Inter-firm R&D collaboration within and across national borders

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11 April 2019

Abstract

We set up a model to investigate the strategic aspect of a firm's incentive to collaborate in cost-reducing R&D with either a local or a foreign partner. We argue that collaboration with a foreign firm is preferred to collaboration with a local firm if the extra profits generated by a foreign collaboration exceed the additional cost of coordinating collaboration across national borders. We show that foreign collaboration is more likely the bigger the home-market-size of the foreign firm and, given certain conditions, the higher the international trade cost. We also show that whenever a foreign collaboration arises in equilibrium, it is efficient (i.e. world-welfare-maximising); and that there are cases where: (*i*) a foreign collaboration would be efficient but a local collaboration emerges in equilibrium; and (*ii*) an efficient foreign collaboration emerges in equilibrium, but one of the countries would prefer a local collaboration. We briefly consider the policy implications of these findings.

Keywords: R&D collaboration, RJV, spatial competition, country size, trade costs
JEL Classification: F13, O31

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1 Introduction

The number of research and development (R&D) collaborations between firms from different countries has increased significantly over the past few decades. This increase can be measured using data from the OECD database, which includes patent applications filed in Europe, the United States and Japan.[1] In 2013 there were around 14,000 outstanding international patent collaborations. As is shown by the dashed line in Figure 1, this is equivalent to almost 7% of total registered patents in the world. In Europe, which includes several relatively small countries, the share of patents with a foreign co-inventor was even higher at almost 12% (see the solid line in Figure 1). Both figures represent a threefold increase over the comparable figures for the late '70s and early '80s. Yet the factors that drive firms to collaborate with far-away agents are still poorly understood (Fitjar and Rodriguez-Pose, 2014).

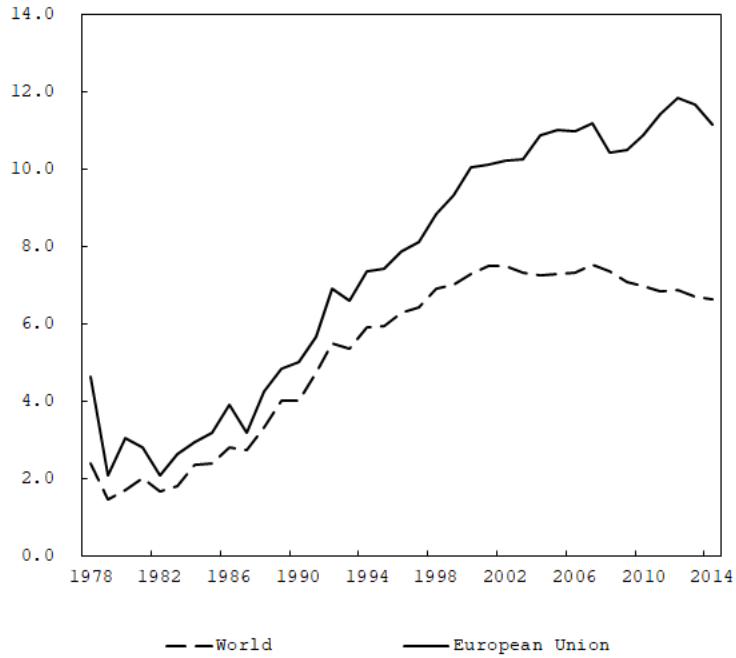
On the one hand, it is taken for granted that geographic proximity greatly facilitates successful collaborations as firms located in the same country can meet and interact more easily (see, for example, OECD, 2013). This view reflects the challenges of coordinating collaboration across national borders that may arise due to factors such as higher communication costs, differences in corporate cultures, time-zone differences, etc. There is, in fact, empirical evidence that the productivity gains of joint R&D projects decline with the geographical distance between R&D partners (Keller, 2002).

On the other hand, strategic considerations may incentivise firms to collaborate with firms that are located in different countries. For example, in a case study of a Canadian ICT cluster, Ben Letaifa and Rabeau (2013) find that some firms prefer collaborating with geographically distant firms – particularly from France and America – because they see local players as their competitors. They argue that geographic distance seems to favour a 'win-win' mind-set among Quebecer business leaders because they feel less threatened in their local markets. In this sense, geographic distance is seen as a facilitator of collaboration in innovation.

Against this background, we set out to investigate the strategic aspect of a firm's incentive to collaborate in cost-reducing R&D with either a local or a

[1]The OECD database covers patent applications to the European Patent Office and the US Patent and Trademark Office, as well as patents filed under the Patent Cooperation Treaty and patents that belong to 'Triadic Patent Families' (see OECD (2009a) and more recent editions for further details).

Figure 1: Share of Patents with a Foreign Co-Inventor



foreign competitor. We set up a model to analyse some of the factors that determine whether the extra profits generated (for the initiating firm) by a foreign collaboration exceed the additional cost of coordinating collaboration across national borders. The model consists of three ex-ante equally efficient firms that produce homogeneous products. We allow for geographic differentiation by assuming that two firms are located in the same country, such that they are in close geographic proximity, while the other firm is located in another country, such that it is geographically distant to the other two firms. All firms serve the market in their own country and, depending on national trade policies and trade costs[2], they may also sell in markets outside their country at a per unit trade cost that is proportional to the firms' distance from the market. One of the two firms located in the same country is assumed to be a 'leading firm' such that it has the opportunity to make a collaboration offer to *either* the local *or* the foreign firm, which in turn can accept or reject the offer.[3] In the case of collaboration with the foreign firm, the collaborating firms

[2]Trade costs being interpreted as transport and related costs. We do not consider tariffs.

[3]In network formation models under oligopoly, it is common to rule out the complete network (perhaps on grounds of diseconomies of coordination as the network expands) and to focus on pairwise collaborations, because the complete network often dominates all other outcomes (see, for example, Westbrock, 2010).

both incur an additional fixed coordination cost over and above what would be incurred if collaboration were local. If two firms collaborate, the collaborating firms both benefit fully from each other's investments in R&D; but there is no cooperation when deciding how much to invest in R&D and how much to produce (Kamien *et al.* [1992] call this 'RJV competition').

Like d'Aspremont and Jacquemin (1988), we show that in the absence of coordination costs, collaborating with a competitor is profitable; and like Motta (1996), we show that this is also true when collaboration does not involve all market players because it gives the firms participating in the collaboration a competitive advantage over their rivals in the product market. However, whereas Motta focuses on a government's policy choice over whether to permit or prohibit inter-firm R&D collaboration in a completely integrated, two-country world economy, our focus is on a firm's choice to collaborate with a foreign or a local partner in a world with two countries that allows for varying degrees of international trade.

We argue that collaboration with a foreign firm is preferred to collaboration with a local firm if the extra profits generated (for the initiating firm) by a foreign collaboration exceed the additional cost of coordinating collaboration over national borders. We show that this is more likely the larger the home-market-size of the foreign firm and, given certain conditions, the higher the international trade cost. Specifically, we show that increasing the trade cost under cross-hauling (including to a prohibitive level) makes a foreign collaboration more likely *unless* the countries are of the same size. As in Zu *et al.* (2011), who consider the impact of free trade agreements on firms' R&D collaboration decisions, this happens because firms gain more when collaborating with firms that are not their product-market competitors.

