} (a - \alpha - 2\tau) \sum_{j \in N_i} \frac{|N_j| + 1}{(|N_j| + 2)^2} + \\
+ \frac{1}{b} (a - \alpha + |N_i|\tau) \frac{|N_i| + 1}{(|N_i| + 2)^2} \tag{4.3}
\end{aligned}$$

for all  $i \in 1 : N$ . In the matrix form, this system can be written as

$$\Sigma \cdot \mathbf{x} = \mathbf{u} \tag{4.4}$$

where  $\mathbf{x} \in \mathbb{R}^N$  is a vector of unknowns,  $\mathbf{u} \in \mathbb{R}^N$ , and  $\Sigma$  is  $(N \times N)$  square matrix. As soon as the network of trade agreements is connected, the matrix  $\Sigma$  is generically nonsingular and the right-hand side vector  $\mathbf{u}$  is non-zero. Then (4.4) has a unique *generic* solution in  $\mathbb{R}^N$ , denoted by  $\mathbf{x}^*$ . This solution is ensured to be positive and such that  $x_i^* \leq \alpha$  for any  $i \in 1 : N$  as soon as  $\delta$  satisfies another condition, stronger than (4.2).

First, notice that in (4.3), the coefficients multiplying  $x_k$ ,  $k \in N_i \cup N_i^2 \cup \{i\}$ , are positive. Therefore, the value of  $x_i$  is larger the smaller the values of  $x_j$  and  $x_k$  for all  $j \in N_i$  and  $k \in N_i^2$ . Hence, the sufficient condition for  $x_i^* > 0$  is that (4.3) evaluated at  $x_j = x_k = \alpha \forall j \in N_i, k \in N_i^2$  defines the value of  $x_i$  that is greater than zero. This condition is provided by Assumption 1. On the other hand, the sufficient condition for  $x_i^* \leq \alpha$  is that (4.3) evaluated at  $x_j = x_k = 0 \forall j \in N_i, k \in N_i^2$  defines  $x_i$  that is smaller than or equal to  $\alpha$ . This condition is equivalent to

$$\mathbf{Assumption\ 2} \quad \delta \geq \frac{1}{\alpha b} \max_{i \in N} \left[ \sum_{j \in N_i} \frac{|N_j|+1}{(|N_j|+2)^2} \left( \alpha |N_j| + a - 2\tau \right) + \frac{|N_i|+1}{(|N_i|+2)^2} (\alpha |N_i| + a + |N_i|\tau) \right]$$

Under Assumption 1, the right-hand side of inequality in Assumption 2 is strictly larger than  $\frac{1}{b} \max_{i \in N} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j|+1)^2}{(|N_j|+2)^2}$ , the right-hand side of the earlier restriction on  $\delta$  in (4.2). Therefore, Assumption 2 is stronger. Together, Assumptions 1 and 2 guarantee that solution  $\mathbf{x}^*$  of a system of the first-order conditions (4.3)(or (4.4)) satisfies  $0 < x_i^* \leq \alpha$  for all  $i \in 1 : N$ , and the second order conditions hold. Moreover, if the inequality in Assumption 2 is strict, solution  $\mathbf{x}^*$  is interior. Intuitively, when Assumption 1 holds, the demand for a good in each market is large, which stimulates R&D investment ( $x_i^* > 0$ ). On the other hand, by Assumption 2, the cost of R&D is high, which confines the amount of R&D expenditures ( $x_i^* \leq \alpha$ ).

The specification of the first-order conditions (4.3) suggests that an increase in R&D efforts of firm  $i$ 's direct and/or two-links-away trade partners trigger a downward shift in firm  $i$ 's response. Intuitively, by exerting higher R&D efforts, firm  $i$ 's rivals capture larger shares of the markets and dampen the incentive of  $i$  to invest in R&D. We say that the efforts of firm  $i$  and its direct and two-links-away trade partners are *strategic substitutes* from  $i$ 's perspective.

The first-order conditions (4.3) imply that in equilibrium the profit function of firm  $i$  is given

by:

$$\begin{aligned}
\pi_i = & \left[ -\frac{1}{b} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} + \delta \right] x_i^{*2} + \\
& + \frac{1}{b} \sum_{j \in N_i} \frac{1}{(|N_j| + 2)^2} \left( a - \alpha - 2\tau - \sum_{k \in N_j \cup \{j\}, k \neq i} x_k^* \right)^2 + \\
& + \frac{1}{b} \frac{1}{(|N_i| + 2)^2} \left( a - \alpha + |N_i|\tau - \sum_{j \in N_i} x_j^* \right)^2
\end{aligned} \tag{4.5}$$

The short proof of this statement is provided in Appendix B. It is easy to see that due to Assumptions 1 and 2, equilibrium profit  $\pi_i$  of any firm  $i$  is strictly positive.

## 5 The impact of trade liberalization on equilibrium R&D efforts

In the framework of the model, trade liberalization is defined as an expansion of the network of trade agreements through an increase in the number of concluded trade agreements (links or links and nodes).

Consider an impact of trade liberalization on equilibrium R&D efforts of firms in two countries which negotiate a trade agreement with each other. Two major mechanisms are at work. On the one hand, a new trade agreement creates an additional market for each firm (*scale effect*). Since the cost of R&D is independent of the amount produced, larger market amplifies the return to productivity-enhancing investment, increasing the equilibrium R&D efforts of the firms. On the other hand, a new agreement opens the markets of both countries to a new competitor (*competition effect*). This has two opposite effects on R&D. The enhanced competition dampens the return to R&D through a reduction in the domestic market share of each firm (market share effect of competition); yet, it also increases the return to R&D through a reduction in price markups, which boosts the demand and hence, expands the domestic market (markups effect of competition). Thus, in general, trade liberalization between two countries has an ambiguous impact on equilibrium R&D efforts of the firms.

Furthermore, trade liberalization between any two countries affects R&D decisions of firms in other countries, too. For example, when  $i$  and  $j$  negotiate a trade agreement, R&D investments of other direct trade partners of  $i$  and  $j$  are affected because firms in these countries face higher competition in  $i$  and  $j$ . Then, the impact on R&D of the direct trade partners of  $i$  and  $j$  "spreads" to a larger network: direct trade partners of the direct trade partners of  $i$  and  $j$  face different

environment due to the changed R&D and hence, competitive power of their trade partners, and this has an impact on their own optimal R&D, etc.

Thus, scale and competition effects of trade liberalization (in any part of the network) can reinforce or dampen the incentive for firms to innovate. The sign and strength of the overall impact are determined by the specific network structure. In the following section, this issue is addressed in case of symmetric and hub-and-spoke network structures, which represent the scenario of multilateral and regional trade liberalization, respectively.

## 6 Two scenarios of trade liberalization: Multilateralism versus regionalism

### 6.1 Scenario 1: Symmetric network of trade agreements. Multilateral trade system

Consider a class of symmetric networks of degree  $n \geq 1$ . A *symmetric*, or *regular*, network of degree  $n$  is a network where every node has the same number  $n$  of direct contacts. In this paper, we are particularly interested in one representative of this class – a *complete* network, that has all its nodes linked with each other. A complete network of degree greater than one represents a multilateral trade system, where all participant countries have a trade agreement with each other and neither country has a trade agreement with a third party. In this framework, an expansion of the complete trade network represents a scenario of multilateral trade liberalization. When multilateral trade liberalization involves all world economies, this results in a "global free trade".

Another symmetric network of interest is a symmetric network of degree one. It is composed of one or several disjoint *simple bilaterals*, where every country signs a trade agreement with one and only one other country.<sup>19</sup>

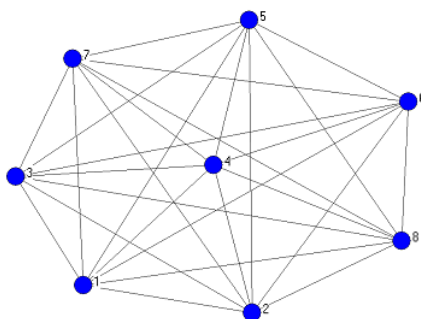


Figure 1: Complete network of degree 7 – multilateral trade agreement between 8 countries

<sup>19</sup>Up to the early 1990s, trade agreements were, with only a few exceptions, a set of non-intersecting bilateral or "small" multilateral trade agreements (the latter are also called plurilateral RTAs). One source of this evidence is Lloyd and Maclaren (2004).

In the symmetric network, all countries/firms are identical and hence, exert identical R&D efforts. Denote the level of this effort by  $x$ . Then the (single) first-order condition (4.3) becomes:

$$\left[ -\frac{(n+1)^3}{(n+2)^2} + \delta b \right] x + 2n \frac{n+1}{(n+2)^2} x + n \frac{(n+1)(n-1)}{(n+2)^2} x = \frac{(n+1)^2}{(n+2)^2} (a - \alpha) + \frac{n+1}{(n+2)^2} (-2\tau n + \tau n)$$

Solving this equation results in the equilibrium effort

$$x^* = \frac{a - \alpha - \frac{n}{n+1}\tau}{-1 + \delta b \left(1 + \frac{1}{n+1}\right)^2} \quad (6.1)$$

Plugging  $x^*$  into (4.5), we derive the equilibrium profit of a firm in the symmetric network:

$$\begin{aligned} \pi &= \left( -\frac{1}{b} \frac{(n+1)^3}{(n+2)^2} + \delta \right) \left( \frac{a - \alpha - \frac{n}{n+1}\tau}{-1 + \delta b \left(1 + \frac{1}{n+1}\right)^2} \right)^2 + \\ &+ \frac{n}{b(n+2)^2} \left( a - \alpha - 2\tau - n \frac{a - \alpha - \frac{n}{n+1}\tau}{-1 + \delta b \left(1 + \frac{1}{n+1}\right)^2} \right)^2 + \\ &+ \frac{1}{b(n+2)^2} \left( a - \alpha - n \left( \frac{a - \alpha - \frac{n}{n+1}\tau}{-1 + \delta b \left(1 + \frac{1}{n+1}\right)^2} - \tau \right) \right)^2 \end{aligned} \quad (6.2)$$

The usual comparative statics analysis leads to the following result:

**Proposition 1** *Suppose that Assumptions 1 and 2 hold for all  $n < \bar{n}$ , where  $\bar{n} \geq 1$ . Then for any  $n < \bar{n}$ , firm's equilibrium R&D effort  $x^*$  is monotonically increasing in  $n$ , while firm's profit  $\pi$  is monotonically decreasing in  $n$ .*

Proposition 1 is illustrated with Figure 2, where the equilibrium R&D effort and the profit of a firm in the symmetric network are drawn against the network degree  $n$ .<sup>20</sup>

Proposition 1 suggests that multilateral trade liberalization depreciates firms' profits. Nevertheless, the incentive for firms to invest in R&D increase. Intuitively, as a new country enters the multilateral trade agreement (or any other agreement which can be represented by the symmetric network), the reduction in the domestic and foreign market shares suffered by each firm is exactly compensated by participation in the entrant's market. That is, the negative market share effect of increased competition exactly offsets the positive scale effect associated with access to a new market. As a result, trade liberalization affects R&D only through the remaining component of the competition effect – the reduction in price markups. Since the reduction in markups increases the aggregate market size of a firm, the optimal R&D of each firm in the multilateral agreement is increasing in the size of the agreement. On the other hand, the profit of each firm is decreasing as a result of increasing R&D expenditures and declining prices.

<sup>20</sup>The simulation is done for the specific parameter values:  $\alpha = 7$ ,  $b = 1$ ,  $\bar{n} = 10$ , and  $\tau = 2$ ;  $a$  and  $\delta$  fulfill Assumptions 1 and 2.

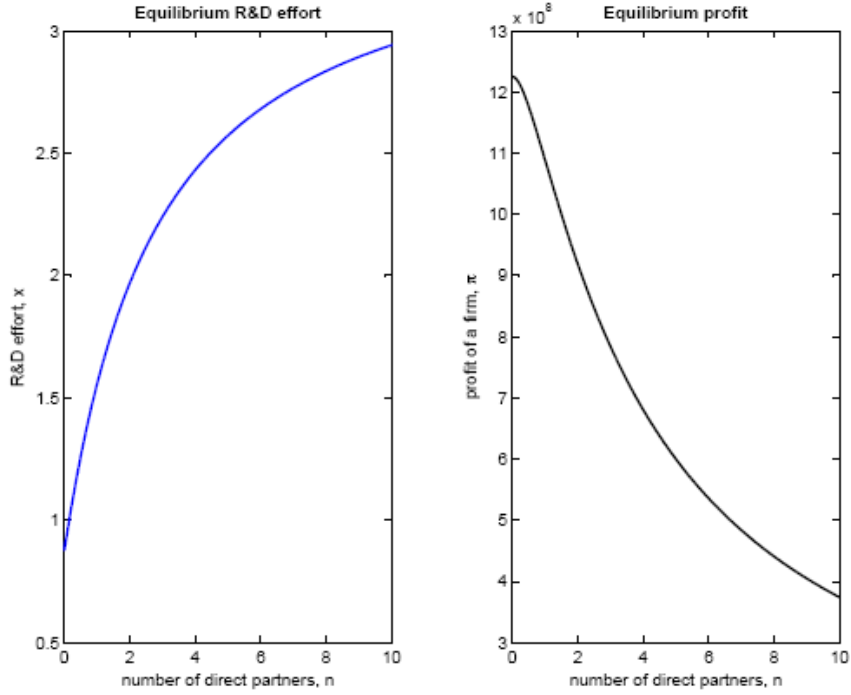


Figure 2: Equilibrium R&D effort and profit of a country in a symmetric network of degree  $n$

Furthermore, the rates of increase in R&D and decrease in profit are both declining in the size of the agreement, as illustrated by Figure 2. This is implied by the fact that the markup-reducing effect of trade liberalization in the multilateral agreement becomes weaker as the agreement expands. Formally, the price of the good in each market, as defined by (2.1), is given by the decreasing and convex function of  $n$ :

$$p = \frac{\delta b(n+2)(a + \alpha(n+1) + \tau n) - a(n+1)^2}{-(n+1)^2 + \delta b(n+2)^2} \quad (6.3)$$

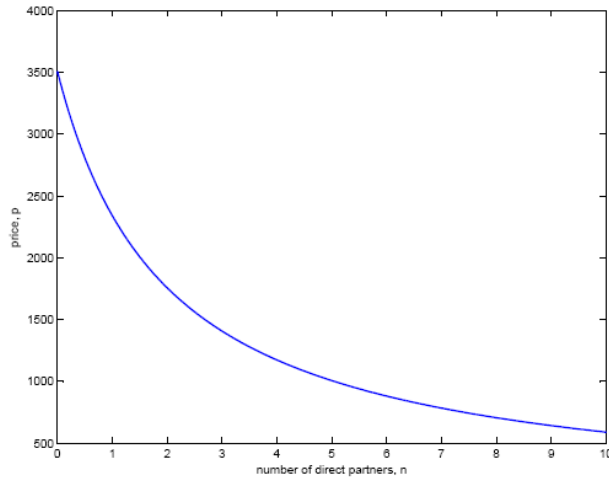


Figure 3: Price on the market of a country in a symmetric network of degree  $n$



Since Proposition 1 applies to *any* symmetric trade agreement of degree  $n$ , it allows for the comparison of equilibrium R&D efforts and an individual firm's profits in a multilateral agreement with those in a bilateral agreement or in autarky. Denote by  $x_a^*$  and  $\pi_a$  the equilibrium R&D effort and the profit of a firm in autarky, by  $x_b^*$  and  $\pi_b$ , the R&D effort and the profit of a firm in the bilateral agreement, and by  $x^*(n)$  and  $\pi(n)$ , the R&D effort and the profit of a firm in the multilateral agreement of degree  $n$  (of size  $n + 1$ ). Then we obtain

**Corollary 1** *For any  $2 \leq n < \bar{n}$ ,  $x_a^* < x_b^* < x^*(n)$  and  $\pi_a > \pi_b > \pi(n)$ .*

Due to the presence of markup reducing effect of multilateral trade liberalization, which promotes R&D, the individual R&D investment of a firm is higher in the multilateral agreement than in the bilateral agreement or in autarky, while the profit of a firm in multilateral agreement is the lowest.


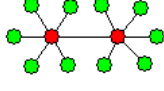
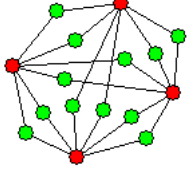
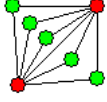
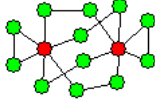
For the same reason the aggregate level of R&D activities within the multilateral trade system is increasing in the size of the system and exceeds the aggregate R&D of the same number of countries involved in simple bilaterals.

