# International R&D Collaboration and Strategic Trade Policy *

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**Abstract**

We study an international trade model with symmetric countries and symmetric firms, with countries making strategic trade policies, anticipating the decisions of firms on R&D collaboration at the subsequent stage. In general we should observe a conflict between the equilibrium outcome and the efficient one. We show that an asymmetric outcome where one country unilaterally liberalizes trade while the other does not is likely to occur. Finally, while banning international R&D collaboration may help to reach free trade equilibrium in certain situation, it is far from helping to reach the outcome that maximizes the global welfare.

**Keywords**: Trade Policies, R&D Collaborations, Oligopolistic Competition

**JEL Classification**: F12; F15; J31; O18; R12

## 1 Introduction

Recently, as the technologies have become more complex and the pace of the innovation process has accelerated, collaboration has clearly become the preferred option for companies' research and development (R&D) consideration (see Nummela, 2003). Many markets are characterized by a high level of inter-firm collaboration in R&D activity, and a significant proportion of such collaboration takes place in the international context. The OECD documents[1] show that an increasing number of R&D alliances are international, involving partners from several countries and even continents. Indeed, the number of agreements

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[1]OECD, *Science, Technology and Industry Outlook 2000*, Paris, 2000.

on international R&D collaboration has been increasing at an unprecedented rate. For instance, Chesnais (1988) has reported that among inter-firm agreements in high technology industries in Italy, where the product markets are characterized by imperfect competition, a large portion were for R&D collaboration, and more than half were for international collaboration.[2]

Many studies have given theoretical support to the empirical observation that a large share of international trade is intra-industry, i.e., consists of two-way trade in identical, or similar, products. Monopolistic or imperfect competition plays an important role behind the reason advocated in the explanations (see Anderson, Donsimoni and Gabszewicz, 1989). Bander (1980) shows that there are reasons to expect two-way trade even in identical products and between similar countries, due to strategic interaction among firms. It is also well-recognized that the presence of oligopolistic competition implies (i) that economic profits are not driven to zero, this means that government policies that shift the industrial equilibrium to the advantage of domestic firms may be socially beneficial from a national perspective; (ii) that price equal to marginal cost does not generally obtain. This suggests that trade policy may be a substitute for antitrust policy if policies can be devised that shrink the wedge between opportunity cost in production and marginal valuation to consumers (see Eaton and Grossman, 1986). This leads to the central game-theoretical insight of strategic trade policies and industrial policies: intervention to alter the strategic interaction between oligopolistic firms can itself be an important basis for trade and industrial policy. Government policies that affect the competitiveness of their firms in international markets, as well as the welfare of their consumers, involve not only traditional trade policy (e.g. tariffs or trade liberalization) but policies that affect other aspects of firms' costs, such as R&D subsidies. We refer to intervention of this sort as industrial policies. Through these policies, governments influence the behavior of domestic firms in their subsequent strategic interaction with foreign rivals. The purpose of the current paper is to study the optimal strategic trade and industrial policy in the presence of oligopoly, and incorporate them into the formal analysis of international trade and industrial policies so as to be in line with important empirical regularities and policy concerns.

In this paper we address the following questions:

**(i)** What are the incentives of firms to collaborate in R&D and of governments to liberalize trade? What are the properties of equilibrium structure of R&D collaboration and

[2]Hagedoorn (2002), who has provided a survey of empirical work on R&D collaborations among firms, has also reported that during the 1980s, on average there were an additional 100 collaborative agreements every year in biotechnology, and over 200 every year in information technologies.

trade regimes?

**(ii)** Are individual incentives of firms to form international R&D collaboration and individual incentives of governments to liberalize trade adequate from a social welfare point of view?

To answer these questions we develop a setting with two countries, each of which has one firm producing some homogeneous good that can be sold in the domestic market as well as in the foreign market. Within the two countries population tastes and income are identically distributed, i.e., the demand functions are identical. A firm's ability to sell in foreign markets, however, depends on the level of import tariffs set by the foreign country. Each country could unilaterally remove tariff (then there will be no tariff levied on imports from the other country) or choose a strategically optimal tariff given the rival country's choice. Firms conduct cost-reducing R&D activity. They can collaborate in R&D, or they just do in-house R&D alone, but cannot rule out that some knowledge is publicly spread (public spillovers). Thus, given a configuration of R&D collaborations and trade policies, firms choose a level of effort in R&D. Then, firms compete in the different markets by choosing quantities based on Cournot conjectures, regarding each country as a separate market. We examine the possibility of cross-hauling[3] in a Cournot setting and are interested in the structure of R&D collaborations and strategic trade policies that emerges in this context.