We also show that if a foreign collaboration arises in equilibrium, it is efficient (i.e. it maximises the sum of the social welfares of both countries). Note that this result differs from those obtained in other papers that consider the welfare effects of policy interventions either when a foreign collaboration is compared to no collaboration (as in Zu *et al.*, 2011) or when a foreign collaboration is modelled as a top-up to local collaboration (as in Motta, 1996). In our paper, we consider the case of collaboration with a foreign partner against the alternative of collaboration with a local partner (with no collaboration at all providing a disagreement point, which is never reached in equilibrium).

Finally, note that in spite of its efficiency property, an equilibrium with a foreign collaboration may not maximise the welfare of individual countries (see section

4 for some policy implications). Moreover, there are cases where a foreign collaboration would be efficient but a local collaboration emerges in equilibrium. The latter finding is similar to the results in Song and Vannetelbosch (2007), who study the stability and efficiency of R&D collaboration networks between three firms located in different countries. They show that a conflict between the firms' collaboration choices and efficiency is likely to arise unless governments subsidise R&D.

There is, in fact, a strand of literature on international, inter-firm R&D collaborations that focuses on R&D subsidies and/or protectionist policies (see, for example, Qui and Tao, 1998; Leahy and Neary, 1999; Edwards and Poyago-Theotoky, 2013; Falvey and Teerasuwannajak, 2016). But none of those contributions focus on the strategic aspect of a firm's decision to collaborate with either a local or a foreign partner; and most of them are based on Spencer and Brander (1983) and/or Brander and Spencer (1983), in which firms from different countries compete on a third country's product market. In that setup, trade costs do not have the effect of separating a firm's 'home' and 'foreign' markets (since there is only one product market), and those earlier contributions do not analyse how trade costs affect firms' R&D collaboration decisions. A partial exception is Edwards and Poyago-Theotoky (2013), whose cross-hauling model consists of two firms located in different countries that compete in both their home and the foreign market. This allows the authors to analyse a firm's incentive for cross-border collaboration in the presence of endogenously determined, government-imposed barriers to trade. They show that firms are willing to forego the cost savings from international collaboration in return for a local monopoly position that is facilitated by regulatory protection; but they do not consider this against the option of a local collaboration.

The rest of the paper is organised as follows. We discuss the setup of the model and the resulting outcomes under 'autarky' and 'cross-hauling' scenarios in section 2. We analyse the welfare implications in section 3, and section 4 concludes.

2 Model of collaboration choice

The model consists of three profit-maximising firms that produce homogeneous products, and two countries, A and B; with country B being δ times the size of country A. Firms 1 and 2 are located in country A, such that they are in close geographic proximity, while firm 3 is located in country B, such that it is geographically distant to firms 1 and 2. All firms serve the market in their country and, depending on national trade policies and trade costs, they may also sell in the other country's market at a per unit trade cost, t, that is proportional to the firms' distance from the market.[4] The inverse demand functions for the markets in countries A and B are $P_A = 1 - Q_A$ and $P_B = 1 - \frac{1}{\delta}Q_B$, respectively, where P_i is the market price in country i and $Q_i = \sum q_j$ is the total quantity sold in country i.

We think of firm 1 as a 'leading firm' that has the opportunity to initiate a collaborative partnership with *either* the local firm (2) *or* the foreign firm (3).[5] The possibility of firm 1 collaborating with more than one firm is ruled out by the assumption that it would give rise to prohibitive coordination costs. Within any collaboration, the participating firms share their R&D, but we rule out financial transfers between the participants. If the firm receiving the collaboration offer from firm 1 accepts, the collaborating firms both benefit fully from each other's cost-reducing investments in R&D, but otherwise there is no R&D sharing/spillover. Thus, firm i's marginal costs are $c_i = \bar{c} - \left(x_i + \sum_{j \neq i} \lambda_{ij} \cdot x_j\right)$, where $\bar{c} < 1$ is the marginal cost without R&D (that is common to all three firms), x_i is the R&D effort of firm i, and λ_{ij} is a parameter that takes the value of 1 if firm i collaborates with firm j and zero otherwise.

A firm's R&D costs are quadratic, $\frac{1}{2}\gamma x_i^2$, reflecting diminishing marginal returns to R&D expenditure, where $\gamma > 0$. In addition, when collaboration crosses borders, both collaborating firms incur an *additional* cost that reflects the "bigger" challenge of coordinating collaboration over large distances. This is modeled as a fixed cost, as in Goyal and Joshi (2003), and takes a value of $\phi \geq 0$.

The order of moves in the game is as follows:

- at $t = 1$, firm 1 chooses between making no collaboration offers and making a collaboration offer *either* to the local firm (2) *or* to the foreign firm (3);

[4] Empirical evidence suggesting that distance has a substantial impact on trade costs can be found in Disdier and Head (2008).

[5] An equivalent assumption is adopted in Raff *et al* (2009). They analyse the case of three ex-ante equally efficient firms, where one firm (labeled the multinational firm) makes a take-it-or-leave-it offer to one of the other two firms to form a research joint venture.

– at $t = 2$, the firm receiving the offer accepts or rejects firm 1's offer (in the case of rejection, firm 1 cannot make another offer);

– at $t = 3$, all firms decide independently how much to invest in R&D; and

– at $t = 4$, all firms compete *à* la Cournot in each market.

We solve the game backwards to find its sub-game perfect Nash equilibria. To retain tractability and to facilitate the development of intuition, we do this for two "extreme" scenarios: one where no firm trades across borders (autarky) and another where all firms sell in both countries (cross-hauling). (For simplicity, we thus ignore the intermediate case of one-way trade, which could arise in our internationally asymmetric market structure.)

2.1 Autarky

Solving backwards, in stage 4, the three profit-maximising firms decide how much to produce for given levels of R&D. This gives the following profits:

$$\left.\begin{aligned} \pi_1 &= \frac{1}{9}\left(1 - 2c_1 + c_2\right)^2 - \frac{1}{2}\gamma x_1^2 - \lambda_{13}\phi \\ \pi_2 &= \frac{1}{9}\left(1 + c_1 - 2c_2\right)^2 - \frac{1}{2}\gamma x_2^2 \\ \pi_3 &= \frac{\delta}{4}\left(1 - c_3\right)^2 - \frac{1}{2}\gamma x_3^2 - \lambda_{13}\phi \end{aligned}\right\} \tag{1}$$

where the first term on the right-hand side of each equation in (1) represents the gross profit earned in the firm's home market, the second term represents the costs of R&D and the third term the coordination costs for cross-border collaboration.

In stage 3, firms decide how much to invest in R&D. We consider this for three collaboration cases, $k \in \{n, l, f\}$: no collaboration (n) where firm i's marginal cost of production is $c_i^n = \bar{c} - x_i^n$; or firm 1 collaborates with local firm 2 (l) such that the marginal costs are $c_1^l = c_2^l = \bar{c} - x_1^l - x_2^l$ while that of firm 3 remains c_3^n (since, under autarky, firm 3 is unaffected by a collaboration abroad); or firm 1 collaborates with foreign firm 3 (f) such that the marginal costs of