## 6.2 Scenario 2: Asymmetric network of trade agreements. Hub-and-spoke trade system

I now examine the case of regional trade liberalization. In the process of regional trade liberalization, some countries (or groups of countries) negotiate one or several *bilateral* and/or *plurilateral* agreements with each other. Thus, in contrast to the multilateral type of liberalization considered in Scenario 1, each country may actually be a party to several different trade agreements where other countries do not necessarily have an agreement with each other. As a result, a complex trade system emerges where various regional (preferential) agreements overlap. In the literature, this system is often described as a *hub-and-spoke* trade system, where some countries (hubs) have a relatively large number of direct trade partners as compared to other countries (spokes), which are mainly involved in trade agreements with hubs.

In this model, I approximate the hub-and-spoke structure by the asymmetric network with two types of nodes – nodes of high degree  $n$  (hubs) and of low degree  $m$  (spokes),  $1 \leq m < n$ . I assume that a *fixed positive* share of direct trade partners of hubs and spokes is represented by countries of the opposite type. For any hub, other hubs form a share  $0 \leq \psi < 1$  of its direct trade partners while a share  $0 < 1 - \psi \leq 1$  is represented by spokes. Similarly, for any spoke, other spokes form a share  $0 \leq \varphi < 1$  of its direct trade partners and the remaining positive share

Table 1: Examples of hub-and-spoke trade system

Network characteristics	Network
Type 1: Single star ( $n$ bilaterals of a hub with spokes)  $n > 1, m = 1, \psi = 0, \varphi = 0$	
Type 2: Stars with linked hubs  $n > 1, m = 1, \psi > 0, \varphi = 0$	
Type 3: Stars sharing spokes  $n > 1, m > 1, \psi = 0, \varphi = 0$	
Type 4: Stars with linked hubs, sharing spokes  $n > 1, m > 1, \psi > 0, \varphi = 0$	
Type 5: Stars where some spokes are linked with each other  $n > 1, m > 1, \psi = 0, \varphi > 0$	

Remark: Red nodes stand for hubs, green nodes stand for spokes.

$0 < 1 - \varphi \leq 1$  is represented by hubs.<sup>21</sup>

These four parameters,  $n$ ,  $m$ ,  $\varphi$  and  $\psi$ , define a rich set of possible hub-and-spoke architectures. Some examples are demonstrated in Table 1. Furthermore, interesting comparative statics results, allowing for changes not only in the *number* of countries' trade partners but also in the *proportion* of partners of a particular type.

In any given hub-and-spoke trade system, all hubs exert identical R&D effort  $x_h$  and all spokes exert identical R&D effort  $x_s$ . Then the system (4.3) of the first-order conditions reduces to two

<sup>21</sup>Notice that in case when  $\psi = 1$  ( $\varphi = 1$ ), we obtain the complete network of degree  $n$  ( $m$ ).

equations:

$$\begin{aligned}
& \left( - (1 - \psi)n \frac{(m+1)^2}{(m+2)^2} - (n\psi + 1) \frac{(n+1)^2}{(n+2)^2} + \delta b + \psi n \frac{2(n+1)}{(n+2)^2} + \right. \\
& + (1 - \psi)n \frac{m+1}{(m+2)^2} ((1 - \varphi)m - 1) + \psi n \frac{n+1}{(n+2)^2} (\psi n - 1) \left. \right) \cdot x_h + \\
& + (1 - \psi)n \left( \frac{n+1}{(n+2)^2} + \frac{m+1}{(m+2)^2} + \frac{n+1}{(n+2)^2} n\psi + \frac{m+1}{(m+2)^2} \varphi m \right) \cdot x_s = \\
& = (a - \alpha - 2\tau) \left( (1 - \psi)n \frac{m+1}{(m+2)^2} + \psi n \frac{n+1}{(n+2)^2} \right) + \frac{n+1}{(n+2)^2} (a - \alpha + n\tau)
\end{aligned} \tag{6.4}$$

$$\begin{aligned}
& \left( - (1 - \varphi)m \frac{(n+1)^2}{(n+2)^2} - (\varphi m + 1) \frac{(m+1)^2}{(m+2)^2} + \delta b + \varphi m \frac{2(m+1)}{(m+2)^2} + \right. \\
& + (1 - \varphi)m \frac{n+1}{(n+2)^2} ((1 - \psi)n - 1) + \varphi m \frac{m+1}{(m+2)^2} (\varphi m - 1) \left. \right) \cdot x_s + \\
& + (1 - \varphi)m \left( \frac{n+1}{(n+2)^2} + \frac{m+1}{(m+2)^2} + \frac{n+1}{(n+2)^2} n\psi + \frac{m+1}{(m+2)^2} \varphi m \right) \cdot x_h = \\
& = (a - \alpha - 2\tau) \left( (1 - \varphi)m \frac{n+1}{(n+2)^2} + \varphi m \frac{m+1}{(m+2)^2} \right) + \frac{m+1}{(m+2)^2} (a - \alpha + m\tau)
\end{aligned} \tag{6.5}$$

These equations uniquely identify equilibrium R&D efforts of a hub and a spoke,  $(x_h^*, x_s^*)$ , and the closed-form solution, due to its cumbersome representation, is left for the Appendix.<sup>22</sup>

As before, trade liberalization in the hub-and-spoke trade system affects equilibrium R&D efforts  $x_h^*$ ,  $x_s^*$  via the scale and the competition effects. However, in contrast to the case with the multilateral trade system, in the asymmetric hub-and-spoke structure, the negative component of the competition effect of trade liberalization (market share effect) is generally *not* offset by the positive scale effect. Therefore, a priori, the impact of trade liberalization on R&D in the hub-and-spoke system is ambiguous. The results are derived using the comparative statics.

The main finding is that the larger the number of directly accessible markets and the lower the number of competitors in these markets, the higher the incentive for firms to innovate. Specifically, Proposition 2 claims that as soon as the stated parameter restrictions hold, the equilibrium R&D effort of a hub (spoke) is increasing in the number of its direct trade partners but is decreasing in the number of direct trade partners of spokes (hubs). Furthermore, for both a hub and a spoke, the higher the share of hubs among their direct trade partners, the lower the optimal R&D.

**Proposition 2** *Suppose that Assumptions 1 and 2 hold for all  $m < n \leq \bar{n}$ , where  $\bar{n} > 1$ . Then there exists  $\Delta > 0$  such that for any  $\delta \geq \Delta$  and for any  $m < n < \bar{n}$ , the following statements are fulfilled:*

1. *the equilibrium R&D effort  $x_h^*$  of a hub is monotonically increasing in  $n$  and monotonically*

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<sup>22</sup>See the proof of Proposition 2 in Appendix B.

decreasing in  $m$  and in  $\psi$ ;

2. the equilibrium R&D effort  $x_s^*$  of a spoke is monotonically decreasing in  $n$  and monotonically increasing in  $\varphi$ . Furthermore,  $x_s^*$  is monotonically increasing in  $m$  if at least one of the conditions holds:

(a) the trade costs are sufficiently high:  $\tau \geq \frac{1-\varphi}{3-2\varphi}(a-\alpha)$

(b) the share of other spokes among direct trade partners is at least  $1/3$ :  $\varphi \geq \frac{1}{3}$

(c) the gap between  $n$  and  $m$  is relatively small:  $n \leq m^2$ , that is,  $1 < \frac{n}{m} \leq m$

Notice that studying the effect of a variation in  $n$  on R&D effort of a spoke and the effect of a variation in  $m$  on R&D effort of a hub allows me to isolate competition effect of trade from the scale effect and thus, to determine its sign. This effect turns out to be negative – two-links-away trade partners dampen R&D of a firm, so that in accordance with intuition, negative component of the competition effect outweighs its positive component.<sup>23</sup> Yet, the scale effect of trade between directly linked countries is strong enough, so that the effect of an increase in the number of direct trade partners still tends to be positive. This is always true for hubs, and in a range of specified cases – for spokes.

For spokes, conditions (a) – (c) restrain the competition effect to guarantee that an increase in  $m$  enhances spokes' R&D investments. Recall that the specification of a hub-and-spoke trade system in this model is such that an increase in the number of a spoke's direct trade partners  $m$  is associated with an increase in the number of *both* types of partners – hubs and spokes.<sup>24</sup> Since the market of a hub is "small" – smaller than the market of a spoke, an increase in the spoke's foreign market share may actually be smaller than a decrease in the share of the domestic market. As a result, the positive scale effect of an increase in  $m$  on R&D investment of a spoke may be dominated by the negative competition effect.<sup>25</sup> Conditions (a) – (c) ensure that this would not be the case if: (a) the trade costs of firms are sufficiently high to restrict the amount of exports from new trade partners, (b) hubs represent only a minor share of direct trade partners of a spoke, or alternatively, (c) the number  $m$  of competitors in the spoke's market is comparable

<sup>23</sup>The two-links-away trade partner effect is related to *concession erosion* effect described in Bagwell and Staiger (2004) and in Schwartz and Sykes (1997). These papers evaluate the effectiveness of GATT/WTO principles in protecting the welfare of governments whose direct trade partner negotiates a bilateral trade agreement with a third party.

<sup>24</sup>The proportion of spokes to hubs among the new trade partners is determined by  $\varphi$ : the lower  $\varphi$ , the higher the relative number of hubs.

<sup>25</sup>This outcome seems to be rather rare though. For example, by simulating the model for the star network under various parameter assumptions, I find that initiating trade with the hub decreases R&D of a spoke only when the number of competitors in the hub's market is above 100.

to  $n$ , so that the loss in the domestic market share of the spoke is not larger than the gain in the market of a new hub market.

The results of Proposition 2 are illustrated with Figures 7 and 8 in Appendix C.<sup>26</sup>

The negative impact on R&D of two-links-away trade partners implies that unlike in the multilateral trade system, in the regional, hub-and-spoke system, the impact of trade liberalization on R&D is not always positive. The effect of a new country on R&D is often positive for its *direct* trade partners but negative for its *two-links-away* partners.

### 6.3 Comparison of multilateral and regional trade systems

In this section, I examine how different types of trade liberalization compare in terms of their impact on R&D investments of firms. The comparison is made in two steps. First, I investigate the relationship between the R&D level of a firm in the multilateral trade agreement and a firm in the regional, hub-and-spoke trade system. After that I distinguish between different types of the hub-and-spoke system and study the *ranking* of R&D efforts of firms across various types of the hub-and-spoke system and the multilateral system. Consider each step in turn.

**Step 1** To gain some insights about the sources of variation in R&D efforts of a firm across the multilateral and the regional, hub-and-spoke trade systems, let us first abstract from possible variations in the demand/price for the good across markets, and consider that all firms operating in one market obtain the same share of the market. Then, given the fixed number of direct trade partners, it is purely the *number* of rival firms present in each export country that determines the aggregate market size of a firm. The fewer competitors, the larger the aggregate market size of a firm and the higher the return to R&D investment.

In this simplified framework, for any number  $n$  of direct trade partners, the aggregate market size of a hub in a hub-and-spoke trade system is larger than that of a firm in the multilateral agreement. Indeed, while in the multilateral agreement of degree  $n$ , the number of competitors of a firm is  $n$  in *each* of its  $n$  foreign markets, in the hub-and-spoke trade system, the number of competitors of a hub is  $n$  only in  $\psi \cdot n$  of its foreign markets and it is less than  $n$  in the remaining markets. A similar argument applies for spokes with the result that for any number  $m$  of direct trade partners, the total market size of a spoke is smaller than that of a country in the multilateral agreement. Therefore, for the same number of direct trade partners, benefits of innovation for a hub are higher than for a country in the multilateral agreement and the reverse

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<sup>26</sup>Both figures are produced using the same parameter values as for Figure 2 in Scenario 1. In addition, for Figure 7, I set  $\psi = \varphi = 0$  and for Figure 8,  $n = 6$ ,  $m = 2$ .

is true for a spoke.

In fact, this conclusion holds even when demand in all markets and market shares of firms in every market are not the same. Formally, the result is an immediate implication of Proposition 2 and the short proof is provided in Appendix B:

**Proposition 3** *For any  $0 \leq \psi, \varphi < 1$  and for any  $n, m > 1$  such that  $n > m$ ,*

$$x_h^* > x^*(n) > x^*(m) > x_s^*,$$

*where  $x^*(k)$  denotes the equilibrium R&D effort of a firm in the multilateral agreement of degree  $k$ . Moreover, the same inequalities hold when a hub and a spoke belong to different types of the hub-and-spoke structure.*

**Step 2** Consider now various types of the hub-and-spoke trade system and compare equilibrium R&D efforts of firms across these types. To that end, I restrict attention to the specific types of the hub-and-spoke structure presented in Table 1. Notice that by Proposition 3, it only remains to compare separately R&D efforts of hubs and R&D efforts of spokes, since R&D of a hub is always higher than R&D of a spoke both in one and in different types of the hub-and-spoke structure.

As before, assume that the demand for the good is the same in all markets and that all firms (hubs and spokes) share each market equally. Consider the differences in market sizes of hubs and spokes across various hub-and-spoke structures. With regard to hubs, given any number  $n$  of a hub's direct trade partners, a hub in the star (Type 1 system) enjoys the lowest competition in any of its foreign markets as compared to hubs in the other systems. Therefore, a hub in the star has the largest total market size. As a number of rival firms in a hub's export markets increases, the aggregate market size of the hub declines. This is the case when either the number of a spoke's direct trade partners,  $m$ , grows (Type 3 system), or the share of hubs among direct trade partners,  $\psi$ , increases (Type 2 system), or when both changes in  $m$  and  $\psi$  happen simultaneously (Type 4 system). Furthermore, the larger the increase in  $m$  and/or  $\psi$ , the smaller the size of a hub's aggregate market.

For spokes the situation is symmetric. Given any number,  $n$ , of a hub's direct trade partners, a spoke in the star (Type 1 system) has access to a single foreign market ( $m = 1$ ). Therefore, a spoke's market in the star is smaller than a spoke's market in any other hub-and-spoke trade system.<sup>27</sup> As the number of direct trade partners of a spoke,  $m$ , increases (Type 3 system), the

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<sup>27</sup>In fact, under the assumption of equal demand and equal market shares of firms in every market, the market

market of a spoke expands. It expands even further if the share of spokes among direct trade partners,  $\varphi$ , grows (Type 5 system). Moreover, the larger the increase in  $m$  and/or  $\varphi$ , the larger the aggregate market size of a spoke.

As at Step 1, these insights prove to be valid even if demand in all markets and firms' shares in every market are not identical. Proposition 4 ranks R&D efforts of hubs,  $x_{hi}^*$ , and R&D efforts of spokes,  $x_{si}^*$ , across various types of hub-and-spoke systems  $i$ ,  $i \in 1 : 5$ .

**Proposition 4** *Consider Types 1–5 of the hub-and-spoke trade structure. Suppose that (i)  $n$  is the same across all types, (ii)  $m$  is the same across all types where  $m > 1$  (Types 3, 4 and 5), and (iii)  $\psi$  is the same across all types where  $\psi > 0$  (Types 2 and 4). Let  $x^*(n)$  and  $x^*(m)$  be defined for  $n$  and  $m > 1$ , identical to those in Types 1 – 5 of the hub-and-spoke structure. Then firms' equilibrium R&D efforts in Types 1–5 of the hub-and-spoke structure and in the multilateral agreement rank as follows:*

$$x_{h1}^* > x_{h3}^* > x_{h4}^* > x^*(n) > x^*(m) > x_{s5}^* > x_{s3}^* > x_{s1}^*.$$

*With respect to the equilibrium R&D effort  $x_{h2}^*$  of a hub and  $x_{s2}^*$  of a spoke in Type 2 system, the following inequalities hold:*

$$x_{h1}^* > x_{h2}^* > x_{h4}^* \quad \text{and} \quad x_{s4}^* > x_{s2}^*.$$

Proposition 4 is illustrated with Figure 4 and Figure 9.

Thus, the R&D investments of firms in the multilateral system and in various types of the hub-and-spoke trade systems vary substantially. The highest R&D incentives exist for a hub, especially for a hub in the star (Type 1 system), whereas for a spoke in the star the incentives are the lowest. As the number of direct trade partners of a spoke and/or the share of spokes (hubs) among direct trade partners of each spoke (hub) increase, the levels of R&D investment of hubs and spokes converge. They coincide at the level of R&D investment of a firm in the multilateral agreement, which therefore, takes an average position: it is lower than R&D of a hub but higher than R&D of a spoke.

In addition to comparison of individual R&D investments by firms, I compare the aggregate levels of R&D activities of the same total number of countries in the multilateral trade agreement and in the simple star, where one country, a hub, has several bilaterals with spokes. I find that although the individual R&D effort of a hub in the star is higher than the R&D effort of a size of a spoke in Type 2 system is the same as in the star.