Table 1: R&D investment levels (x) in Autarky

collaboration choice (k)	no (n)	local (l)	foreign (f)
x_1^k	$\frac{4(1-\bar{c})}{9\gamma-4}$	$\frac{2(1-\bar{c})}{9\gamma-4}$	$\frac{4(1-\bar{c})(8-3\delta-6\gamma)}{96\gamma-54\gamma^2+3\delta(-8+9\gamma)-32}$
x_2^k	$\frac{4(1-\bar{c})}{9\gamma-4}$	$\frac{2(1-\bar{c})}{9\gamma-4}$	$\frac{8(1-\bar{c})(4+3\delta-3\gamma)}{96\gamma-54\gamma^2+3\delta(-8+9\gamma)-32}$
x_3^k	$\frac{(1-\bar{c})\delta}{2\gamma-\delta}$	$\frac{(1-\bar{c})\delta}{2\gamma-\delta}$	$\frac{9\delta(1-\bar{c})(4-3\gamma)}{96\gamma-54\gamma^2+3\delta(-8+9\gamma)-32}$

production are $c_1^f = c_3^f = \bar{c} - x_1^f - x_3^f$ and $c_2^f = \bar{c} - x_2^f$. Substituting for c_i into the profit functions in (1), and solving the system of first-order conditions for R&D choices (x), we obtain firms' R&D investment levels for each of the three collaboration cases under consideration. These are presented in Table 1.[6] [7]

We make a number of observations on Table 1. First, there are several symmetries: $x_1^n = x_2^n$, $x_1^l = x_2^l$, and $x_3^n = x_3^l$ (since firm 3 is unaffected by a local collaboration under autarky). Second, firms' R&D efforts are decreasing in the cost of R&D, as measured by γ. Third, δ affects only firm 3's R&D efforts in the no and local collaboration cases, but it affects the R&D efforts of all three firms when collaboration crosses borders; x_1^f and x_3^f positively, and x_2^f negatively. Fourth, when firm 1 chooses to collaborate with the local firm, it halves its R&D expenditure relative to the no collaboration case but gets to benefit from the same marginal-cost reduction as under no collaboration. If instead it chooses to collaborate with the foreign firm, firm 1's investment in R&D is greater than under no collaboration, such that we have $x_1^f > x_1^n = 2x_1^l$. For firms 2 and 3, we have $x_2^f < x_2^n = 2x_2^l$ and $x_3^f > x_3^n = x_3^l$, respectively. These turn out to be an important results when we consider the welfare implications of firm 1's collaboration choices.

Finally, in stage 2, the firm receiving the collaboration offer from firm 1 accepts or rejects, and in stage 1, firm 1 decides whether to make a collaboration offer to the local or the foreign firm. The firms' decisions are based on the equilibrium profits, π_i^k, under the various collaboration scenarios, k. We obtain these by

[6] As is standard in models of process innovation of our type, γ is implicitly assumed to be large enough to ensure that: (i) every firm's second-order condition for R&D choice is satisfied; and (ii) every firm's equilibrium marginal cost is positive.

[7] Formulae for profits in autarky are shown in 4.2 in the Appendix, while the next subsection shows them for the free trade case. Note that formulae are long in the case where there is a non-prohibitive tariff, and so have not been shown.

using the equilibrium R&D efforts obtained in stage 3 and substituting for c_i in equations (1). Then we can state the following proposition.

Proposition 1: *Equilibrium collaborative agreement under autarky. Let δ^* be such that, under autarky, $\pi_1^f = \pi_1^l$ at $\delta = \delta^*$; while $\pi_1^f > \pi_1^l$ if $\delta > \delta^*$ and $\pi_1^f < \pi_1^l$ otherwise. Then, a foreign collaboration arises in equilibrium if $\delta > \delta^*$ (and ϕ is sufficiently small); while a local collaboration arises if $\delta < \delta^*$.*

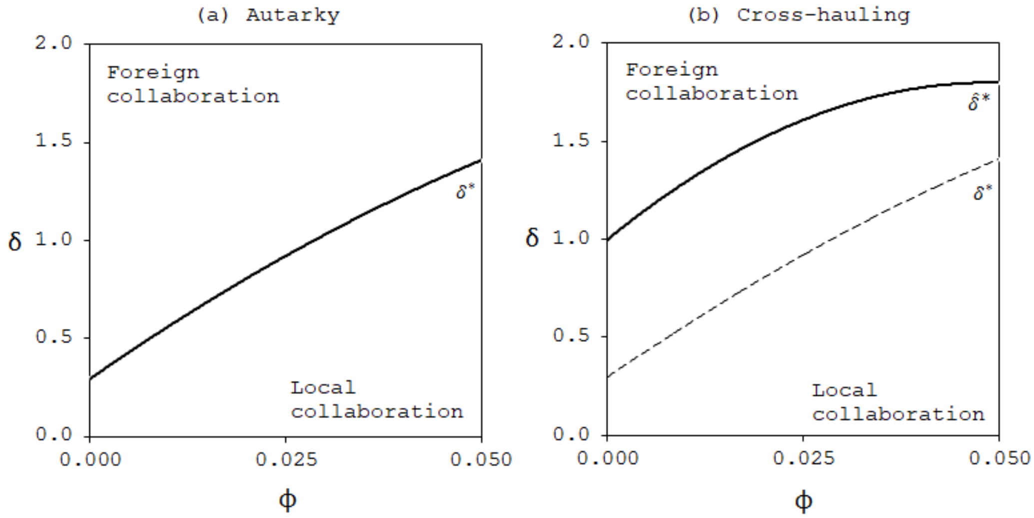
Proof: If $\delta > \delta^*$, then $\pi_1^f > \pi_1^l$ by definition. For a foreign collaboration to arise in equilibrium, we also require $\pi_3^f > \pi_3^n$ (which ensures that firm 3 accepts firm 1's offer) and $\pi_1^f > \pi_1^n$ (which ensures that a foreign collaboration is firm 1's most-preferred arrangement). We show numerically in 4.2 in the Appendix that, for all ranges of γ and δ which we consider, if ϕ is not high enough to deter firm 1 from participating in a foreign collaboration, it will not deter firm 3 either. A rationale for this is as follows: if $\phi = 0$, we certainly have $\pi_3^f > \pi_3^n$ because participating in a collaboration (and receiving x_1^f) lowers firm 3's marginal cost on its uncontested home market. Thus, in general, we have $\pi_3^f > \pi_3^n$ for sufficiently small values of the fixed cost ϕ. Moreover, because $\pi_1^l > \pi_1^n$ for all δ under autarky (since a local collaboration halves the R&D costs of firms 1 and 2 but leaves their equilibrium marginal costs unchanged), it follows that $\pi_1^f > \pi_1^n$ whenever $\pi_1^f > \pi_1^l$. When $\delta < \delta^*$, we have $\pi_1^l > \pi_1^f$. For a local collaboration to arise in equilibrium, we also require $\pi_2^l > \pi_2^n$ (i.e. acceptance by firm 2) and $\pi_1^l > \pi_1^n$, both of which hold for all δ under autarky. □

The intuition is fairly straightforward. All three firms prefer participating in a collaboration to the no collaboration case.[8] Thus, the equilibrium outcome is determined by firm 1's preference between local and foreign collaboration. In Figure 2a, which assumes $\bar{c} = 0.2$ and $\gamma = 5.75$, firm 1 is indifferent between the two forms of collaboration along the δ^* locus, which sets $\pi_1^f = \pi_1^l$. Whereas a rise in the fixed cost ϕ clearly makes a local collaboration more attractive, a rise in δ makes a foreign collaboration more attractive. The latter effect arises because firm 3 invests more in R&D as country B grows in size, and this extra R&D is then enjoyed equally by firm 1 within a cross-border collaboration. Thus, a rise in ϕ must be counterbalanced by a rise in δ in order to maintain indifference ($\pi_1^f = \pi_1^l$) on the part of firm 1.

Note that if foreign collaboration is costless ($\phi = 0$) and the countries are the same size ($\delta = 1$), then firm 1 *strictly* prefers foreign to local collaboration. Two

[8] We are ignoring here the case where ϕ is so large that firm 3 will choose not to collaborate, since we have shown that firm 1 will prefer a local collaboration anyway in this case.

Figure 2: Collaboration choices in autarky and cross-hauling



($\bar{c} = 0.2$, $\gamma = 5.75$) (where $\bar{c} = 0.2$, $\gamma = 5.75$, $t = 0.05$)

forces work together here. With equal country sizes, firm 3 tends to undertake more R&D as a monopolist than does firm 2 as a duopolist, thus making firm 3 more attractive as a source of R&D within a collaboration. Moreover, in contrast to firm 2, firm 3 doesn't compete on the product market with firm 1, which means that sharing its own R&D in a foreign collaboration is less costly for firm 1 than in a local one.

2.2 Cross-hauling

In the cross-hauling scenario we assume that trade costs are sufficiently low that all three firms sell in the two countries. For ease of reference we call the prohibitive level of trade costs t^*.[9] Again, we solve the game by backward induction. In stage 4, the firms decide how much to produce for each market for given levels of R&D. This gives profits:

[9]Because the two national markets have asymmetric structures (duopoly in A versus monopoly in B), there are actually two prohibitive trade costs, one to choke off trade in each direction. However, for simplicity, we ignore the case of one-way trade and focus in our cross-hauling scenario on trade costs that are low enough to permit two-way trade.

Table 2: R&D investment levels ($\hat{x}$) with free trade ($t = 0$)

collaboration choice (k)	no (n)	local (l)	foreign (f)
$\hat{x}_1^k$	$\frac{3(1-\bar{c})(1+\delta)}{8\gamma-3-3\delta}$	$\frac{(1-\bar{c})(1+\delta)(3+3\delta-2\gamma)}{17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2}$	$\frac{(1-\bar{c})(1+\delta)(3+3\delta-2\gamma)}{17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2}$
$\hat{x}_2^k$	$\frac{3(1-\bar{c})(1+\delta)}{8\gamma-3-3\delta}$	$\frac{(1-\bar{c})(1+\delta)(3+3\delta-2\gamma)}{17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2}$	$\frac{3(1-\bar{c})(1+\delta)(2+2\delta-\gamma)}{17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2}$
$\hat{x}_3^k$	$\frac{3(1-\bar{c})(1+\delta)}{8\gamma-3-3\delta}$	$\frac{3(1-\bar{c})(1+\delta)(2+2\delta-\gamma)}{17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2}$	$\frac{(1-\bar{c})(1+\delta)(3+3\delta-2\gamma)}{17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2}$

$$\hat{\pi}_1 = \frac{1}{16}\left(1 - 3c_1 + c_2 + c_3 + t\right)^2 + \frac{\delta}{16}\left(1 - 3c_1 + c_2 + c_3 - 2t\right)^2 - \frac{1}{2}\gamma\hat{x}_1^2 - \lambda_{13}\phi$$

$$\hat{\pi}_2 = \frac{1}{16}\left(1 - 3c_2 + c_1 + c_3 + t\right)^2 + \frac{\delta}{16}\left(1 - 3c_2 + c_1 + c_3 - 2t\right)^2 - \frac{1}{2}\gamma\hat{x}_2^2 \tag{2}$$

$$\hat{\pi}_3 = \frac{1}{16}\left(1 - 3c_3 + c_1 + c_2 - 3t\right)^2 + \frac{\delta}{16}\left(1 - 3c_3 + c_1 + c_2 + 2t\right)^2 - \frac{1}{2}\gamma\hat{x}_3^2 - \lambda_{13}\phi$$

where we use hats (^) to denote key variables in the cross-hauling case. The first term on the right-hand side of the equations in (2) represents the gross profit earned in country A; the second term represents the gross profit earned in country B; the third term the costs of R&D; and the fourth term the cost of coordinating collaboration across borders.

In stage 3, we again consider three collaboration cases, $k \in \{n, l, f\}$, with the expressions representing firms' marginal costs of production being the same as those in the autarky scenario. Then, substituting for c_i in the profit functions in (2), and solving the system of first-order conditions for R&D choices ($\hat{x}$), we obtain the firms' R&D investment levels for each of the three collaboration cases under consideration. To facilitate analytical tractability, we do this in two steps. First we consider the case of free trade, where $t = 0$, and then we consider the case where $t \in [0, t^*)$.[10]

[10] As in the autarky analysis, we are again implicitly assuming that γ is 'sufficiently large'.

The firms' equilibrium R&D efforts in the case of free trade[11] are presented in Table 2, where there are only three distinct equilibrium R&D levels because: $\hat{x}_1^n = \hat{x}_2^n = \hat{x}_3^n$ for all firms under no collaboration; $\hat{x}_1^l = \hat{x}_2^l = \hat{x}_1^f = \hat{x}_3^f$ for collaboration participants; and $\hat{x}_3^l = \hat{x}_2^f$ for collaboration outsiders. Under free trade, each firm can supply both national product markets at the same marginal cost. Thus, under free trade, the fact that the firms' plants are located in different countries is irrelevant: all that matters for equilibrium outcomes is whether a collaboration occurs and whether the firm in question participates in any collaboration. Note that, as in autarky, γ has the effect of decreasing firms' investments in R&D. But δ now affects (and increases) the R&D efforts of *all* three firms in *all* collaboration cases. In the no collaboration case, the R&D efforts of all three firms are increasing in δ, whilst in the cases of local and foreign collaboration we have $\frac{d\hat{x}_i^k}{d\delta} > 0$ and $\frac{d^2\hat{x}_i^k}{d\delta^2} > 0$ for collaborating firm i, and $\frac{d\hat{x}_j^k}{d\delta} > 0$ and $\frac{d^2\hat{x}_j^k}{d\delta^2} < 0$ for non-collaborating firm j. Whether collaborating firms' individual R&D efforts exceed that of the non-collaborating firm depends on the value of δ. Specifically, collaborating firms invest more in R&D than the non-collaborating firm for sufficiently large δ. Intuitively, collaborating firms increase their spending on R&D by more in response to a rise in market size because they are already operating at a larger scale (and thus earn a bigger return from a given fall in marginal cost).

If we allow for any $t \in [0, t^*)$, then the firm i's R&D efforts in collaboration case k are:

$$\hat{x}_i^k(t) = \hat{x}_i^k(0) + [X(\delta, \gamma)]t \tag{3}$$

where $X(\delta, \gamma)$ is a term that determines the direction and extent to which t affects firms' R&D efforts (see Appendix for explicit definition). In the cases of no or local collaboration, $dX/d\delta < 0$ for firms 1 and 2 but $dX/d\delta > 0$ for firm 3, such that, in the presence of trade costs, a rise in the size of country B increases the R&D effort of firm 3 but decreases those of firms 1 and 2. In the case of foreign collaboration, $dX/d\delta \lesseqgtr 0$ for firm 1, $dX/d\delta < 0$ for firm 2, and $dX/d\delta > 0$ for firm 3. Thus, for sufficiently high δ, t has the effect of increasing the R&D efforts of firms 1 and 3, and decreases that of firm 2.