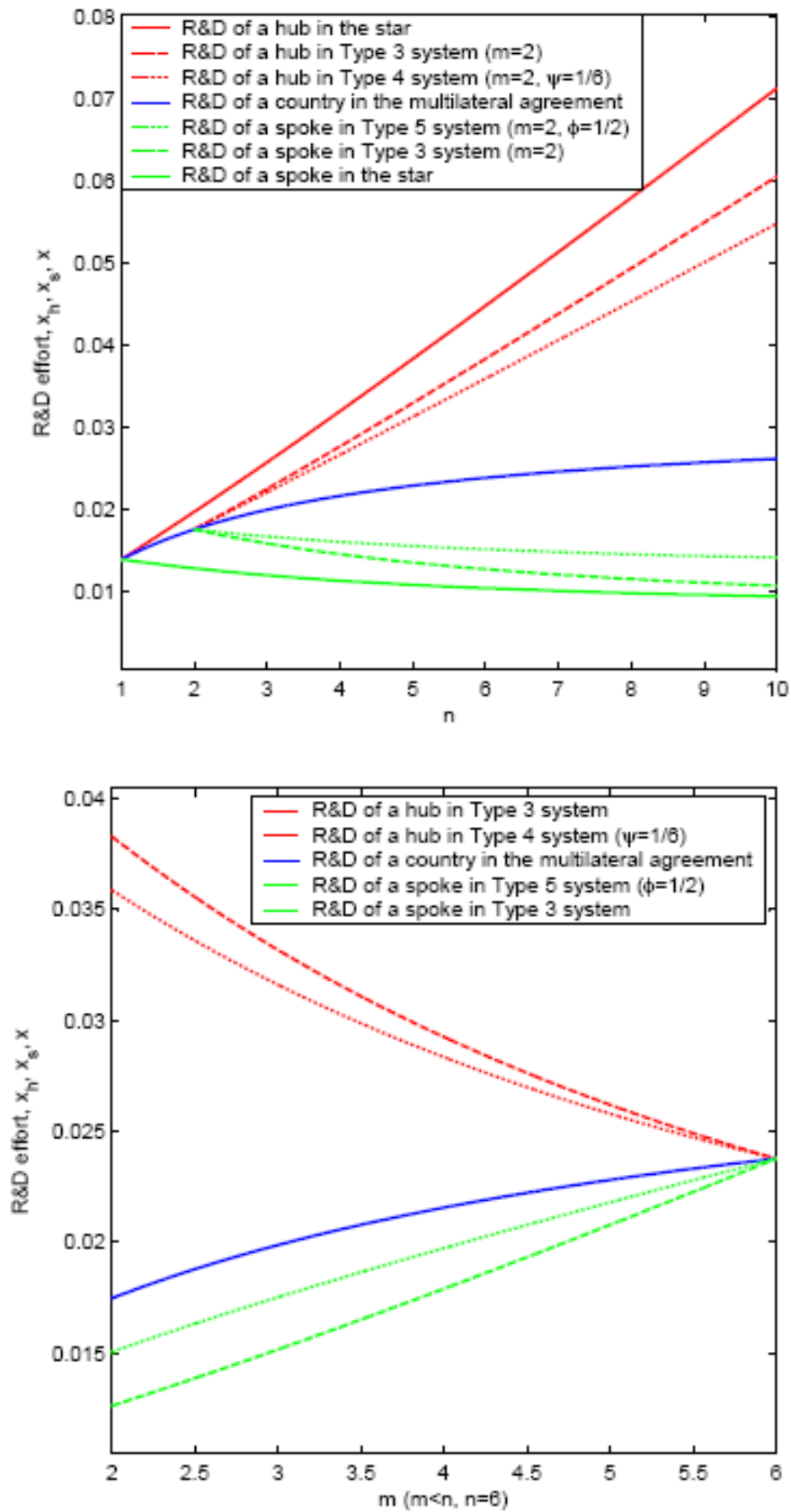


Figure 4: Equilibrium R&D efforts in the multilateral and in the hub-and-spoke trade systems as a function of  $n$  (the upper sub-figure) and as a function of  $m$  (the lower sub-figure).



single country in the multilateral agreement, the aggregate R&D in the star is *lower* than in the multilateral agreement. This observation is demonstrated by Figure 10 in Appendix C.

## 7 Welfare analysis

To complement the analysis of the impact of trade liberalization on R&D, this section addresses implications of trade liberalization for the *social welfare* of a country. I examine the impact on welfare of multilateral and regional trade liberalization and based on that, compare welfare benefits of multilateral and regional types of trade. For simplicity, the case of regional trade liberalization is studied on the example of a single star (Type 1 system in Table 1), where trade liberalization is defined as an increase in the number of spoke economies.

In the following the social welfare of country  $i$ ,  $W_i$ , is regarded as the sum of firm  $i$ 's profit,  $\pi_i$ , and consumer surplus,  $CS_i$ , where

$$CS_i = \frac{b}{2} \left( \sum_{k \in N_i \cup \{i\}} y_{ki} \right)^2 \quad (7.1)$$

due to linearity of the demand function in (2.1).

Let us first consider the case of the multilateral trade liberalization. As it has been shown in section 6.1, the profit of a firm in the multilateral system is decreasing in  $n$ , the number of direct trade partners of a country. Now, I also find that the consumer surplus of each country is *increasing* in  $n$ . Intuitively, an increase in the number of direct trade partners and associated increase in aggregate market size of each firm lead to an increase in firms' output. Therefore, total production for country  $i$  by its domestic and foreign firms grows and the consumer surplus of the country rises.

As a result, the social welfare of country  $i$  may increase or decrease in  $n$  depending on which of the two effects – increase in  $CS$  or decrease in  $\pi$  – prevails. I find that under certain restrictions on parameters, this is predetermined by the value of trade costs  $\tau$  and in some cases, by the original size of the trade agreement, that is, the initial amount of country's trade partners. Namely, the social welfare of a country is monotonically increasing in  $n$  for values of  $\tau$  below a certain threshold and monotonically decreasing in  $n$  for values of  $\tau$  above another, larger threshold. For values of  $\tau$  between the two thresholds, the social welfare of a country is monotonically increasing in  $n$  up to a certain size of trade agreement and it is decreasing in  $n$  afterwards. Formally, these findings are stated in Proposition 5:

**Proposition 5** *Suppose that Assumptions 1 and 2 hold for all  $n < \bar{n}$ , where  $\bar{n} \geq 1$ . Then for any*

$n < \bar{n}$ , the consumer surplus of a country within a multilateral system is monotonically increasing in  $n$ . Furthermore, as soon as the additional restriction  $a > \alpha(1 + \bar{n} + 2\bar{n}/(n + 2))$  holds, there exist  $\Delta > 0$  and two thresholds of trade costs  $\underline{\tau}, \bar{\tau} > 0$ , with  $\underline{\tau} \leq \bar{\tau}$ , such that for any  $\delta \geq \Delta$ , the following statements are fulfilled:

1. the social welfare of a country is monotonically increasing in  $n$  for any  $\tau < \underline{\tau}$  and it is monotonically decreasing in  $n$  for any  $\tau > \bar{\tau}$ ;
2. for  $\tau \in [\underline{\tau}, \bar{\tau}]$ , there exists  $\tilde{n}(\tau)$ ,  $1 \leq \tilde{n}(\tau) \leq \bar{n}$ , such that the social welfare of a country is monotonically increasing in  $n$  for any  $n \leq \tilde{n}(\tau)$  and it is monotonically decreasing in  $n$  for  $n > \tilde{n}(\tau)$ .

Such a dependence of a behavior of social welfare on  $\tau$  and, at medium values of  $\tau$ , on the original number of trade partners can be explained as follows. At low trade costs (below a certain threshold), trade volumes between countries are substantial and any new trade agreement boosts total output in each market, so that an increase in the consumer surplus outweighs a decline in firm's profit. As the level of trade costs increases, the amount of trade between any two countries shrinks and at some point, the negative impact of trade liberalization on firm's profit becomes stronger than its positive impact on consumer surplus. First, this negative impact shows only in trade systems of large original size, where the rate of increase in consumer surplus with an additional trade partner is low, lower than in small trade systems (see Figure 11). However, when  $\tau$  gets very high (above a certain threshold), benefits from trade are minor in trade system of any size and a new trade agreement unequivocally decreases countries' welfare.

Alternatively, the welfare-reducing effect of trade liberalization at high  $\tau$  can be viewed as a result of forces opposite to those which raise social welfare at low  $\tau$ . In fact, an increase in  $\tau$  may be regarded as a change in trade regime of each country towards higher isolation, or autarky. Then if welfare-enhancing effect of trade liberalization at low  $\tau$  is taken for granted, this "backward" move in the direction of no trade is compelled to reduce the welfare.

Proposition 5 is illustrated with Figures 5 and 6. Notice that the levels of trade costs at which the social welfare of a country decreases at some or all  $n$  are "very high". This means that in most cases, when trade costs are not too high, multilateral trade liberalization improves the welfare of every country.

Similar intuition drives the result for welfare change in a hub within a simple star network: social welfare in a hub is increasing in the number of spokes,  $n$ , at low  $\tau$  and it is decreasing in

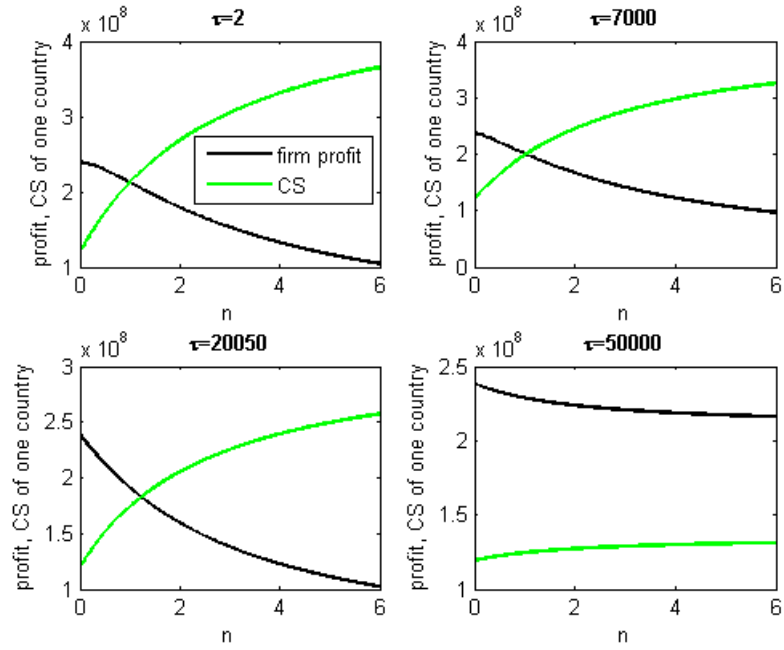


Figure 5: Firm's profit and consumer surplus of a country in the multilateral trade system as a function of  $n$  for different levels of trade costs  $\tau$ .

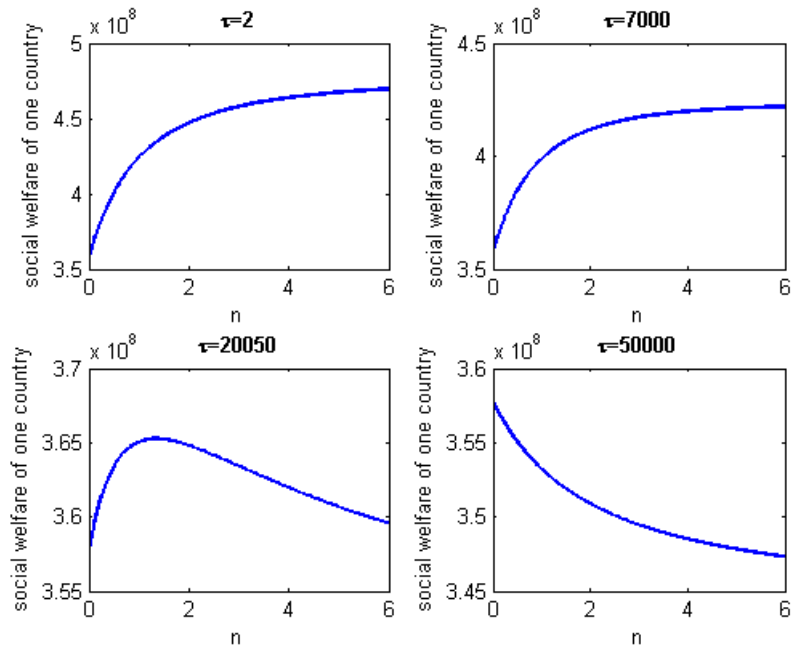


Figure 6: Social welfare of a country in the multilateral trade system as a function of  $n$  for different levels of trade costs  $\tau$ .

$n$  at high  $\tau$ . At medium levels of  $\tau$ , the impact of trade liberalization on welfare depends on the original size of the trade system, or the number of hub's bilaterals. Welfare is increasing in  $n$  up to a certain size of the trade system and it is decreasing in  $n$  afterwards.

However, unlike in case of the multilateral trade system, in a star welfare growth of the hub at low  $\tau$  is caused by an increase in both, consumer surplus and firm's profit. The reason why hub's profit is increasing in  $n$  despite a price reduction in a hub's market is that at low  $\tau$  trade liberalization in a star leads to a large expansion of the aggregate market and hence, total output of the hub's firm and this boost in output turns out to be sufficient to compensate for the price fall.

At higher  $\tau$ , exploitation of spoke markets by the hub becomes expensive and profit of the hub firm declines. In fact, at some high enough level of  $\tau$ , the absolute value of this profit reduction becomes larger than the value of a simultaneous increase in the consumer surplus and the social welfare of the hub declines in the process of trade liberalization. Just as in the multilateral system, this negative impact of trade on welfare first shows only in small agreements, stars with a small number of spoke economies. But at sufficiently high  $\tau$  trade liberalization reduces social welfare of the hub in a star of any original size.

Instead, in a spoke economy, welfare is decreasing in  $n$  for *all* levels of  $\tau$ . Essentially invariable conditions in a spoke market keep the level of its consumer surplus constant as  $n$  increases but the profit of a spoke firm declines due to a price reduction in the market of the hub, spoke's unique trade partner.

These effects of trade liberalization on profits and consumer surplus in a star system are demonstrated by simulation results in the Appendix (Figures 11 and 12). The social welfare implications of trade liberalization are studied both analytically and numerically and the findings are summarized by Proposition 6.

**Proposition 6** *Suppose that Assumptions 1 and 2 hold for all  $n < \bar{n}$  (and  $m = 1$ ), where  $\bar{n} \geq 1$ . Then for any  $n < \bar{n}$ , there exists  $\Delta > 0$  such that for any  $\delta \geq \Delta$ , the social welfare in a spoke economy is monotonically decreasing in  $n$  (for all  $\tau \geq 0$ ). Furthermore, as soon as the additional restriction  $a > \alpha \left(1 + \frac{\bar{n}(2n^3 + 12n^2 + 51n + 16)}{9(n+2)}\right)$  holds, there exist  $\tilde{\Delta} > 0$  and two thresholds of trade costs  $\underline{\tau}, \bar{\tau} > 0$ , with  $\underline{\tau} \leq \bar{\tau}$ , such that for any  $\delta \geq \tilde{\Delta}$ , the following statements are fulfilled:*

1. *the social welfare of a hub economy is monotonically increasing in  $n$  for any  $\tau < \underline{\tau}$  and it is monotonically decreasing in  $n$  for any  $\tau > \bar{\tau}$ ;*
2. *for  $\tau \in [\underline{\tau}, \bar{\tau}]$ , there exists  $\tilde{n}(\tau)$ ,  $1 \leq \tilde{n}(\tau) \leq \bar{n}$ , such that the social welfare of a hub is*

*monotonically increasing in  $n$  for any  $n \leq \tilde{n}(\tau)$  and it is monotonically decreasing in  $n$  for  $n > \tilde{n}(\tau)$ .*

Furthermore, numerical simulations suggest that for any number  $n$  of trade partners, the level of social welfare in a hub is higher than the level of welfare in a country within the multilateral system (see Figure 13 in the Appendix). This is a result of higher profits earned by the firm in a hub than by a firm in the multilateral agreement since as Figure 11 suggests, consumer surplus of the hub and of a country in the multilateral agreement are the same.

However, the aggregate welfare in the star is lower than the aggregate welfare in the multilateral agreement, at least as soon as trade costs are not too high. Moreover, this difference in aggregate welfare is larger for smaller values of trade costs. Thus, so far as the considered example suggests, aggregate welfare benefits of multilateral trade liberalization exceed those of the regional trade liberalization where one (hub) economy signs more and more bilaterals with other countries (spokes). The comparison of the aggregate welfare levels in the star and in the multilateral agreement is presented on Figure 14.