Given these equilibrium R&D levels from stage 3, in stage 2 the recipient of the collaboration offer from firm 1 accepts or rejects, and in stage 1, firm 1

[11]Interpreted here as the extreme case where there are no trade costs of any type, including transport.

chooses whether to make a collaboration offer to the local or the foreign firm (if at all). The firms' decisions are based on their equilibrium profits, $\hat{\pi}_i^k$, under the various collaboration scenarios, k. Proposition 2 begins with an analytical result on collaboration formation under free trade:

Proposition 2: *(a) Under free trade ($t = 0$), firm 1 strictly prefers local to foreign collaboration for all $\phi > 0$. (b) Under cross-hauling, there exists a critical size of country B, $\hat{\delta}^*$, above which firm 1 collaborates with the foreign firm in equilibrium. Moreover, $\hat{\delta}^*$ exceeds δ^*, the critical size in the autarky case, so that foreign collaboration is less likely under cross-hauling than under autarky.*

Proof: Part (a) follows straightforwardly from the various symmetries of the free trade case. We established part (b) using numerical simulations. (Although we are able to prove results for autarky and free trade analytically, multi-stage models are commonly intractable, especially when asymmetric, and the introduction of costly trade to our set-up exacerbates this problem.) Note that the conditions for a foreign collaboration to arise in equilibrium are unchanged from the autarky case: $\hat{\pi}_1^f > \hat{\pi}_1^l$, $\hat{\pi}_3^f > \hat{\pi}_3^n$, and $\hat{\pi}_1^f > \hat{\pi}_1^n$. □

The results in part (b) are best explained in Figure 2b which for ease of exposition assumes $\bar{c} = 0.2$, $\gamma = 5.75$ and $t = 0.05$. Similar to the equilibrium outcomes in the autarky case, collaboration with the foreign firm is preferred for sufficiently high δ and low ϕ. The intuition here follows autarky: in particular, high δ implies that firm 3 invests heavily in R&D and is thus an attractive collaboration partner. However, $\hat{\delta}^* > \delta^*$ for all ϕ and $t \in [0, t^*)$, implying that cross-hauling makes it less likely that firm 1 collaborates with the foreign firm when compared to the autarky case. This happens because the two firms are now competitors in the product market (as in Zu *et al.*, 2011), and the extent to which they compete with each other varies with the level of trade costs, t. Product-market competition between firms 1 and 3 means that, for its participants, the R&D sharing within a foreign collaboration creates costs as well as benefits. Specifically, for example, firm 1 benefits from receiving firm 3's R&D, but firm 1 is harmed when firm 3 employs the R&D *it* receives on the product market. Under autarky, only the former (beneficial) effect is present.

This leads naturally to the following result (established numerically):

Proposition 3: *Under cross-hauling, for any $\delta > 1$, an increase in the trade cost, t, increases the size of the region in parameter space where a foreign collaboration arises in equilibrium.*

Graphically, in Figure 2b, a higher t rotates the $\hat{\delta}^*$ locus clockwise around the point $(\phi, \delta) = (0, 1)$, implying that $\hat{\pi}_1^f > \hat{\pi}_1^l$ becomes more likely.[12] The intuition follows the discussion immediately preceding Proposition 3. Higher t reduces the degree of product-market competition between firms 1 and 3 (as firms' home markets become more important to them), and this means that firm 1 is less troubled by how the R&D it shares within a foreign collaboration helps to reduce firm 3's marginal cost.

We can now consider how t and δ interact in the determination of firm 1's local/foreign collaboration choice. If $t = 0$ and $\phi = 0$, then firm 1 is indifferent between the two forms of collaboration for all δ because each firm can supply both national markets at the same marginal cost. Now let $\delta > 1$, so country B is bigger than A, and start increasing t. With $t > 0$ and $\delta > 1$ (and $\phi = 0$), firm 1 strictly prefers a foreign collaboration to a local one for the reasons discussed in the previous paragraph. Increases in t reduce the degree of product-market competition between firms 1 and 3 (and thus make firm 1 more willing to share its R&D within a foreign collaboration). Finally, maintaining $t > 0$ (and $\phi = 0$), reduce δ towards $\delta = 1$. This will reduce the attractiveness to firm 1 of a foreign collaboration since, intuitively, it means that firm 3 will cut its spending on, and thus sharing of, R&D. At $\delta = 1$, firm 1 will again be indifferent between the two forms of collaboration for all non-prohibitive t (if $\phi = 0$).

To conclude our positive analysis, we note that an alternative modelling approach is what Kamien *et al.* (1992) term 'RJV cartelization'. In this case R&D spending within any collaboration is set to maximise the participants' joint profits. We have studied RJV cartelization within our framework for the case of autarky. The results were intuitively appealing: e.g. because the spillover benefit is internalised, collaboration participants invest more in R&D, and earn higher profits, than in our model. Likewise, outsiders are squeezed more, in terms of both R&D spending and profits.

Under RJV cartelization, R&D investment will be equalised across the collaboration insiders (due to the convex cost of R&D). This raises the potential complication that a firm from a relatively small country might choose not to participate in a foreign R&D cartel because it would find itself undertaking a very large volume of R&D for the benefit of its partner firm abroad. In a supplementary appendix (available from the authors on request), we address this

[12] Note that we do not observe that $\hat{\delta}^* \to \delta^*$ as t rises because our analysis excludes the regime of one-way trade that lies between the cross-hauling and autarky cases.

issue by restricting the parameter space such that the participants in a foreign RJV cartel are better off than under no collaboration. In this restricted space, we are able to show that the trade-off between local and foreign collaboration is qualitatively similar to that plotted in Figure 2a. We also show that, under RJV cartelization, a foreign collaboration is more likely in equilibrium than in our model. (Intuitively, this is because, under autarky, there is no 'business-stealing' effect between firms 1 and 3 to undermine their profitability when they share large volumes of R&D with each other, and also because under autarky the scale of firms 1 and 3 is asymmetric (depending upon δ), allowing for gains from reallocation of R&D spending internationally.)

3 Welfare analysis

In this section we analyse the welfare implications of local and foreign R&D collaborations. Specifically, we assess the impact on consumers and firms to determine the conditions under which firms' collaboration choices are country- and world-welfare-maximising.

Let world welfare in collaboration case k be:

$$W^k = s_A^k + s_B^k + \sum_{i=1}^{3} \pi_i^k \tag{4}$$

where s_A^k and s_B^k are the consumer surplus in countries A and B, respectively. Let also Δs_A^k and Δs_B^k be the additional consumer surplus in countries A and B under scenario k when compared to the no collaboration case; and $\Delta \pi_i^k$ be the change in the profits of firm i in collaboration scenario k relative to the no collaboration case. Then, starting with autarky case, we can state the following results:

Lemma 1: *Welfare under local collaboration in autarky. For all δ and ϕ, local collaboration increases collaborating firms' profits but leaves consumer surplus unchanged relative to the no collaboration case, such that $W^l > W^n$.*

Proof: Under a local collaboration between firms 1 and 2, the consumers and firm 3 in country B are unaffected. To understand why the collaboration benefits accrue entirely to firms 1 and 2 (rather than being shared with the consumers in country A), it suffices to note from table 1 that $x_1^n = x_2^n = x_1^l + x_2^l$.

This implies that the firms' equilibrium marginal costs are unchanged following a local collaboration, and thus the price paid by the consumers in country A also remains unchanged relative to the no collaboration case. (It is a standard property of linear Cournot models like ours that the equilibrium price depends only on the *sum* of firms' marginal costs.) However, the costs of R&D for firms 1 and 2 are halved. Consequently, $\pi_1^l(x_1^l, x_2^l) = \pi_2^l(x_1^l, x_2^l) > \pi_1^n(x_1^n, x_2^n) = \pi_2^n(x_1^n, x_2^n)$. Thus, local collaboration under autarky *always* increases welfare relative to the no collaboration case.