Lastly, notice that if  $\tau$  is interpreted as a tariff on unit of export, then the social welfare of country  $i$  can be defined alternatively as

$$W_i = \pi_i + CS_i + T_i$$

where  $T_i = \tau \sum_{k \in N_i} y_{ki}$  is a sum of trade tariffs collected by country  $i$ . In that case I find that the social welfare *with tariffs* of any country within the multilateral trade agreement and of a hub in the star is monotonically increasing in  $n$  for *any* value of  $\tau$ . The social welfare of a spoke country is decreasing in  $n$ , just as in case of the original welfare formulation. This finding is illustrated with Figure 15.

## 8 Policy implications

The findings of the paper suggest that the structure of the network of trade agreements and the position of a country in this network are key for understanding the differences in firm's R&D and productivity as well as welfare levels of countries across the multilateral and the regional types of trade systems. This feeds into the ongoing debate on gains and losses of multilateralism versus regionalism, especially with respect to the intensive proliferation of regional trade agreements among the WTO member countries. The paper suggests that productivity and welfare gains of regionalism versus those of multilateralism depend heavily on the relative number of regional

trade agreements signed by countries. If a country signs relatively large number of trade agreements within the regional system (core country), then its R&D/productivity and social welfare are higher than R&D/productivity and welfare of a country in the multilateral system. At the same time, a country that signs relatively small number of trade agreements within the regional system (periphery country) has lower productivity and welfare gains than a country in the multilateral system. This observation implies that from the perspective of a small economy, which normally becomes a spoke/periphery in the regional trade system, the prospects for productivity improvements and welfare benefits within the multilateral trade system are generally better than within the regional system.<sup>28</sup>

Furthermore, the finding of the unambiguously positive impact on R&D of the multilateral trade liberalization indicates that the expansion of the WTO as well as the consolidation of several plurilateral blocks or their accession to the WTO enhance R&D in every country.<sup>29</sup> Also, as soon as trade costs are not too high, multilateral trade liberalization improves the welfare of each country, while regional trade liberalization improves welfare of a core economy, signing bilaterals with peripheral countries, but it reduces social welfare of peripheral countries each having a single trade agreement with a core (a star network).

Recall that for the classes of networks considered in Scenario 1 and in Scenario 2, the equilibrium R&D effort of a firm is usually increasing in the number of its direct trade partners but decreasing in the number of its two-links-away trade partners. In Appendix A, I further investigate the issue of the impact which direct and two-links-away trade partners have on R&D of a firm in a *generic* network under the assumption of *small external effects*. Consistent with the results of the previous analysis, I find that new direct trade partners of a firm in a generic trade network (mostly) increase the firm's R&D investment and this effect is stronger, the smaller the number of competitors in the new markets.

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<sup>28</sup>The finding of a substantially lower R&D/productivity and welfare levels in a spoke economy as compared to those in a hub and in a country within the multilateral system, supports the argument of earlier studies about the disadvantageous position of spokes. For instance, Baldwin (2003), Kowalczyk and Wonnacott (1992), Deltas et al. (2006), Lloyd and Maclaren (2004), and De Benedictis et al. (2005) find that welfare and income levels are lower for spokes than for hubs and than for countries in the complete network.

<sup>29</sup>According to Fiorentino et al. (2007), the number of merging regional trade agreements is currently increasing. Examples include EC-GCC, SACU-MERCOSUR, among others.

## 9 Conclusion

This paper develops a model of international trade with firm-level productivity improvements via R&D. Firms in different countries sell their product and compete in a Cournot fashion at the domestic market and at the markets of their trade partners. The trade partners of a country/firm are defined by the network of trade agreements, so that countries which are linked in the network are direct trade partners of each other.

I focus on two types of networks, the complete and the hub-and-spoke network, that represent trade arrangements which arise as a result of multilateral and regional trade liberalization, respectively. I study how the structure of the trade arrangement and the position of a country in this structure affect R&D investments by firms. In this manner, I address the issue of the difference in the impact of multilateral and regional types of trade liberalization on firms' R&D and productivity.

I show that the impact of trade liberalization on firms' R&D is the net outcome of two effects: one, stimulating R&D through the creation of new markets (scale effect), and the other, deterring or improving R&D through the emergence of new competitors (competition effect). The interaction of these two effects depends on structural features of trade arrangements and the resulting impact on R&D varies across the multilateral and the regional, hub-and-spoke trade systems as well as across countries within the hub-and-spoke system.

I find that for the *same number of direct trade partners*, the R&D effort of a hub in the hub-and-spoke trade system is higher than the R&D effort of a country in the multilateral agreement. On the other hand, R&D of a spoke is lower than R&D of a hub and lower than R&D of a country in the multilateral agreement, even if a country in the multilateral agreement has the same number of direct trade partners as a spoke. For the aggregate levels of R&D activities, I find that the aggregate R&D effort within the multilateral trade agreement exceeds that in the *star* – the simplest representative of the hub-and-spoke trade system.

Furthermore, consistent with the empirical evidence, I find that a new market increases R&D of a firm in the multilateral system and R&D of a hub in the regional system. It also increases R&D of a spoke, at least as soon as the level of competition in the new spoke's trade partner is not too high. Since all countries in the multilateral system are direct trade partners of each other, multilateral trade liberalization unequivocally promotes R&D of every firm. At the same time, in the regional, hub-and-spoke trade system, some countries are only two-links-away trade partners and they depress each other's R&D. Therefore, regional trade liberalization within hub-

and-spoke system improves R&D in those countries which gain a new *direct* trade partner but dampens R&D in those countries which only gain a *two-links-away* trade partner.

To complement the analysis I also study welfare implications of trade liberalization in the multilateral system and in the simple star. I find that if trade costs are not too high, trade liberalization is beneficial for the social welfare of a country in the multilateral agreement and for the hub in the star, and it is detrimental for the welfare of spokes in the star. Also, numerical results suggest that for the same number of trade partners, welfare of a hub in the star exceeds welfare of a country in the multilateral agreement. However, total welfare benefits of multilateral trade liberalization are greater than total welfare benefits of regional trade liberalization where one hub economy signs many bilaterals with spokes.

The results of the paper suggest some policy implications. For example, with respect to benefits and losses of regionalism versus multilateralism, they imply that the regional trade liberalization is likely to be more beneficial than the multilateral trade liberalization for core economies, countries with large number of regional trade agreements, since R&D, productivity and social welfare of core economies in the regional system are larger. At the same time, R&D, productivity and welfare level of peripheral economies are higher when they choose the multilateralist alternative.

The important direction for further research is testing the results of the paper empirically. To the best of my knowledge, so far empirical research has not addressed the issue of potential variations in the impact on R&D and productivity of different types of trade liberalization – multilateral versus regional. Theoretical findings of this paper suggest that these variations exist and may not be negligible. Furthermore, relaxing some assumptions of the model, such as equality of geographical size and initial income/resources across countries may provide valuable new insights.



## 10 Appendix

### Appendix A: Equilibrium R&D efforts in arbitrary network. The case of small external effects

Consider the system of first-order optimality conditions (4.3). Below I study the properties of the solution to this system when the magnitude of local effects – effects of interaction between firms in the network – is arbitrarily small. I seek the ranking of optimal R&D decisions of firms in accordance with simple characteristics of firms' positions in the network, such as the nodal degrees and the sum of neighbors' degrees. To derive this ranking, I employ the asymptotic approach suggested by Bloch and Qu  rou (2008).<sup>30</sup>

Notice that the system of linear first-order conditions (4.3) can be written as:

$$\begin{aligned} \delta x_i &= \frac{1}{b} \left[ \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} x_i - \sum_{j \in N_i} \left( \frac{|N_i| + 1}{(|N_i| + 2)^2} + \frac{|N_j| + 1}{(|N_j| + 2)^2} \right) x_j - \right. \\ &\quad \left. - \sum_{j \in N_i} \sum_{k \in N_j, k \neq i} \frac{|N_j| + 1}{(|N_j| + 2)^2} x_k \right] = \\ &= \frac{1}{b} (a - \alpha - 2\tau) \sum_{j \in N_i} \frac{|N_j| + 1}{(|N_j| + 2)^2} + \frac{1}{b} (a - \alpha + |N_i|\tau) \frac{|N_i| + 1}{(|N_i| + 2)^2}, \quad i \in 1 : N \end{aligned}$$

In the matrix form this has a simple representation:

$$\left( \delta \mathbf{I} - \frac{1}{b} \mathbf{B} \right) \cdot \mathbf{x} = \frac{1}{b} \tilde{\mathbf{u}}$$

Alternatively:

$$(\mathbf{I} - \lambda \mathbf{B}) \cdot \mathbf{x} = \lambda \tilde{\mathbf{u}} \tag{10.1}$$

where  $\lambda = \frac{1}{b\delta}$ . In this system, matrix  $\lambda \mathbf{B}$  is the matrix of local effects. Below, I investigate the solution to (10.1) when the norm of matrix  $\lambda \mathbf{B}$  capturing the magnitude of local effects is small.

First, following Bloch and Qu  rou (2008), I define a vector sequence  $\mathbf{f} = (\mathbf{c}^1, \mathbf{c}^2, \dots, \mathbf{c}^m, \dots)$ , where each vector  $\mathbf{c}^m$  is given by:

$$\mathbf{c}^m = \lambda^m \tilde{\mathbf{u}} \mathbf{B}^{m-1}$$

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<sup>30</sup>As emphasized in Bloch and Qu  rou (2008), at least two arguments can defend the usefulness of studying network effects whose magnitude is small. First, when the matrix of interactions is complex, this may be the only way to evaluate the equilibrium R&D decisions for an *arbitrary* network structure. Secondly, by continuity, the insights obtained for small external effects continue to hold as the magnitude of externalities increases.

The first terms of this sequence are

$$\begin{aligned}\mathbf{c}^1 &= \lambda \tilde{\mathbf{u}}, \\ \mathbf{c}^2 &= \lambda^2 \tilde{\mathbf{u}}\mathbf{B}, \\ \mathbf{c}^3 &= \lambda^3 \tilde{\mathbf{u}}\mathbf{B}^2\end{aligned}$$

Using the sequence  $\mathbf{f}$ , I can now state the approximation result, which provides an equivalence between the ranking of the components of the solution  $\mathbf{x}^*$  to (10.1) and the lexicographic ordering of the components of  $\mathbf{f}$  when the magnitude of  $\|\lambda\mathbf{B}\|$  is close to zero.

**Proposition 7** *Consider a system of linear equations (10.1). Suppose that  $\|\lambda\mathbf{B}\|$  is sufficiently small:<sup>31</sup> for a given  $0 < \bar{\varepsilon} < 1$ ,  $\|\lambda\mathbf{B}\| \leq \frac{\bar{\varepsilon}}{N}$ . Then there exists a unique solution  $\mathbf{x}^*$  and  $K > 1$  such that for any  $i, j \in 1 : N$ ,  $i \neq j$ ,*

$$|x_i^* - x_j^* - (c_i^M - c_j^M)| \leq \lambda \cdot \frac{\bar{\varepsilon}^{K+1}}{1 - \bar{\varepsilon}} \cdot 2\|\tilde{\mathbf{u}}\|$$

where  $(c_M)_i$  and  $(c_M)_j$  are the first unequal elements of the sequences  $\mathbf{f}_i = (\mathbf{c}_i^1, \mathbf{c}_i^2, \dots, \mathbf{c}_i^m, \dots)$  and  $\mathbf{f}_j = (\mathbf{c}_j^1, \mathbf{c}_j^2, \dots, \mathbf{c}_j^m, \dots)$ :  $\mathbf{c}_i^M \neq \mathbf{c}_j^M$  and  $\mathbf{c}_i^m = \mathbf{c}_j^m$  for all  $m < M$ .

Thus, if the upper bound for the magnitude of local effects is close to zero,

$$x_i^* > x_j^* \Leftrightarrow \mathbf{f}_i \succ \mathbf{f}_j$$

where  $\mathbf{f}_i \succ \mathbf{f}_j$  stands for lexicographic dominance of  $\mathbf{f}_i$  over  $\mathbf{f}_j$ . This means that in order to compare equilibrium R&D efforts of different firms, one can restrict attention to the first order term  $\mathbf{c}^1$ , or if the first order terms are equal, to the second order term  $\mathbf{c}^2$ , etc. As a result, the ranking of optimal R&D choices of firms reduces to the ranking of characteristics of firms' positions in the network.

Consider a pair of firms  $(i, i')$ ,  $i, i' \in 1 : N$ , such that  $\tilde{\mathbf{u}}_i \neq \tilde{\mathbf{u}}_{i'}$ . Then by Proposition 7, if

$$\|\lambda\mathbf{B}\| \leq \frac{\bar{\varepsilon}}{N}$$

for some  $0 < \bar{\varepsilon} < 1$ , then the difference between  $x_i^*$  and  $x_{i'}^*$  can be approximated by the difference between  $\tilde{\mathbf{u}}_i$  and  $\tilde{\mathbf{u}}_{i'}$  such that the measurement error does not exceed  $\lambda \cdot \frac{\bar{\varepsilon}^{K+1}}{1 - \bar{\varepsilon}} \cdot 2\|\tilde{\mathbf{u}}\|$ , where

$$\|\tilde{\mathbf{u}}\| = \max_i (a - \alpha - 2\tau) \sum_{j \in N_i} \frac{|N_j| + 1}{(|N_j| + 2)^2} + (a - \alpha + |N_i|\tau) \frac{|N_i| + 1}{(|N_i| + 2)^2}$$

So, when the local effects are small, the R&D effort chosen by firm  $i$  is at least as high as the

<sup>31</sup>As in Bloch and Qu  rou (2008), I use the  $l_\infty$  vector norm defined by  $\|\mathbf{A}\| = \max_{i,j} |a_{ij}|$

R&D effort of firm  $i'$  if and only if

$$\begin{aligned}
& (a - \alpha - 2\tau) \sum_{j \in N_i} \frac{|N_j| + 1}{(|N_j| + 2)^2} + (a - \alpha + |N_i|\tau) \frac{|N_i| + 1}{(|N_i| + 2)^2} \geq \\
& \geq (a - \alpha - 2\tau) \sum_{j \in N_{i'}} \frac{|N_j| + 1}{(|N_j| + 2)^2} + (a - \alpha + |N_{i'}|\tau) \frac{|N_{i'}| + 1}{(|N_{i'}| + 2)^2}
\end{aligned} \tag{10.2}$$

The inequality (10.2) suggests that at the first order the R&D effort of firm  $i$  is decreasing in the number  $|N_j|$ ,  $j \in N_i$ , of  $i$ 's two-links-away trade partners. In addition, the R&D effort of firm  $i$  is increasing in the number  $|N_i|$  of  $i$ 's direct trade partners as soon as the new trade partner  $j'$  is such that

$$\frac{|N_i| + 2}{(|N_i| + 3)^2} (a - \alpha + (|N_i| + 1)\tau) - \frac{|N_i| + 1}{(|N_i| + 2)^2} (a - \alpha + |N_i|\tau) + (a - \alpha - 2\tau) \frac{|N_{j'}| + 1}{(|N_{j'}| + 2)^2} > 0$$

Alternatively, this can be written as:

$$(a - \alpha - 2\tau) \frac{|N_{j'}| + 1}{(|N_{j'}| + 2)^2} > \frac{|N_i|^2 + 3|N_i| + 1}{(|N_i| + 2)^2 (|N_i| + 3)^2} (a - \alpha + |N_i|\tau) - \frac{|N_i| + 2}{(|N_i| + 3)^2} \tau \tag{10.3}$$

It is easy to see that under Assumption 1 the left-hand side of inequality (10.3) is decreasing in  $|N_{j'}|$ . This means that the additional direct trade partner  $j'$  of  $i$  increases  $i$ 's incentives to innovate as soon as the number of competitors  $|N_{j'}|$  of  $i$  in market  $j'$  is sufficiently low. Thus, in accordance with the earlier discussion in the paper, opening trade with an additional trade partner increases the R&D investment of firm  $i$  if the actual market size of the new trade partner is large enough.

The finding of a positive effect of direct trade partners and a negative effect of two-links-away trade partners of  $i$  on  $i$ 's equilibrium R&D effort, together with the conditions which guarantee these effects, are consistent with the findings of Scenarios 1 and 2 discussed in Section 6.

## Appendix B: Proofs<sup>32</sup>

### Derivation of the profit function in (4.5)

The profit function in (4.1) can be written as:

$$\begin{aligned}\pi_i &= 2x_i^* \left[ \frac{1}{b}(a - \alpha - 2\tau) \sum_{j \in N_i} \frac{|N_j| + 1}{(|N_j| + 2)^2} + \frac{1}{b}(a - \alpha + |N_i|\tau) \frac{|N_i| + 1}{(|N_i| + 2)^2} - \right. \\ &\quad \left. - \frac{1}{b} \sum_{j \in N_i} \left[ \frac{|N_i| + 1}{(|N_i| + 2)^2} + \frac{|N_j| + 1}{(|N_j| + 2)^2} \right] x_j^* - \frac{1}{b} \sum_{j \in N_i} \sum_{k \in N_j, k \neq i} \frac{|N_j| + 1}{(|N_j| + 2)^2} x_k^* \right] - \\ &\quad - \left[ -\frac{1}{b} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} + \delta \right] x_i^{*2} + f(\{x_k\}_{k \in N_i \cup N_i^2})\end{aligned}$$

By the first-order conditions (4.3), this reduces to:

$$\begin{aligned}\pi_i &= 2 \left[ -\frac{1}{b} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} + \delta \right] x_i^{*2} - \left[ -\frac{1}{b} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} + \delta \right] x_i^{*2} + \\ &\quad + f(\{x_k\}_{k \in N_i \cup N_i^2}) = \left[ -\frac{1}{b} \sum_{j \in N_i \cup \{i\}} \frac{(|N_j| + 1)^2}{(|N_j| + 2)^2} + \delta \right] x_i^{*2} + \\ &\quad + \frac{1}{b} \sum_{j \in N_i} \frac{1}{(|N_j| + 2)^2} \left( a - \alpha - 2\tau - \sum_{k \in N_j \cup \{j\}, k \neq i} x_k^* \right)^2 + \\ &\quad + \frac{1}{b} \frac{1}{(|N_i| + 2)^2} \left( a - \alpha + |N_i|\tau - \sum_{j \in N_i} x_j^* \right)^2\end{aligned}$$

### Proof of Proposition 1

First, notice that in case of a symmetric network of degree  $n$ , the right-hand side of inequality in Assumption 1 is an increasing function of  $n$  and also the right-hand side of inequality in Assumption 2 is an increasing function of  $\bar{n}$ , *provided* that Assumption 1 holds. Therefore, for Assumptions 1 and 2 to be fulfilled for all  $n < \bar{n}$ , it is enough to ensure that these assumptions hold for  $n = \bar{n}$ . The resulting restrictions are

$$a > \alpha(1 + \bar{n}) + 2\tau, \quad \text{and} \quad (10.4)$$

$$\delta \geq \frac{1}{\alpha b} \frac{(\bar{n} + 1)}{(\bar{n} + 2)^2} ((\alpha \bar{n} + a)(\bar{n} + 1) - \tau \bar{n}) \quad (10.5)$$

The proof of Proposition 1 is established in two steps.

1. R&D effort  $x^*$  is monotonically increasing in  $n$

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<sup>32</sup>Due to computational complexity, proofs of some propositions in this section are presented schematically. For more details please contact the author.

Taking a derivative of  $x^*$  in (6.1) with respect to  $n$ , we obtain:

$$\begin{aligned}\frac{\partial x^*}{\partial n} &= \frac{-\frac{\tau}{(n+1)^2}(-1 + \delta b(1 + \frac{1}{n+1})^2) + 2\delta b(1 + \frac{1}{n+1})\frac{1}{(n+1)^2}(a - \alpha - \frac{n}{n+1}\tau)}{(-1 + \delta b(1 + \frac{1}{n+1})^2)^2} = \\ &= \frac{\frac{1}{(n+1)^2}(\tau + \delta b(1 + \frac{1}{n+1})(-\tau(1 + \frac{1}{n+1}) + 2(a - \alpha - \frac{n}{n+1}\tau)))}{(-1 + \delta b(1 + \frac{1}{n+1})^2)^2}\end{aligned}$$

The sign of this derivative is positive as soon as

$$2(a - \alpha - \frac{n}{n+1}\tau) > \tau(1 + \frac{1}{n+1})$$

One can readily see that this inequality holds due to the restriction on  $a$  in (10.4).

## 2. Profit, $\pi$ , is monotonically decreasing in $n$

Due to unhandiness of algebraic expressions, I present only a schematic proof of this statement.

Taking the derivative of  $\pi$  in (6.2) with respect to  $n$ , we obtain the expression represented by the product of the ratio  $\frac{1}{b(2n-4b\delta+n^2-4bn\delta-bn^2\delta+1)^3}$  and the quadratic polynomial of  $\tau$ . The ratio is negative for any  $n \geq 1$  due to the restriction on  $\delta$  in (10.5). On the other hand, the value of the polynomial is positive for any  $n \geq 1$  as soon as parameters satisfy the restrictions (10.4) and (10.5). The latter is established via two steps.

- First, I find that due to the restriction (10.5) the coefficient of the polynomial at the quadratic term  $\tau^2$  is negative for any given  $n \geq 1$ . Besides, the constant term is positive. Hence, the graph of the quadratic function is a parabola with downward-directed branches and two real roots – one positive and one negative.
- Since the unit trade cost  $\tau$  is positive and by the restriction (10.4), it does not exceed  $\frac{1}{2}(a-\alpha)$ , to establish that the value of the polynomial is positive for all  $\tau \in (0, \frac{1}{2}(a-\alpha))$ , it suffices to show that the value of the polynomial is positive at  $\tau := \frac{1}{2}(a-\alpha)$ . One can find that this is indeed the case, provided that (10.4) and (10.5) hold.

Thus, for all  $n \geq 1$  and any parameter values satisfying the conditions (10.4) and (10.5), the derivative of  $\pi$  with respect to  $n$  is negative, so that the profit function is decreasing in  $n$ .

■

## Sketch of the proof of Proposition 2

Notice that to ensure that Assumptions 1 and 2 hold for all  $m < n \leq \bar{n}$ , it is enough to impose the restrictions:

$$a > \alpha(1 + \bar{n}) + 2\tau \quad \text{and} \quad (10.6)$$

$$\delta \geq \frac{1}{\alpha b} \left[ \frac{\bar{n} + 1}{(\bar{n} + 2)^2} \bar{n}(\alpha \bar{n} + a - 2\tau) + \frac{2}{9}((\alpha \bar{n} + a)(\bar{n} + 1) - \tau \bar{n}) \right] \quad (10.7)$$

The equilibrium R&D effort of a hub and a spoke are given by the solution to the system of equations (6.4) – (6.5):

$$x_s^* = \frac{\left( (a - \alpha - 2\tau)(1 - \varphi)m(n + 1)(m + 2)^2 + (m + 1)(n + 2)^2[(a - \alpha - 2\tau)\varphi m + a - \alpha + m\tau] \right) \cdot \left( (n + 2)^2[b\delta(m + 2)^2 - n(1 - \psi)(m + 1)(2 + \varphi m)] - (n\psi + 1)(n + 1)(n(1 - \psi) + 1)(m + 2)^2 \right) - (1 - \varphi)m \left( (n\psi + 1)(n + 1)(m + 2)^2 + (\varphi m + 1)(m + 1)(n + 2)^2 \right) \cdot \left( (a - \alpha - 2\tau)[n\psi(n + 1)(m + 2)^2 + (n - n\psi)(m + 1)(n + 2)^2] + (n + 1)(m + 2)^2(a - \alpha + n\tau) \right)}{\left( (n + 2)^2[b\delta(m + 2)^2 - n(1 - \psi)(m + 1)(2 + \varphi m)] - (n\psi + 1)(n + 1)(n(1 - \psi) + 1)(m + 2)^2 \right) \cdot \left( - (1 - \varphi)m(m + 2)^2(n\psi + 2)(n + 1) + (n + 2)^2\delta b(m + 2)^2 - (n + 2)^2[(\varphi m + 1)(m + 1)^2 - m\varphi(m + 1)(1 + \varphi m)] \right) - (1 - \varphi)(1 - \psi)mn \left( (n + 1)(m + 2)^2(1 + n\psi) + (m + 1)(n + 2)^2(1 + \varphi m) \right)^2}$$

$$x_h^* = \frac{(a - \alpha - 2\tau)(n\psi(n + 1)(m + 2)^2 + (n - n\psi)(m + 1)(n + 2)^2) + (n + 1)(m + 2)^2(a - \alpha + n\tau) - x_s^*(n - n\psi)((m + 1)(n + 2)^2 + (n + 1)(m + 2)^2 + \varphi m(m + 1)(n + 2)^2 + n\psi(n + 1)(m + 2)^2)}{b\delta(n + 2)^2(m + 2)^2 - (n\psi + 1)(n + 1)^2(m + 2)^2 - (n - n\psi)(m + 1)^2(n + 2)^2 + n\psi(2n + 2)(m + 2)^2 + ((1 - \varphi)m - 1)(n - n\psi)(m + 1)(n + 2)^2 + n\psi(n\psi - 1)(n + 1)(m + 2)^2}$$

Taking a derivative of  $x_h^*$  and  $x_s^*$  with respect to each of the parameters  $m$ ,  $n$ ,  $\varphi$  and  $\psi$ , we obtain a ratio, where the denominator is unambiguously positive while the sign of the numerator is determined by the sign of a cubic polynomial in  $\delta$ . As soon as  $\delta$  is sufficiently large – greater than the largest real root of the polynomial, the sign of the polynomial is defined by the sign of the coefficient at the highest degree.

Thus, to simplify calculations, I assume that  $\delta$  is large enough ( $\delta > \Delta$ ) and focus on the sign of the polynomial's coefficient at  $\delta^3$ . I obtain that under the parameter restriction (10.6), partial derivatives  $\frac{\partial x_s^*}{\partial n}$ ,  $\frac{\partial x_h^*}{\partial m}$ , and  $\frac{\partial x_h^*}{\partial \psi}$  are negative and the derivatives  $\frac{\partial x_h^*}{\partial n}$  and  $\frac{\partial x_s^*}{\partial \varphi}$  are positive. As regarding the derivative  $\frac{\partial x_s^*}{\partial m}$ , this derivative is positive if and only if the following inequality holds:

$$(a - \alpha - 2\tau)(1 - \varphi) \cdot A + (a - \alpha - 2\tau) \cdot B + \tau \cdot C > (a - \alpha - 2\tau)(1 - \varphi) \cdot D - (a - \alpha - 2\tau)\varphi \cdot E \quad (10.8)$$

where

$$\begin{aligned} A &= m^6 n^4 + 7m^6 n^3 + 18m^6 n^2 + 20m^6 n + 8m^6 + 12m^5 n^4 + 84m^5 n^3 + 216m^5 n^2 + \\ &\quad + 240m^5 n + 96m^5, \\ B &= -30m^4 n^4 \varphi + 50m^4 n^4 - 300m^4 n^3 \varphi + 380m^4 n^3 - 840m^4 n^2 \varphi + 1000m^4 n^2 - \\ &\quad - 960m^4 n \varphi + 1120m^4 n - 384m^4 \varphi + 448m^4 + 40m^3 n^4 \varphi + 100m^3 n^4 - \\ &\quad - 320m^3 n^3 \varphi + 880m^3 n^3 - 1280m^3 n^2 \varphi + 2400m^3 n^2 - 1600m^3 n \varphi + 2720m^3 n - \\ &\quad - 640m^3 \varphi + 1088m^3 + 240m^2 n^4 \varphi + 120m^2 n^4 + 240m^2 n^3 \varphi + 1200m^2 n^3 - \\ &\quad - 480m^2 n^2 \varphi + 3360m^2 n^2 - 960m^2 n \varphi + 3840m^2 n - 384m^2 \varphi + 1536m^2 + 288mn^4 \varphi \\ &\quad + 112mn^4 + 576mn^3 \varphi + 1024mn^3 + 384mn^2 \varphi + 2816mn^2 + 3200mn + 1280m + \\ &\quad + 16n^5 \varphi + 96n^4 \varphi + 64n^4 + 192n^3 \varphi + 448n^3 + 128n^2 \varphi + 1152n^2 + 1280n + 512, \\ C &= 160n^4 + 1024m + 1280n + 768m^2 + 256m^3 + 32m^4 + 1280n^2 + 640n^3 + 512 + \\ &\quad + 16n^5 + 1929m^2 n^2 + 960m^2 n^3 + 640m^3 n^2 + 320m^3 n^3 + 80m^4 n^2 + 24m^2 n^5 + \\ &\quad + 80m^3 n^4 + 40m^4 n^3 + 1286mn^3 + 8m^3 n^5 + 10m^4 n^4 + m^4 n^5 + 2560mn + \\ &\quad + 2560mn^2 + 1920m^2 n + 640m^3 n + 80m^4 n + 32mn^5 + 320mn^4 + 240m^2 n^4, \\ D &= m^4 n^5 + 6m^3 n^5 + 12m^2 n^5 + 8mn^5, \\ E &= 2m^4 n^5 + 14m^3 n^5 + 36m^2 n^5 + 40mn^5 \end{aligned}$$

Notice that  $A$ ,  $B$ ,  $C$ ,  $D$ , and  $E$  are all positive, so that the left-hand side of (10.8) is positive, while the sign of the right-hand side is determined by the relative values of  $(1 - \varphi) \cdot D$  and  $\varphi \cdot E$ . It is easy to see that  $2D < E$ . Hence, for  $\varphi \geq 1/3$ ,  $(1 - \varphi) \cdot D < \varphi \cdot E$  and the right-hand side of (10.8) are negative. This establishes condition (b) of the proposition.

Observe also that  $C > D$ . Then as soon as  $\tau \geq (a - \alpha - 2\tau)(1 - \varphi)$ , inequality (10.8) holds. This justifies condition (a).

Finally, condition (c) follows from the series of inequalities. First, when  $n \leq m^2$ ,

$$A > m^4 n^5 + 12m^3 n^5 + 7m^2 n^5 + 84mn^5 \quad (10.9)$$

Secondly, since  $m > n$ ,

$$m^4 n^5 + 12m^3 n^5 + 7m^2 n^5 + 84mn^5 > m^4 n^5 + 6m^3 n^5 + 13m^2 n^5 + 84mn^5 > D \quad (10.10)$$

Combining (10.9) and (10.10), we obtain that  $A > D$ , so that inequality (10.8) is satisfied. ■

### Proof of Proposition 3

First, notice that a complete network of degree  $n$  ( $m$ ) can be regarded as a hub-and-spoke network "composed only of hubs", that is, where  $\psi = 1$  (composed only of spokes where  $\varphi = 1$ ). Then inequality  $x_h^* > x^*(n)$  follows from part 1 of Proposition 2, stating that  $x_h^*$  is decreasing in  $\psi$ . Similarly,  $x^*(m) > x_s^*$  is implied by the result that  $x_s^*$  is increasing in  $\varphi$ . Lastly, the inequality  $x^*(n) > x^*(m)$  follows from Proposition 1. ■

### Proof of Proposition 4

Consider the first series of inequalities in Proposition 4:

$$x_{h1}^* > x_{h3}^* > x_{h4}^* > x^*(n) > x^*(m) > x_{s5}^* > x_{s3}^* > x_{s1}^*$$

There, the first three inequalities follow from part 1 of Proposition 2:  $x_{h1}^* > x_{h3}^*$  since  $x_h^*$  is decreasing in  $m$ , while  $x_{h3}^* > x_{h4}^* > x^*(n)$  since  $x_h^*$  is decreasing in  $\psi$ . Similarly, the last three inequalities are implied by part 2 of Proposition 2:  $x^*(m) > x_{s5}^* > x_{s3}^*$  since  $x_s^*$  is increasing in  $\varphi$ , while  $x_{s3}^* > x_{s1}^*$  since  $x_s^*$  is increasing in  $m$ . The intermediate inequality  $x^*(n) > x^*(m)$  is a result of Proposition 1.

Likewise, with regard to the equilibrium R&D efforts  $x_{h2}^*$  and  $x_{s2}^*$  in Type 2 system, the inequality  $x_{h1}^* > x_{h2}^*$  follows from the fact that  $x_h^*$  is decreasing in  $\psi$ , while  $x_{h2}^* > x_{h4}^*$  and  $x_{s4}^* > x_{s2}^*$  are the result of  $x_h^*$  and  $x_s^*$  being decreasing and increasing in  $m$ , respectively. ■

### Proof of Proposition 5

As it was noticed in the proof of Proposition 1, for Assumptions 1 and 2 to be fulfilled for all  $n < \bar{n}$ , it is enough to guarantee that inequalities (10.4) and (10.5) hold. Under these restrictions,



the proof of Proposition 5 is established in two steps.