Lemma 2: *Whenever a foreign collaboration arises in equilibrium (i.e. $\delta > \delta^*$), consumer surplus in countries A and B increases relative to the no collaboration case while the profits of the collaborating firms increase at the expense of the non-collaborating firm, such that $W^f > W^n$.*

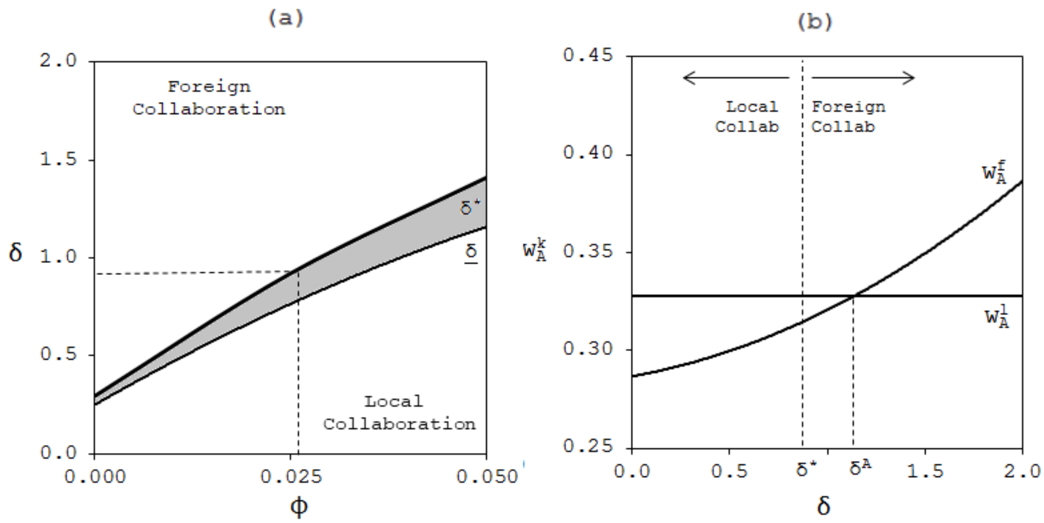
Proof: The positive impact on the profits of firms 1 and 3 is implied by the formation of the partnership; as stated in the proof of Proposition 1, $\pi_1^f > \pi_1^n$ and $\pi_3^f > \pi_3^n$ are both necessary conditions for a foreign collaboration to arise. However, there is a negative impact on firm 2's profits (which results from firm 1's reduced marginal cost under a foreign collaboration), which leads to total profits of the three firms being reduced (numerical analysis, available on request). However, the impact on consumer surplus in countries A and B is positive. From table 1 we know that $x_1^f + x_2^f + x_3^f > x_1^n + x_2^n$. Consequently, P_A falls in the transition from n to f, implying $\Delta s_A^f > 0$. (Here, we again appeal to the "sum of marginal costs" property invoked in the previous proof.) Likewise, $x_1^f + x_3^f > x_3^n$ implies that $\Delta s_B^f > 0$. Numerical analysis confirms that, when foreign collaboration emerges in equilibrium it increases welfare relative to the no collaboration case, since the sum of the gain to consumers and to firms 1 outweighs the loss to firm 2.

By Lemma 1, we know that $W^l > W^n$ for all δ and ϕ. Therefore, whenever $W^f > W^l$, a foreign collaboration is the socially optimal ("efficient") outcome; whereas a local collaboration is efficient if $W^l > W^f$. Thus, we define a variable $\underline{\delta}$ such that $W^f = W^l$ at $\delta = \underline{\delta}$. This is plotted in Figure 3a for $\overline{c} = 0.2$ and $\gamma = 5.75$. Noting that $\underline{\delta} < \delta^*$ for all ϕ, we have thus established the following proposition.

Proposition 4: *Under autarky, firms' choices are socially optimal whenever:*
(a) a foreign collaboration is formed in equilibrium, i.e. $\delta > \delta^*$; or
(b) a local collaboration is formed in equilibrium and country B is sufficiently small, i.e. $\delta < \underline{\delta}$.

For both 'large' and 'small' δ (the unshaded parts of Figure 3a), the equilibrium collaborative agreement is efficient. However, for $\delta \in (\underline{\delta}, \delta^*)$, a foreign collaboration is efficient but a local collaboration emerges in equilibrium. This implies that there might be a conflict between the firms' collaboration choices and what is socially optimal. Specifically, firms are too likely, from an efficiency viewpoint, to choose to form a local collaboration rather than a foreign one. Intuitively, this occurs because while a local collaboration affects *only* the participating firms (i.e. consumers everywhere and firm 3 are unaffected; see Lemma 1 above), a foreign collaboration results in 'external' benefits (e.g. to consumers in both countries) that firms 1 and 3 ignore.

Figure 3: Welfare impacts



$(\bar{c} = 0.2,\ \gamma = 5.75)$ $(\bar{c} = 0.2,\ \gamma = 5.75,\ \phi = 0.025)$

The outcome under cross-hauling is similar, i.e. whenever a foreign collaboration arises in equilibrium, it is socially optimal; and there are cases where foreign collaboration would be socially optimal but local collaboration emerges in equilibrium. The intuition for these results is similar to that under autarky, and we will not repeat it here. The main difference is that all three firms compete against each other in both markets. Consequently, the equilibrium outcome always has the effect of increasing consumer surplus and collaborating firms' profits at the expense of the non-collaborating firm (i.e. the non-collaborating firm is never 'insulated', as is firm 3 under autarky from the effects of a local collaboration).

Finally, we consider the welfare levels of individual countries and show that they might disagree concerning the preferred collaborative agreement. Defining the welfare of countries A and B in scenario k as:

$$\left. \begin{aligned} W_A^k &= s_A^k + \sum_{i=1}^{2} \pi_i^k \\ \\ W_B^k &= s_B^k + \pi_3^k \end{aligned} \right\} \tag{5}$$

and letting δ^j be the level of δ that makes country j indifferent between local and foreign collaboration, $W_j^f = W_j^l$, we can establish the following propositions:

Proposition 5: Under autarky, a foreign collaboration: (a) maximises country B's welfare; and (b) maxmises country A's welfare when $\delta > \delta^A$, but otherwise doesn't.

Proof: *(a)* From Lemma 1, we know that, relative to no collaboration, a local collaboration leaves country B's welfare unchanged (i.e. $\Delta s_B^l = \Delta \pi_3^l = 0$). However, from Lemma 2, a foreign collaboration benefits country B (i.e. $\Delta s_B^f + \Delta \pi_3^f > 0$) by reducing firm 3's marginal cost. (b) From Lemma 1, we know that country A's welfare is higher under local than no collaboration (because the equilibrium P_A doesn't change but firms 1 and 2 both halve their R&D spending). Therefore, a foreign collaboration maximises country A's welfare whenever $W_A^f > W_A^l$, i.e. $\delta > \delta^A$ (given that W_A^f is increasing in δ). $\square$

Building on the above Proposition, we can show that there are cases where a foreign collaboration emerges in equilibrium, and is thus efficient, but country A would be better off with a local one. This occurs because the condition for A to prefer a foreign collaboration (i.e. $\delta > \delta^A$) is more demanding than that for a foreign collaboration to arise in equilibrium (i.e. $\delta > \delta^*$). Figure 3 illustrates these tensions (between the social welfare of country A and the profits of firm 1) for the case of $\phi = 0.025$. From Figure 3a, we see that with $\phi = 0.025$, $\pi_1^l = \pi_1^f$ at $\delta = \delta^* \approx 0.9$. From Figure 3b, we see that at that level of δ, $W_A^l > W_A^f$. This happens because the gain in consumer surplus and firm 1's profits brought about by a shift from local to foreign collaboration do not make up for the loss in firm 2's profits. Only at $\delta = \delta^A > \delta^*$ would $W_A^l = W_A^f$. Whereas the equilibrium collaboration fails to maximise country A's welfare for 'middling' values of δ (specifically, $\delta^* < \delta < \delta^A$); for country B the equilibrium collaboration fails to maximise welfare for all 'low' δ – since B always prefers a foreign collaboration, but a local one arises if $\delta < \delta^*$.

If we now consider the situation where there is free trade: as before, the three firms are symmetric in the absence of R&D collaboration. The main difference between local and foreign collaboration is that the latter involves higher coordination costs, but that, if ϕ is not too high, firm 3's profits gain.

Proposition 6: Under free trade ($t = 0$): (a) a local collaboration always maximises both country A's welfare and global welfare; and (b) a foreign collaboration maximises country B's welfare as long as ϕ is sufficiently small.

Proof: Part (a) follows from the various symmetries under free trade (see, e.g., Table 2). Specifically, the equilibrium P_A is the same under local and foreign collaboration, but $\hat{\pi}_1^l = \hat{\pi}_1^f + \phi$ and $\hat{\pi}_2^l > \hat{\pi}_2^f$. To establish part (b), note that the equilibrium P_B is the same under local and foreign collaboration, and that $\hat{\pi}_3^f > \hat{\pi}_3^l$ if $\phi = 0$.

Intuitively, in the cross-hauling scenario, country A is always better off with firm 1 choosing to collaborate with the local rather than the foreign firm because any gain in consumer surplus that may result from collaboration with the foreign firm is outweighed by the loss in profits of the local non-collaborating firm. In the case of country B, welfare is maximised with cross-border collaboration unless the cost of coordinating collaboration is "too" high.

4 Concluding remarks

On the basis of the model presented in this paper we draw a number of lessons. First, we showed that lower international trade costs reduce the incentive for cross-border collaboration because they intensify the product-market competition between local and foreign firms and thus make them more reluctant to share their R&D results with each other. This is consistent with the findings of Ben Letaifa and Rabeau (2013), who argue that limited product-market interaction is seen as an advantage of cross-border collaborations: "[G]eographical clusters are not always welcomed by local entrepreneurs who would prefer international networking and clusters. Some entrepreneurs rather see local players as their competitors and have little confidence or interest in their local network" (Ben Letaifa and Rabeau, 2013, p. 2073).

Second, we showed that a firm's willingness to collaborate with a foreign rather than a local firm increases with the size of the foreign market. This is consistent with the findings of Hernan *et al.* (2003) who used firm-level data on

RJVs formed under the umbrella of the EUREKA framework and found some evidence that the size of a firm's home market negatively affects the probability that it will participate in pan-European RJVs. It is also consistent with the *OECD Science, Technology and Industry Scorecard 2009* (OECD, 2009b), which showed that, on average, firms from small and less developed economies engaged more actively in international collaborations. Of course, these empirical findings may stem from limited collaboration opportunities in smaller countries; but they may also be the result of the strategic advantage that arises from collaborating with firms from larger countries that typically invest more in R&D (and thus have more R&D to share within an RJV).

Third, if we think of the set-up presented in this paper as representing two countries that belong to the same supranational economic union, where union-level policies are aimed at maximising the union's overall welfare, then it can pay to facilitate cross-border R&D collaborations. This follows from the conclusion that in our model there are cases where a foreign collaboration would be efficient (i.e. union-welfare-maximising) but a local collaboration emerges in equilibrium. The result that, from an efficiency perspective, firms are 'too likely' to choose to form local collaborations can be used to explain the requirement imposed by the European Union to allow bids for R&D funding only if they are made by consortia that involve at least two member states (but preferably more).

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Appendix

4.1 R&D with a non-zero but non-prohibitive trade cost

If we allow for any $t \in [0, t^*)$, then the firm's R&D efforts in the no collaboration case are:

$$\hat{x}_1^n(t) = \hat{x}_1^n(0) + \left[\frac{3(3+3\delta-4\gamma)\delta+2\gamma}{(3+3\delta-2\gamma)(8\gamma-3-3\delta)}\right] t = \hat{x}_2^n(t)$$

$$\hat{x}_3^n(t) = \hat{x}_3^n(0) + \left[\frac{3(3-6\gamma+\delta(3+4\gamma))}{(3+3\delta-2\gamma)(8\gamma-3-3\delta)}\right] t$$

while those in the local collaboration case are:

$$\hat{x}_1^l(t) = \hat{x}_1^l(0) + \left[\frac{(3+3\delta-4\gamma)\delta+2\gamma}{6(1+\delta)^2-17(1+\delta)\gamma+8\gamma^2}\right] t = \hat{x}_2^l(t)$$

$$\hat{x}_3^l(t) = \hat{x}_3^l(0) + \left[\frac{3(2-3\gamma+2\delta(1+\gamma))}{6(1+\delta)^2-17(1+\delta)\gamma+8\gamma^2}\right] t$$

If instead firm 1 collaborates with foreign firm 3, then for any given $t \in [0, t^*)$ the firm's R&D efforts are:

$$\hat{x}_1^f(t) = \hat{x}_1^f(0) + \left[\frac{(3+3\delta)(1+\delta)^2+(1+\delta)(10\delta-7)\gamma+2(1-2\delta)\gamma^2}{(6(1+\delta)^2-17(1+\delta)\gamma+8\gamma^2)\gamma}\right] t$$

$$\hat{x}_2^f(t) = \hat{x}_2^f(0) + \left[\frac{3(2\delta(1+\delta-\gamma)+\gamma)}{6(1+\delta)^2-17(1+\delta)\gamma+8\gamma^2}\right] t$$

$$\hat{x}_3^f(t) = \hat{x}_3^f(0) + \left[\frac{3(\delta-1)(1+\delta)^2+(10(3-7\delta)\delta\gamma+2(2\delta-3)\gamma^2}{(6(1+\delta)^2-17(1+\delta)\gamma+8\gamma^2)\gamma}\right] t$$