1. The consumer surplus of a country within a multilateral system is monotonically increasing in  $n$

According to (7.1), the consumer surplus of country  $i$  in the multilateral trade system is given by:

$$CS_i = \frac{b}{2}(y_{ii} + ny_{ji})^2 \quad (10.11)$$

where  $y_{ji}$  is the production of any trade partner  $j$  of country  $i$  for  $i$ 's market. Using (3.2), (3.3) for production levels and (6.1) for the equilibrium R&D effort of a country in the multilateral agreement, (10.11) can be written as

$$\begin{aligned} CS_i = CS &= \frac{b}{2} \left( \frac{1}{b(n+2)} \left( a - \alpha + \frac{a - \alpha - \frac{n}{n+1}\tau}{-1 + \delta b \left(1 + \frac{1}{n+1}\right)^2} + n\tau \right) + \right. \\ &+ \left. \frac{n}{b(n+2)} \left( a - \alpha + \frac{a - \alpha - \frac{n}{n+1}\tau}{-1 + \delta b \left(1 + \frac{1}{n+1}\right)^2} - 2\tau \right) \right)^2 \\ &= \frac{1}{2} b \delta^2 (n+2)^2 \frac{(\alpha - a + n\alpha + n\tau - na)^2}{(2n - 4b\delta + n^2 - 4bn\delta - bn^2\delta + 1)^2} \end{aligned}$$

Taking a derivative of  $CS$  with respect to  $n$ , we obtain:

$$\begin{aligned} \frac{\partial CS}{\partial n} &= \frac{(\alpha - a + n\alpha + n\tau - na)^2}{(2n - 4b\delta + n^2 - 4n\delta b - n^2\delta b + 1)^2} \left( \frac{1}{2} \delta^2 b (n+2)(n+4) + \right. \\ &+ \left. \frac{\delta^2 b (n+2)^2 (4\delta b - 2n + 2n\delta b - 2)}{(n+1)^2 - \delta b (n+2)^2} + \frac{\delta^2 b (n+2)^2 (\alpha + \tau - a)}{\alpha - a + n\alpha + n\tau - na} \right) \end{aligned}$$

The sum of the first two terms in large brackets is positive due to the fact that  $\delta b > 1$ , which follows from inequalities (10.4) and (10.5). The last, third term is positive, too, as an immediate consequence of (10.4). Therefore, the whole expression for the derivative of  $CS_i$  with respect to  $n$  is positive.

2. The second part of Proposition 5 is an immediate corollary of Lemma 1 stated below if one defines the lower threshold  $\underline{\tau} = \min_{n \in [1, \bar{n}]} \tilde{\tau}(n)$  and the upper threshold  $\bar{\tau} = \max_{n \in [1, \bar{n}]} \tilde{\tau}(n)$ , where  $\tilde{\tau}(n)$  is characterized by Lemma 1.

**Lemma 1** *Suppose that inequalities (10.4) and (10.5) and the additional restriction  $a > \alpha(1 + \bar{n} + 2\bar{n}/(n+2))$  hold. Then there exist  $\Delta > 0$  such that for any  $\delta \geq \Delta$ , the following statements are fulfilled:*

- (a) *for any  $n \in [1, \bar{n}]$  there exists a threshold of trade costs  $\tilde{\tau}(n)$ ,  $0 < \tilde{\tau}(n) < \hat{\tau}$ , where  $\hat{\tau} = \frac{a - \alpha(1 + \bar{n})}{2}$  is the upper bound of trade costs at which (10.4) binds, such that the*

derivative of the social welfare function with respect to  $n$  is positive for any  $\tau < \tilde{\tau}(n)$  and it is negative for any  $\tau > \tilde{\tau}(n)$ ;

(b) the threshold  $\tilde{\tau}(n)$  is decreasing in  $n$ .

### Sketch of the proof of Lemma 1

Parts (a) and (b) of the Lemma are proved in turn.

(a) Social welfare,  $W$ , of a country in the multilateral agreement is given by a sum of the firm's profit,  $\pi$ , in (6.2) and the consumer surplus,  $CS$ , calculated above. Taking the derivative of  $W$  with respect to  $n$ , we obtain the expression represented by the product of the ratio  $-\frac{1}{b(2n-4b\delta+n^2-4bn\delta-bn^2\delta+1)^3}$  and the quadratic polynomial of  $\tau$ . The ratio is positive for any  $n \geq 1$  due to the restriction on  $\delta$  in (10.5). On the other hand, the value of the polynomial for any given  $n \geq 1$  is positive when  $\tau$  is below a certain threshold  $\tilde{\tau}(n)$  and it is negative when  $\tau$  is above that threshold, provided that parameter restrictions of the Lemma hold. The latter is established via two steps.

- First, I find that due to the restrictions (10.4) and (10.5), the coefficient of the polynomial at the quadratic term  $\tau^2$  and the constant term are positive, while the coefficient at the linear term  $\tau$  is negative for any given  $n \geq 1$ . Hence, the graph of the polynomial is a parabola with upward-directed branches, crossing the axis  $\tau = 0$  in the positive part and reaching the extremum at a positive value of  $\tau$ . Besides, two roots of the polynomial exist and are both real-valued functions of  $n$ . Clearly, these two roots are also positive for any  $n$ .

Given the above, the smaller root of the polynomial is a point on a scale of  $\tau$  where the polynomial changes its sign from positive to negative. In other words, it is such a value  $\tilde{\tau}(n)$  of trade costs that the derivative of the social welfare with respect to  $n$  is positive for any  $\tau$  from 0 up to  $\tilde{\tau}(n)$  and it is negative for any  $\tau$  above  $\tilde{\tau}(n)$  but below the second, larger root of the polynomial. It remains to show that the larger root of the polynomial is actually greater than the upper bound of trade costs  $\hat{\tau} = \frac{a-\alpha(1+\bar{n})}{2}$  defined by inequality (10.4), so that the derivative of the social welfare is negative for any  $\tau \in (\tilde{\tau}(n), \hat{\tau})$ .

- I prove that the larger root of the polynomial is greater than  $\hat{\tau}$  by showing that the sign of the polynomial at  $\tau = \hat{\tau}$  is negative.

Evaluating the polynomial at  $\hat{\tau}$ , I obtain a cubic polynomial in  $\delta$ . As soon as  $\delta$  is

large enough – higher than the largest real root of the cubic polynomial, the sign of the polynomial is determined by the sign of the coefficient at the highest degree of  $\delta$ . To simplify things, I assume that  $\delta$  is indeed sufficiently large and focus on the sign of the coefficient at  $\delta^3$ . This coefficient is equal to

$$\frac{1}{2}\bar{n}\alpha(n+2)^3(-a(2+n) + \alpha(2+4\bar{n}+n+\bar{n}n))$$

Due to (10.4),  $a$  is at least as large as  $\alpha(1+\bar{n})$ . In fact, if  $a > \alpha(1+\bar{n}+2\bar{n}/(n+2))$  (the additional restriction on  $a$  in Lemma 1), then the coefficient above is negative for any  $n \geq 1$ . Hence, as soon as  $\delta$  is large enough and the additional restriction on  $a$  holds, the value of the polynomial and of the derivative of the social welfare with respect to  $n$  is negative at the upper bound of trade costs,  $\hat{\tau}$ .

- (b) To prove that the threshold  $\tilde{\tau}(n)$  is decreasing in  $n$ , I show that the derivative of  $\tilde{\tau}(n)$  with respect to  $n$  is negative for any  $n \geq 1$ . The derivative of  $\tilde{\tau}(n)$  is represented by the product of the fraction

$$\frac{1}{2}\delta b \frac{\alpha - a}{(-2n^4\delta^3b^3 + 8n^4\delta^2b^2 - 5n4\delta b + n^4 - 20n^3\delta^3b^3 + 44n^3\delta^2b^2 - 24n^3\delta b + 4n^3 - 72n^2\delta^3b^3 + 102n^2\delta^2b^2 - 45n^2\delta b + 6n^2 - 112n\delta^3b^3 + 116n\delta^2b^2 - 38n\delta b + 4n - 64\delta^3b^3 + 48\delta^2b^2 - 12\delta b + 1)^2}$$

which is negative for any  $n$  due to (10.4), and the sum of two terms. The first term is a polynomial of the fifth degree in  $\delta$  and the second is a product of a positive ratio and a polynomial of the sixth degree in  $\delta$ . As soon as  $\delta$  is assumed to be greater than any of the largest real roots of the two polynomials, the sign of each term is defined by the sign of the coefficient at the fifth and the sixth degree of  $\delta$ , respectively. Both coefficients are positive:  $4b^5(n+2)^6 > 0$  and  $4b^6(n+2)^8(n+3) > 0$ . So, at least for sufficiently large  $\delta$ , the derivative of  $\tilde{\tau}(n)$  is negative for any  $n \geq 1$ .

This concludes the (schematic) proof of Lemma 1 and Proposition 5. ■

### Sketch of the proof of Proposition 6

As in the proof of Proposition 2, I claim that the sufficient conditions for Assumptions 1 and 2 to be fulfilled for any  $n < \bar{n}$  are the restrictions (10.6) and (10.7). Under these restrictions, the proof of Proposition 6 is established in two steps.

1. If  $\delta$  is large enough, the social welfare in a spoke economy is monotonically decreasing in  $n$

Social welfare,  $W_s$ , of a spoke in a star is given by a sum of the firm's profit,  $\pi_s$ , and the consumer surplus,  $CS_s$ , in a spoke market, where

$$\begin{aligned}\pi_s &= -by_{ss}^2 - by_{hs}y_{ss} - by_{sh}^2 - b(n-1)y_{sh}^2 - by_{hh}y_{sh} + \\ &\quad + (a - \alpha + x_s^*)(y_{ss} + y_{hs}) - \delta(x_s^*)^2 - \tau y_{sh} \\ CS_s &= \frac{b}{2}(y_{ss} + y_{hs})^2\end{aligned}$$

as implied by (4.5) and (7.1). Here  $y_{ss}$  and  $y_{hh}$  denote the domestic market production of a spoke and a hub, respectively, and  $y_{hs}$ ,  $y_{sh}$  denote the production of a hub for each spoke's market and production of a spoke for a hub's market, respectively. Using (3.2), (3.3) for production levels and the expressions for equilibrium R&D efforts of a hub and a spoke in a star,<sup>33</sup>  $W_s$  can be written as a function of  $n$  and parameters only.

Taking a derivative of  $W_s$  with respect to  $n$  (and keeping the other parameters fixed), I obtain a product of the ratio

$$-\frac{3}{b(27b^2(n+2)^3\delta^2 + (-12bn^4 - 111bn^3 - 378bn^2 - 537bn - 258b)\delta + (4n^4 + 48n^3 + 159n^2 + 170n + 51))^3} \quad (10.12)$$

and a polynomial of the second degree in  $\tau$ . To evaluate the sign of this expression, I first derive that the ratio is negative for any  $n \geq 1$  due to the restrictions (10.6) and (10.7). Then I evaluate the signs of all the polynomial's coefficients, assuming that  $\delta$  is sufficiently large. In fact, each coefficient is itself a polynomial of the sixth degree in  $\delta$  and as soon as  $\delta$  is greater than the largest real root of this polynomial, the sign of a coefficient is given by the sign of the term at  $\delta^6$ . In that way I find that the coefficient of the polynomial at the quadratic term  $\tau^2$  and the constant term are positive, while the coefficient at the linear term  $\tau$  is negative for any given  $n \geq 1$ . Taking into account the negative sign of the ratio in front of the polynomial, I conclude that the derivative of  $W_s$  with respect to  $n$  can be graphically represented by a parabola with downward-directed branches, crossing the axis  $\tau = 0$  in its negative part and reaching the extremum at a negative part of the  $\tau$ -scale. This means that for  $\tau \geq 0$  the value of the derivative is always negative. That is, the welfare in a spoke economy is decreasing in  $n$  for all (non-negative) trade costs  $\tau$ .

2. The second part of Proposition 6 is an immediate corollary of Lemma 2 stated below if one

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<sup>33</sup>See the formulas for  $x_h^*$  and  $x_s^*$  in the proof of Proposition 2 using  $\psi = \varphi = 0$  and  $m = 1$  for the single-star network.

defines the lower threshold  $\underline{\tau} = \min_{n \in [1, \bar{n}]} \tilde{\tau}(n)$  and the upper threshold  $\bar{\tau} = \max_{n \in [1, \bar{n}]} \tilde{\tau}(n)$ , where  $\tilde{\tau}(n)$  is characterized by Lemma 2. The formulation and the proof of Lemma 2 are very similar to those of Lemma 1. However, Lemma 2 refers to the case of a star, not a complete network, with correspondingly different form of the welfare function and restrictions on parameters.

**Lemma 2** *Suppose that inequalities (10.6) and (10.7) and the additional restriction  $a > \alpha \left(1 + \frac{\bar{n}(2n^3 + 12n^2 + 51n + 16)}{9(n+2)}\right)$  hold. Then there exist  $\tilde{\Delta} > 0$  such that for any  $\delta \geq \tilde{\Delta}$ , the following statements are fulfilled:*

- (a) *for any  $n \in [1, \bar{n}]$  there exists a threshold of trade costs  $\tilde{\tau}(n)$ ,  $0 < \tilde{\tau}(n) < \hat{\tau}$ , where  $\hat{\tau} = \frac{a - \alpha(1 + \bar{n})}{2}$  is the upper bound of trade costs at which (10.6) binds, such that the derivative of the social welfare function with respect to  $n$  is positive for any  $\tau < \tilde{\tau}(n)$  and it is negative for any  $\tau > \tilde{\tau}(n)$ ;*
- (b) *the threshold  $\tilde{\tau}(n)$  is decreasing in  $n$ .*

### Sketch of the proof of Lemma 2

Parts (a) and (b) of the Lemma are proved in turn.

- (a) Social welfare,  $W_h$ , of a hub in a star is given by a sum of the firm's profit,  $\pi_h$ , and the consumer surplus,  $CS_h$ , in a hub's market, where

$$\begin{aligned} \pi_h &= -by_{hh}^2 - bny_{sh}y_{hh} + n(-by_{hs}^2 by_{ss}y_{hs}) + \\ &\quad + (a - \alpha + x_h^*)(y_{hh} + ny_{sh}) - \delta(x_h^*)^2 - \tau ny_{hs} \\ CS_h &= \frac{b}{2}(y_{hh} + ny_{sh})^2 \end{aligned}$$

as follows from (4.5) and (7.1). Using (3.2), (3.3) for production levels and the formulas for equilibrium R&D efforts of a hub and a spoke in a star,  $W_h$  can be expressed solely in terms of  $n$  and parameters.

Taking a derivative of  $W_h$  with respect to  $n$ , I obtain a product of the ratio

$$\frac{3}{b(27b^2(n+2)^3\delta^2 + (-12bn^4 - 111bn^3 - 378bn^2 - 537bn - 258b)\delta + (4n^4 + 48n^3 + 159n^2 + 170n + 51))^3}$$

and the quadratic polynomial of  $\tau$ . The ratio turns out to be the same as in (10.12) but without a "–" sign in front of it, so that it is positive for any  $n \geq 1$  due to (10.6)

and (10.7). On the other hand, the value of the polynomial for any given  $n \geq 1$  is positive when  $\tau$  is below a certain threshold  $\tilde{\tau}(n)$  and it is negative when  $\tau$  is above that threshold, provided that parameter restrictions of the Lemma hold.

The latter is established via two steps.

- The coefficients of the polynomial are themselves polynomials of the sixth degree in  $\delta$ . In each of these polynomials I focus on the sign of the term at  $\delta^6$ , the highest degree of  $\delta$ , since for sufficiently large  $\delta$  the sign of this term determines the sign of the whole polynomial in  $\delta$ , that is, the sign of the corresponding coefficient in the polynomial of  $\tau$ . In that way I find that for sufficiently large  $\delta$  and for any  $n \geq 1$  the coefficient at the quadratic term and the constant term in the polynomial of  $\tau$  are positive. The coefficient at the linear term is negative, provided that (10.6) holds. So, the graph of the polynomial (and of the derivative of  $W_h$  with respect to  $n$ ) is a parabola with upward-directed branches, crossing the axis  $\tau = 0$  in the positive part and reaching the extremum at a positive value of  $\tau$ . Besides, two roots of the polynomial exist and are both real-valued, positive functions of  $n$ .

From the above it is clear that the smaller root of the polynomial is a point on a scale of  $\tau$ ,  $\tilde{\tau}(n)$ , where the polynomial and therefore, the derivative of  $W_h$  with respect to  $n$  change their sign from positive to negative. It remains to show that the larger root of the polynomial, where the sign of the derivative changes back to positive, is actually greater than the upper bound of trade costs  $\hat{\tau} = \frac{a-\alpha(1+\bar{n})}{2}$  defined by (10.6). In that case the derivative of the hub's welfare is negative for *any* possible  $\tau \in (\tilde{\tau}(n), \hat{\tau})$ .

- I prove that the larger root of the polynomial is greater than  $\hat{\tau}$  by showing that the sign of the polynomial at  $\tau = \hat{\tau}$  is negative.

Evaluating the polynomial at  $\hat{\tau}$ , I obtain another polynomial of the sixth degree in  $\delta$ . For sufficiently high  $\delta$  – higher than the largest real root of that polynomial, only the sign of the coefficient at the highest degree of  $\delta$ ,  $\delta^6$ , matters. This coefficient is equal to

$$\frac{729}{2}b^6\bar{n}\alpha(n+2)^6((a-\alpha)(-18-9n)+\bar{n}\alpha(2n^3+12n^2+51n+16))$$

Due to (10.6),  $a$  is at least as large as  $\alpha(1+\bar{n})$ . In fact, if  $a > \alpha\left(1 + \frac{\bar{n}(2n^3+12n^2+51n+16)}{9(n+2)}\right)$  (the additional restriction on  $a$  in Lemma 2), then this coefficient is negative for

any  $n \geq 1$ . Hence, as soon as  $\delta$  is large enough and the additional restriction on  $a$  holds, the value of the polynomial and of the derivative of  $W_h$  with respect to  $n$  is negative at the upper bound of trade costs,  $\hat{\tau}$ .