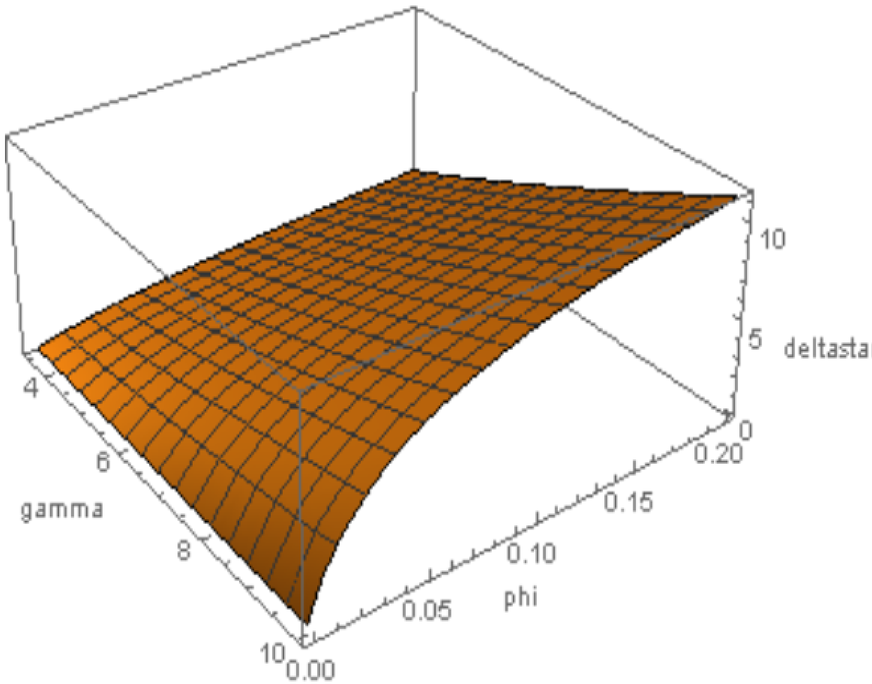
4.2 Firm profits under autarky

	No collaboration	Local collaboration	Foreign collaboration
Firm 1	$\frac{(1-c)^2\gamma(9\gamma-8)}{(9\gamma-4)^2}$.	$\frac{(1-c)^2\gamma(9\gamma-2)}{(9\gamma-4)^2}$.	$\frac{(1-c)^2\gamma(3\delta+6\gamma-8)^2(9\gamma-8)}{(96\gamma-54\gamma^2-3\delta(8-9\gamma)-32)^2} - \phi$.
Firm 2	$\frac{(1-c)^2\gamma(9\gamma-8)}{(9\gamma-4)^2}$.	$\frac{(1-c)^2\gamma(9\gamma-2)}{(9\gamma-4)^2}$.	$\frac{(1-c)^2\gamma(6\delta-6\gamma+8)^2(9\gamma-8)}{(96\gamma-54\gamma^2-3\delta(8-9\gamma)-32)^2}$.
Firm 3	$\frac{(1-c)^2\delta\gamma}{2(\delta-2\gamma)}$.	$\frac{(1-c)^2\delta\gamma}{2(\delta-2\gamma)}$.	$\frac{(1-c)^2\delta\gamma(3\gamma-4)^2(\delta-2\gamma)}{(96\gamma-54\gamma^2-3\delta(8-9\gamma)-32)^2} - \phi$.

Points to note: $\pi_1^l - \pi_1^n = 6\frac{(1-c)^2\gamma}{(9\gamma-4)^2} > 0$. Same for $\pi_2^l - \pi_2^{nc}$.

When $\pi_1^l = \pi_1^f,\ \phi = \frac{(1-c)^2\gamma(9\gamma-2)}{(9\gamma-4)^2} - \frac{(1-c)^2\gamma(3\delta+6\gamma-8)^2(9\gamma-8)}{(96\gamma-54\gamma^2-3\delta(8-9\gamma)-32)^2}$.

We can plot this relationship for firm 1, below, showing the critical values of $\delta = \delta^*$, below which firm 1 will not choose to engage in a foreign collaboration.



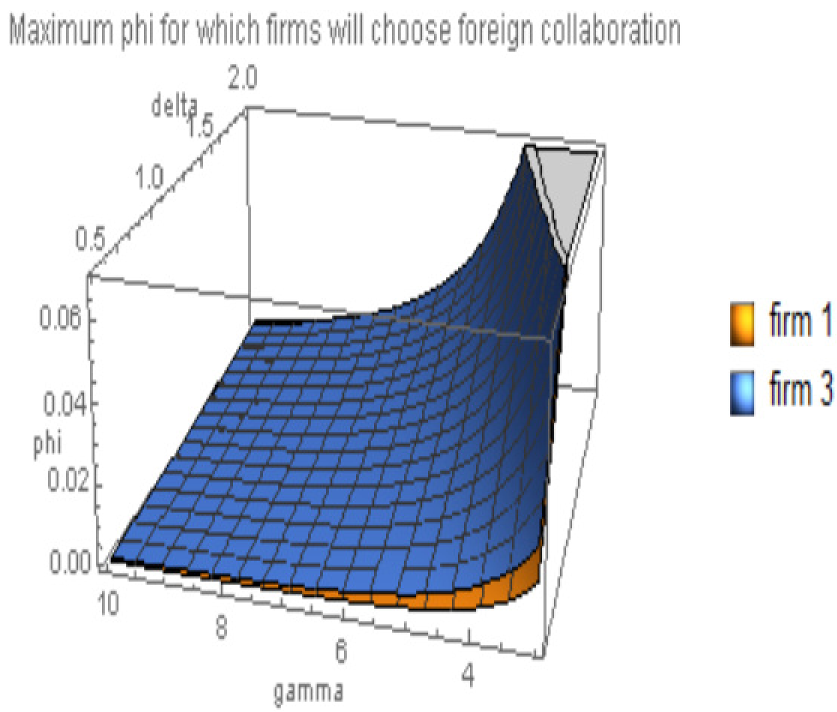
We can also show numerically that, across this range, if firm 1 prefers a foreign to a local collaboration

$$\pi_1^f > \pi_1^l$$

, then firm 3 will also select the foreign collaboration

$$\pi_3^f > \pi_3^n.$$

This is achieved by creating alternative values $(\pi_1'^f = \pi_1^f + \phi,\ \pi_3'^f = \pi_3^f + \phi)$ and then comparing these over $\{\gamma,\ \delta)$ space. It can be seen that firm 3 always gains more from a foreign collaboration than firm 1 does.



Profits under free trade ($t = 0$)

Points to note: $\pi_1^{lft} - \pi_1^{fft} = \phi$. Firm 1 will never choose foreign collaboration if $\phi > 0$.

4.3 Firm profits under free trade

	No collaboration	Local collaboration	Foreign collaboration
1	$\frac{(1-c)^2(1+\delta)\gamma(8\gamma-9\delta-9)}{2(3+3\delta-8\gamma)^2}$	$\frac{(1-c)^2(1+\delta)\gamma(2\gamma-\delta-1)(3+3\delta-2\gamma)^2}{2(17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2)^2}$	$\frac{(1-c)^2(1+\delta)\gamma(2\gamma-\delta-1)(3+3\delta-2\gamma)^2}{2(17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2)^2} - \phi$
2	$\frac{(1-c)^2(1+\delta)\gamma(8\gamma-9\delta-9)}{2(3+3\delta-8\gamma)^2}$	$\frac{(1-c)^2(1+\delta)\gamma(2\gamma-\delta-1)(3+3\delta-2\gamma)^2}{2(17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2)^2}$	$\frac{(1-c)^2(1+\delta)\gamma(8\gamma-9\delta-9)(2+2\delta-\gamma)^2}{2(17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2)^2}$
3	$\frac{(1-c)^2(1+\delta)\gamma(8\gamma-9\delta-9)}{2(3+3\delta-8\gamma)^2}$	$\frac{(1-c)^2(1+\delta)\gamma(8\gamma-9\delta-9)(2+2\delta-\gamma)^2}{2(17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2)^2}$	$\frac{(1-c)^2(1+\delta)\gamma(2\gamma-\delta-1)(3+3\delta-2\gamma)^2}{2(17\gamma(1+\delta)-6(1+\delta)^2-8\gamma^2)^2} - \phi$

Points to note: $\pi_1^{lft} - \pi_1^{fft} = \phi$. Firm 1 will never choose foreign collaboration if $\phi > 0$.