- (b) Consider the derivative of the threshold  $\tilde{\tau}(n)$  with respect to  $n$ . I find that it is given by the product of the ratio, negative under condition (10.6), and a continuous function of  $\delta$ . For  $\delta$  greater than the largest real root of this function, the sign of the function is determined by the sign of the term at the highest degree of  $\delta$ . I focus on that term and after a series of algebraic calculations I derive that for sufficiently large  $\delta$  and for any  $n \geq 1$  the highest-degree term is positive. So, at least for sufficiently large  $\delta$ , the derivative of  $\tilde{\tau}(n)$  with respect to  $n$  is negative for any  $n \geq 1$ , which implies that  $\tilde{\tau}(n)$  is monotonically decreasing in  $n$ .

This completes the (schematic) proof of Lemma 2 and Proposition 6. ■

### Proof of Proposition 7

The proof is suggested by the proof of Lemma 2.3 and Lemma 7.1 in Bloch and Quérou (2008).

Consider the system of linear equations (10.1). Since  $\|\lambda \mathbf{B}\| \leq \frac{\bar{\varepsilon}}{N} < \frac{1}{N}$ , Lemma 7.1 in Bloch and Quérou (2008) states that (10.1) possesses a unique solution and

$$\|\mathbf{x}^* - \lambda \tilde{\mathbf{u}} \cdot \sum_{k=0}^K \lambda^k \mathbf{B}^k\| \leq \frac{N^{K+1} \|\lambda \mathbf{B}\|^{K+1} \lambda \|\tilde{\mathbf{u}}\|}{1 - N \|\lambda \mathbf{B}\|} \leq \frac{\lambda \bar{\varepsilon}^{K+1} \|\tilde{\mathbf{u}}\|}{1 - \bar{\varepsilon}}$$

Observe that  $\mathbf{c}^m$  is defined so that

$$\lambda \tilde{\mathbf{u}} \sum_{k=0}^K \lambda^k \mathbf{B}^k = \sum_{m=1}^{K+1} \mathbf{c}^m$$

So,

$$\|\mathbf{x}^* - \sum_{m=1}^{K+1} \mathbf{c}^m\| \leq \frac{\lambda \bar{\varepsilon}^{K+1} \|\tilde{\mathbf{u}}\|}{1 - \bar{\varepsilon}}$$

By definition of the  $l_\infty$  vector norm, this means that  $\forall i \in 1 : N$

$$|\mathbf{x}_i^* - \sum_{m=1}^{K+1} \mathbf{c}_i^m| \leq \frac{\lambda \bar{\varepsilon}^{K+1} \|\tilde{\mathbf{u}}\|}{1 - \bar{\varepsilon}} \quad (10.13)$$

Consider a pair  $(i, j)$  of players and let  $M$  be the first element of the sequences  $\mathbf{f}_i, \mathbf{f}_j$  such that  $\mathbf{c}_i^M \neq \mathbf{c}_j^M$ . Applying (10.13) to  $i$  and  $j$ , we obtain:

$$|\mathbf{x}_i^* - \mathbf{x}_j^* - (\mathbf{c}_i^M - \mathbf{c}_j^M)| \leq 2 \cdot \frac{\lambda \bar{\varepsilon}^{K+1} \|\tilde{\mathbf{u}}\|}{1 - \bar{\varepsilon}}$$

This concludes the proof. ■

### Appendix C: Figures

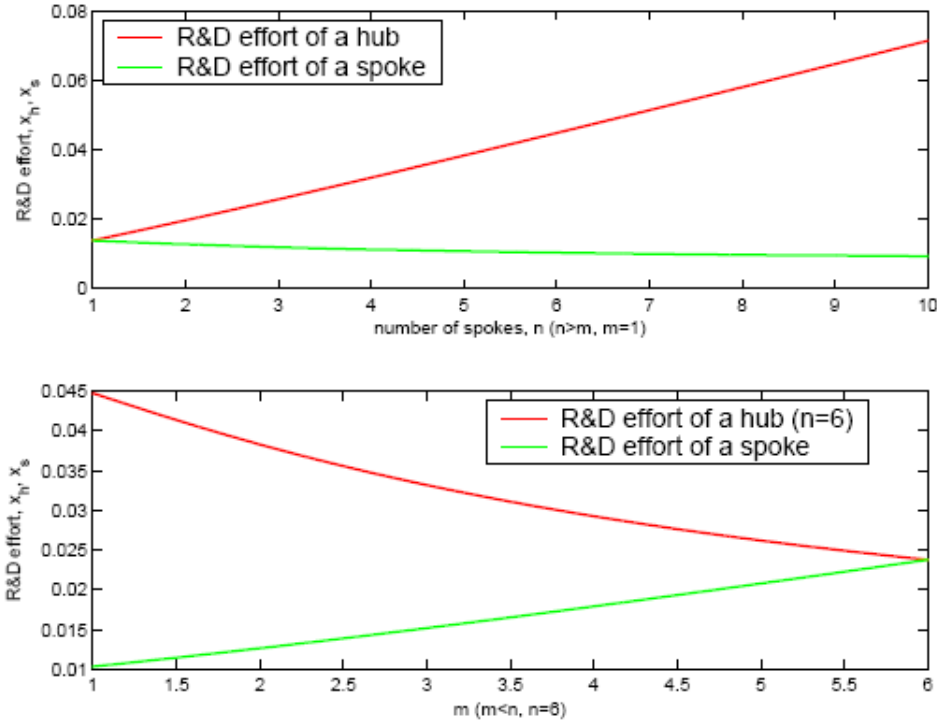


Figure 7: Equilibrium R&D efforts in the hub-and-spoke trade system as a function of  $n$  (the upper sub-figure) and as a function of  $m$  (the lower sub-figure).



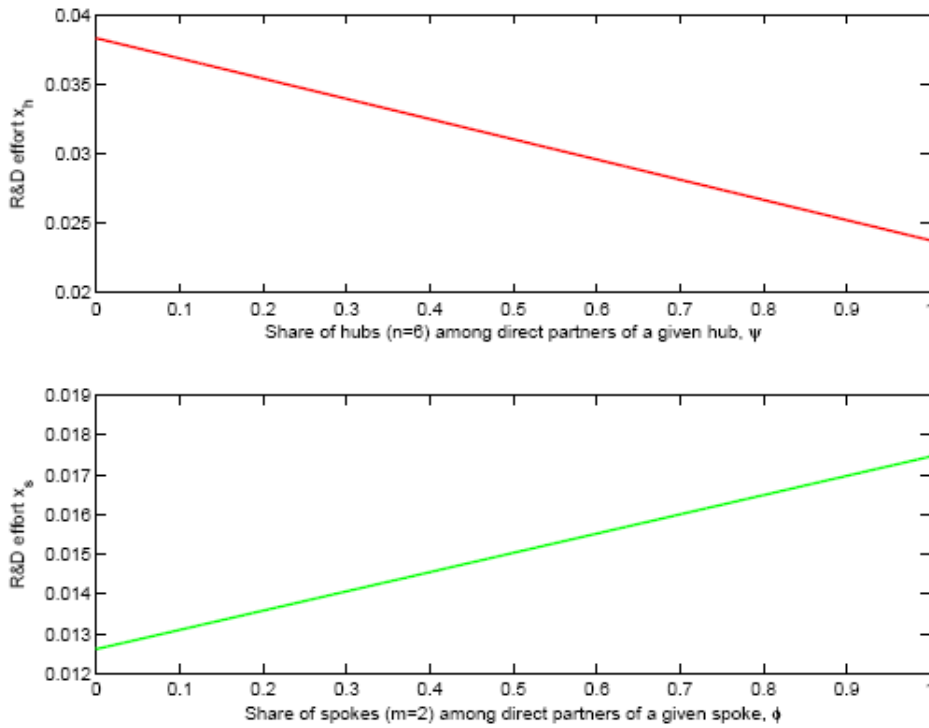


Figure 8: Equilibrium R&D efforts in the hub-and-spoke trade system as a function of  $\psi$  (the upper sub-figure) and as a function of  $\phi$  (the lower sub-figure).

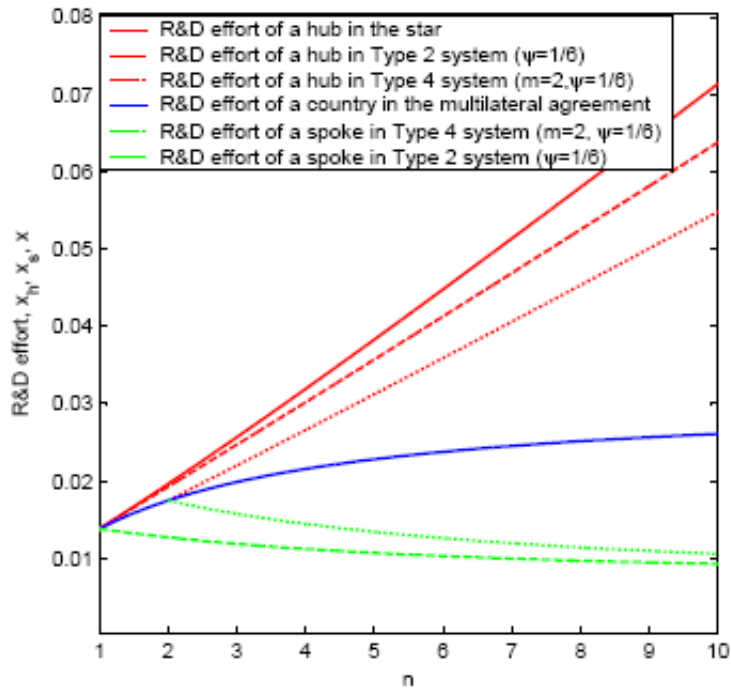


Figure 9: Equilibrium R&D efforts in Type 2 system as compared to R&D efforts in other hub-and-spoke systems and to R&D of a country in the multilateral agreement.

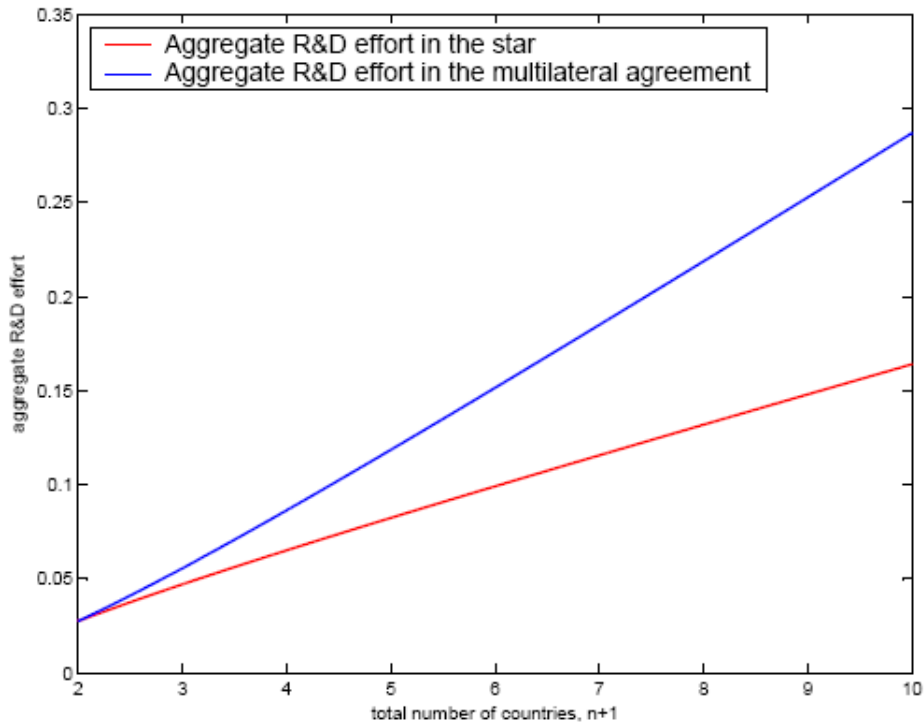


Figure 10: Aggregate equilibrium R&D efforts of  $n$  countries in the star and in the multilateral agreement.

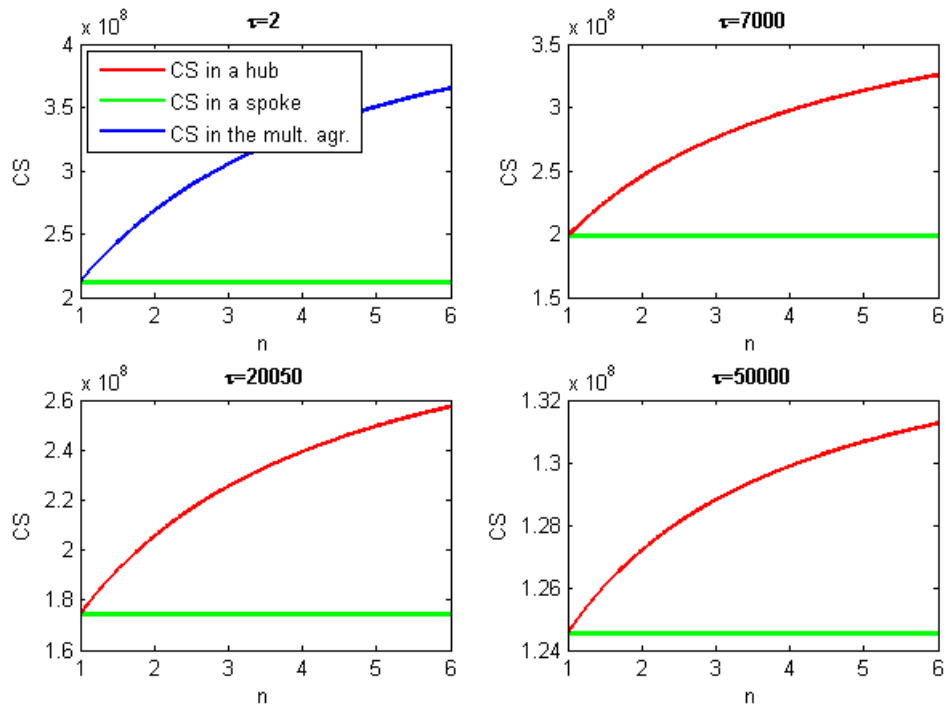


Figure 11: Consumer surplus of a country in the star and in the multilateral agreement. Consumer surplus in a hub of the star and in a country within multilateral agreement coincide.

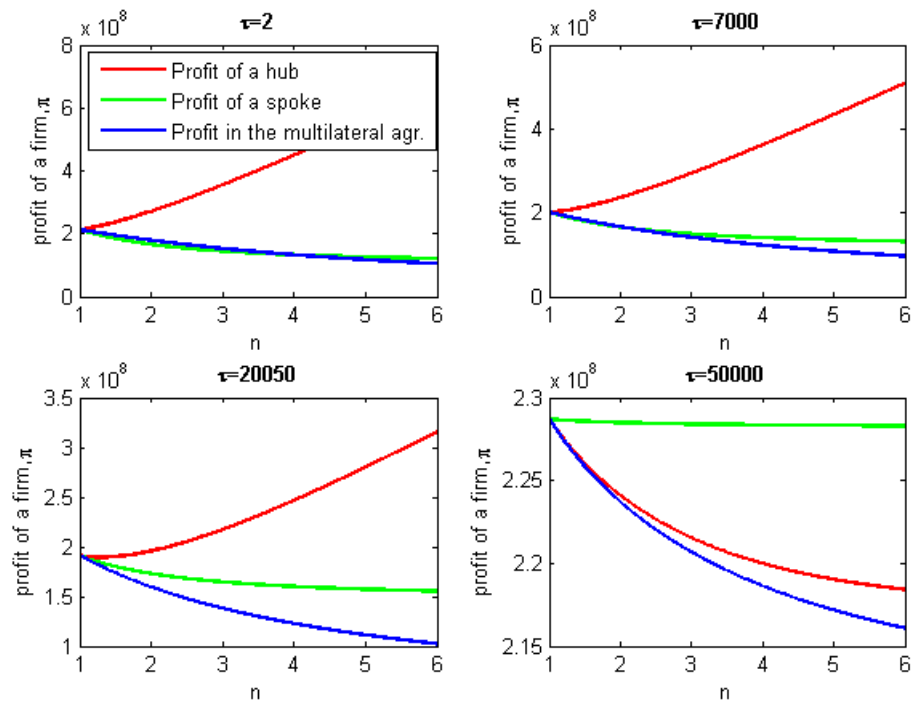


Figure 12: Firm's profit in the star and in the multilateral agreement.

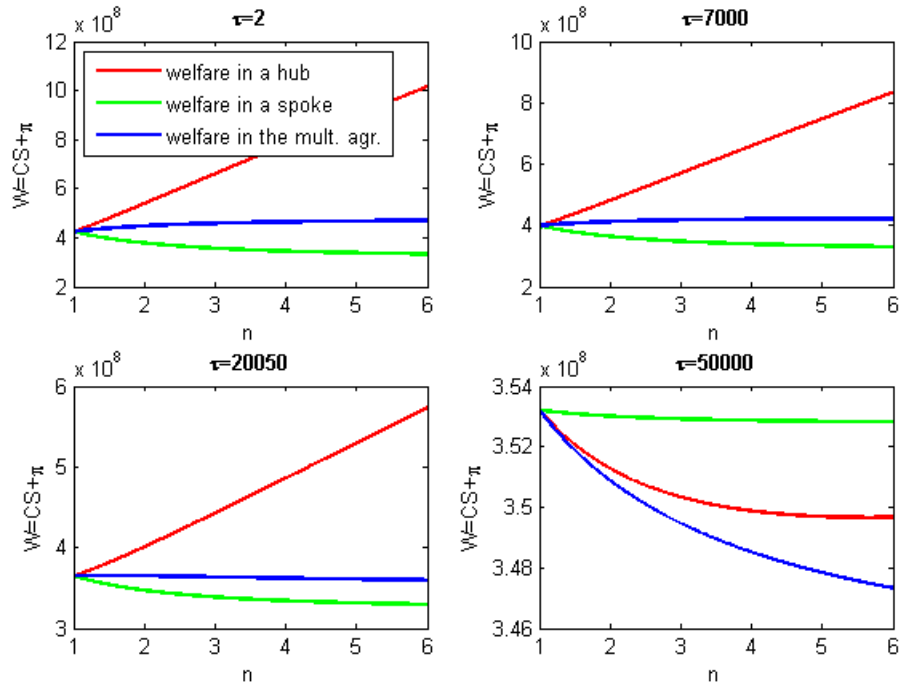


Figure 13: Social welfare of a country in the star and in the multilateral agreement.

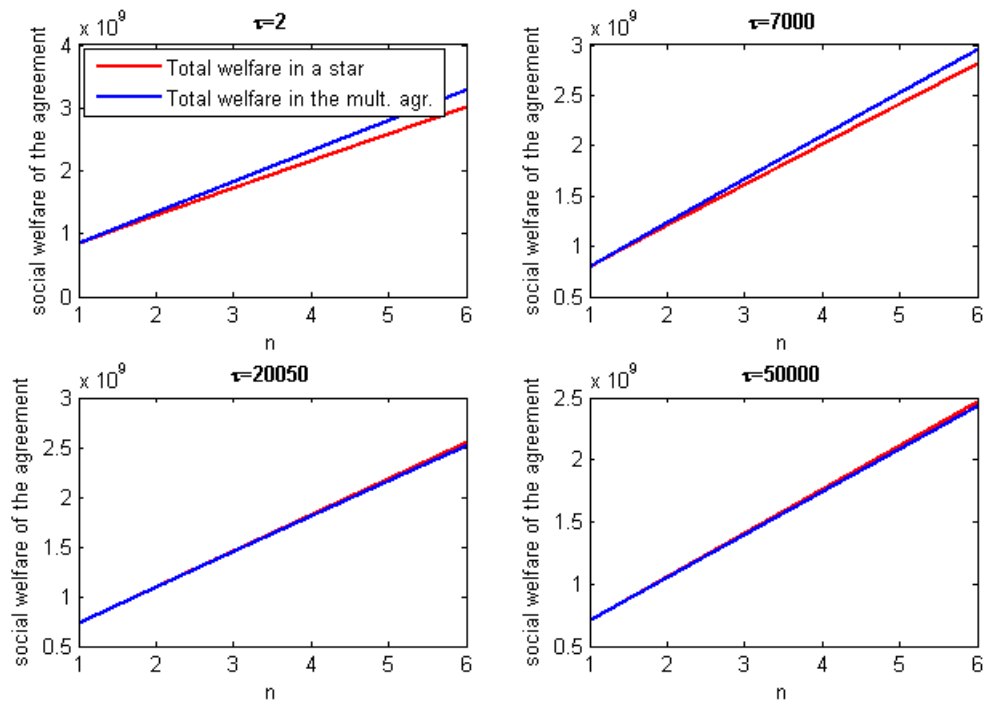


Figure 14: Aggregate welfare of  $n$  countries in the star and in the multilateral agreement.

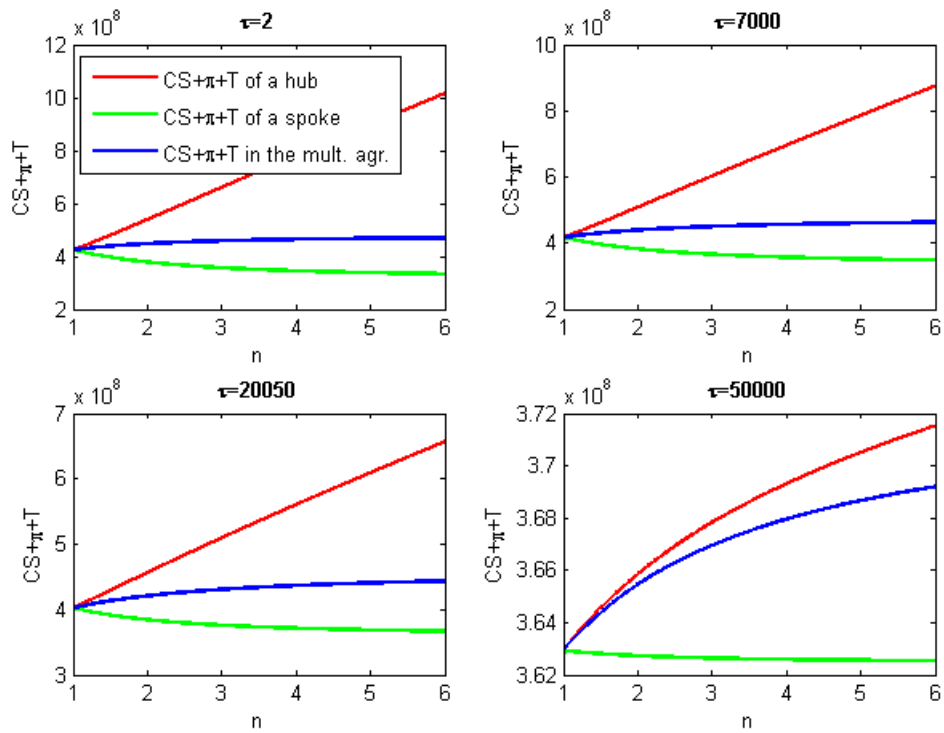


Figure 15: Social welfare with trade tariffs of a country in the star and in the multilateral agreement.

## References

- [1] Aghion, P., Bloom N., Blundell R., Griffith R., and P. Howitt. 2005. "Competition and Innovation: An Inverted-U relationship." *The Quarterly Journal of Economics*, 120(2): 701-728.
- [2] Alcalá, F. and A. Ciccone. 2004. "Trade and Productivity." *The Quarterly Journal of Economics*: 613-646.
- [3] Alvarez, R., and R. Lopez. 2005. "Exporting and Performance: Evidence from Chilean Plants." *Canadian Journal of Economics*, 38(4): 1384-1400.
- [4] Aw, B. Y., Chung S., and M. J. Roberts. 2000. "Productivity and Turnover in the Export Market: Micro-Level Evidence from the Republic of Korea and Taiwan." *World Bank Economic Review*, 14(1): 65-90.
- [5] Baggs, J., Head K., and J. Ries. 2002. "Free Trade, Firm Heterogeneity and Canadian Productivity." Paper presented at the conference "Canada-U.S. Economic and Monetary Integration", Kennedy School of Government, Harvard University, 9-11 May 2002
- [6] Bagwell, K., and R. W. Staiger. 1999a. "An Economic Theory of GATT." *American Economic Review*, 89 (1), 215-248.
- [7] Bagwell, K., and R. W. Staiger. 1999b. "Regionalism and Multilateral Tariff Cooperation." In: Piggott, J., Woodland, A. (Eds.), *International Trade Policy and the Pacific Rim*. MacMillan: 157-185.
- [8] Bagwell, K., and R. W. Staiger. 2004. "Multilateral Trade Negotiations, Bilateral Opportunism and the Rules of GATT/WTO", *Journal of International Economics*, 63(1): 1-29.
- [9] Baldwin, R. E. 2003. "The Spoke Trap: Hub-and-Spoke Regionalism in East Asia." *KIEP Discussion Paper 04-02*, Seoul: Korea Institute for International Economic Policy.
- [10] Baldwin, R. E. 2005. "Stepping Stones or Building Blocks? Regional and Multilateral Integration." in *Regional Economic Integration in a Global Framework*, ed. J. McKay, M. O. Armengol, and G. Pineau. European Central Bank, Frankfurt.
- [11] Bernard, A. B., Jensen J. B., and P.K. Schott. 2006. "Falling Trade Costs, Heterogeneous Firms, and Industry Dynamics." *Journal of Monetary Economics*, 53: 917-937.
- [12] Bernard, A. B., Redding S. J., and P.K. Schott. 2007. "Comparative Advantage and Heterogeneous Firms." *Review of Economic Studies*, 74(1): 31-66.
- [13] Bhagwati, J. 1993. "Regionalism and Multilateralism: an Overview," in *New Dimensions in Regional Integration*, ed. Melo and Panagariya.
- [14] Bloch F., and N. Quérou. Forthcoming. "Optimal Pricing and Strategic Decisions in Networks."
- [15] Bustos, P. Forthcoming. "Multilateral Trade Liberalization, Exports and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinian Firms." *American Economic Review*.
- [16] Dasgupta, P. 1986. "The Theory of Technological Competition." in *New Developments in the Analysis of Market Structure*, ed. J. E. Stiglitz and F. Matthews. London: Macmillan and Cambridge, Mass: MIT Press. Reprinted in K. Binmore and P. Dasgupta.
- [17] D'Aspremont, C., and A. Jacquemin. 1988. "Cooperative and Noncooperative R&D in Duopoly with Spillovers." *American Economic Review*, 78: 1133-1137.
- [18] De la Torre, A., and M. R. Kelly. 1992. "The Regional Trade Arrangements." *IMF Occasional Paper*, 93, IMF, Washington, DC.
- [19] De Benedictis, L., De Santis R., and C. Vicarelli. 2005. "Hub-and-Spoke or Else? Free Trade Agreements in the 'Enlarged' European Union." *ENERPI and ISAE*.
- [20] Del Gatto, M., Mion G., and G. I. P. Ottaviano. 2006. "Trade Integration, Firm Selection and the Costs of Non-Europe." *CEPR Discussion Paper No. 5730*.

- [21] Deltas, G., Desmet K., and G. Facchini. 2006. "Hub-and-Spoke Free Trade Areas." *CEPR Discussion Paper No. 5960*.
- [22] Devereux, M., and B. Lapham. 1994. "The Stability of Economic Integration and Endogenous Growth." *The Quarterly Journal of Economics*, 109: 299-305.
- [23] Diao, X., Diaz-Bonilla E., and S. Robinson. 2003. "Scenarios for Trade Integration in the Americas." *Economie Internationale*, 94-95: 33-52.
- [24] Fiorentino, R. V., Verdeja L., and C. Toqueboeuf. 2007. "The Changing Landscape of Regional Trade Agreements: 2006 Update." *WTO Discussion Paper 12*.
- [25] Frankel, J. A. 1997. *Regional Trading Blocs in the World Trading System*. Washington, DC: Institute for International Economics.
- [26] Furusawa, T., and H. Konishi. 2007. "Free Trade Networks." *Journal of International Economics*, 72: 310-335.
- [27] Goyal, S., and J. Moraga. 2001. "R&D Networks." *RAND Journal of Economics*, 32(4): 686-707.
- [28] Goyal, S., and S. Joshi. 2006. "Bilateralism and Free Trade." *International Economic Review*, 47 (3): 749-778.
- [29] Helpman, E. 1981. "International Trade in the Presence of Product Differentiation, Economies of Scale, and Monopolistic Competition: A Chamberlin-Heckscher-Ohlin Approach." *Journal of International Economics*, 11(3): 305-340.
- [30] Kowalczyk, C., and R. Wonnacott. 1991. "Substitute and Complement Trading Clubs." Dartmouth College, Department of Economics, working paper 91-16.
- [31] Kowalczyk, C., and R. Wonnacott. 1992. "Hubs and Spokes, and Free Trade in the Americas." *NBER Working Paper 4198*.
- [32] Krueger, A. O. 1999. "Are Preferential Trading Agreements Trade-Liberalizing or Protectionist?" *Journal of Economic Perspectives*, 13(4): 105-24.
- [33] Licandro, O., and A. Navas-Ruiz. 2011. "Trade Liberalization, Competition, and Growth." *The B.E. Journal of Macroeconomics*, Berkeley Electronic Press, 11(1), pages 13.
- [34] Lipsey, R. G. 1990. "Canada and the U. S. - Mexico Free Trade Dance: Wallflower or Partner?" *C. D. Howe Institute Commentary 20*.
- [35] Lipsey, R. G. 1991. "The Case for Trilateralism." in *Continental Accord: North American Economic Integration*, ed. S. Globerman. Vancouver: The Fraser Institute.
- [36] Lloyd, P. J., and D. Maclaren. 2004. "Gains and Losses from Regional Trading Agreements: A Survey." *The Economic Record*, 80(251): 445-467. )
- [37] Mauleon, A., Song H., and V. Vannetelbosch. 2006. "Networks for Free Trade Agreements among Heterogeneous Countries." Working Paper 2006029, Université catholique de Louvain, Département des Sciences Economiques.
- [38] Melitz, M. J. 2003. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." *Econometrica*, 71: 1695-1725.
- [39] Muendler, M. A. 2004. "Trade, Technology, and Productivity: A Study of Brazilian Manufacturers, 1986-1998." *CESifo Working Paper 1148*, Munich: CESifo GmbH.
- [40] Panagariya, A. 2000. "Preferential Trade Liberalization: The Traditional Theory and New Developments." *Journal of Economic Literature*, 38 (2): 287-331.
- [41] Pavcnik, N. 2002. "Trade Liberalization, Exit, and Productivity Improvements: Evidence from Chilean Plants." *Review of Economic Studies*, 69 (1): 245-276.
- [42] Peretto, P. 2003. "Endogenous Market Structure and the Growth and Welfare Effects of Economic Integration." *Journal of International Economics*, 60: 177-201.
- [43] Rivera-Batiz, L., and P. Romer. 1991. "Economic Integration and Endogenous Growth." *The Quarterly Journal of Economics*, 106: 531-556.

- [44] Schwartz, W.F., and Sykes, A.O. 1997. "The Economics of the Most Favored Nation Clause." In: Bhandani, J.S., Sykes, A.O. (Eds.), *Economic Dimensions in International Law: Comparative and Empirical Perspectives*, Cambridge University Press: 4379.
- [45] Srinivasan, T. N., Whalley J., and I. Wooton. 1993. "Measuring the Effects of Regionalism on Trade and Welfare." in *Regional Integration and the Global Trading System*, ed. K. Anderson and R. Blackhurst, 52-79. NY: St. Martin's Press.
- [46] Trefler, D. 2004. "The Long and Short of the Canada-U.S. Free Trade Agreement." *American Economic Review*, 94(4): 870-895.
- [47] Van Biesebroeck, J. 2005. "Exporting Raises Productivity in sub-Saharan African Manufacturing Firms." *Journal of International Economics*, 67(2): 373-391.
- [48] Wonnacott, R. 1990. "U. S. Hub-and-Spoke Bilaterals and the Multilateral Trading System." *C. D. Howe Institute Commentary 23*.
- [49] Wonnacott, R. 1991. "The Economics of Overlapping Free Trade Areas and the Mexican Challenge." C. D. Howe Institute and National Planning Association.
- [50] Wonnacott, R. 1996. "Trade and Investment in a Hub-and-Spoke System versus a Free Trade Area." *World Economy*, 19: 237-252.
- [51] World Trade Report 2008. "Trade in a Globalizing World."
- [52] Yeaple, S. R. 2005. "A Simple Model of Firm Heterogeneity, International Trade, and Wages." *Journal of International Economics*, 65: 1-20.  
 Brander (1981), Brander and Krugman (1983), Weinstein (1992), Yomogida (2008), Dixit and Grossman (1986), Neary (1994, 2002, 2009), and Eckel and Neary (2010)