We develop a four-stage game. In stage one, each government simultaneously decides its trade policies, i.e., either to liberalize trade or to fix a tariff on its imports from another country, in order to maximize the social welfare level. Notice that if both countries choose to liberalize trade, then a "free-trade" regime is observed. In stage two, firms choose whether or not to collaborate in R&D by forming a research joint venture (RJV). In stage three, each firm chooses simultaneously and unilaterally its R&D effort. In the last stage, firms compete a la Cournot in the product market, by choosing their output levels for the separate markets. The model is solved backwards.

We show that each government almost always prefers the situation in which it could choose its own strategically optimal tariff on imports while its rival unilaterally removing tariffs. Each firm almost always prefers the domestic market being protected while the foreign market opened to it, and prefers to collaborate in R&D for small public spillovers and not to collaborate for large public spillovers. Due to the strategic interactions be-

[3]Cross-hauling phenomenon happens in that the firm located in country 1 exports to country 2 and produces for its home market, while the firm in 2 exports to 1 and produces for its home market. In other words, the market equilibrium involves trade in spite of the fact that both countries produces exactly the same product, and there is an obvious loss due to trade-related costs.

tween firms and governments, equilibrium outcomes do not coincide, in general, with the preferred outcomes of one of the parties. Precisely,(i) when public spillovers are relatively small, governments will not liberalize trade but firms will collaborate in R&D; (ii) when public spillovers are large, we observe an asymmetric situation: one governments will liberalize trade while the other does not liberalize, and both firms stop collaborating in R&D; (iii) when public spillovers are very large, both governments will not liberalize trade and firms do not collaborate in R&D. Thus, even if countries are symmetric, it is not unlikely to observe an asymmetric outcome where one country liberalizes trade and the other does not, while firms do not collaborate. We also find that in general we should observe a conflict between the equilibrium outcome and the efficient one. By efficiency, we mean the outcome that maximizes the global social welfare. Finally, we show that, it is sometimes possible to improve national welfare by jointly implementing trade and industrial policies.

Before presenting the model, in order to place our paper in context, it is worth mentioning some related literature. For general background on R&D cooperation in oligopoly the readers are directed to Amir (2000), d'Aspremont and Jacquemin (1988), Kamien, Muller and Zang (1992), Katz (1986), Suzumura (1992), and Spencer and Brander (1983).[4] Concerning the motivation for R&D collaboration, the readers are referred to the survey by Hagedoorn (1993).[5] Our work could also be regarded as a simplified version of the oligopolistic intra-industry trade models of Anderson, Donsimoni and Gabszewicz (1989) and Cordella (1993), in the sense that we only allow completely symmetric setting between countries: one firm in each country, identical demand function and production technologies. But we enrich their models by incorporating and endogenizing the cost-reduction R&D process, and unlike their restriction to the space of strategies to the binary choices between keeping domestic market protected or opening to foreign competition, we endogenize and accommodate more flexible tariff schemes.

## 2 The Model

Following the model of Brander (1981) and Brander and Krugman (1983), we consider a setting with two identical countries, each of which has one firm producing some homogeneous good that can be sold in the domestic market as well as in the foreign markets. A firm's ability to sell in foreign markets, however, depends on the level of import tariffs set

[4] Goyal and Moraga-Gonzalez (2001) have analyzed the incentives for R&D collaborations between horizontally related firms in the absence of governments' industrial policy. They have basically shown that a conflict between the incentives of firms to collaborate and social welfare is likely to occur, and will arise if public spillovers from research are not too small.

[5] Narula and Dunning (1998) have provided an in-depth investigation on interaction between governments and international R&D alliances.

by the foreign country. Each country can either liberalize trade or impose a strategically chosen tariff on its imports from its rival. Firms can undertake R&D to look for cost reducing innovations. Moreover, firms may engage in bilateral international R&D collaboration. Firms compete in the different markets by choosing quantities. Each firm regards each country as a separate market and chooses the profit-maximizing quantity for each market, based on the Cournot assumption that the other firm's outputs in each market are given.

We assume that product demand is linear

$$P_i = a - (X_{ii} + X_{ji}), \text{ for } i, j = 1, 2,\ i \neq j. \tag{1}$$

where $P_i$ is the price of the homogeneous good in country $i$, $X_{ii}$ is production by firm $i$ for consumption in country $i$, $X_{ji}$ is production by firm $j$ for consumption in country $i$, $i \neq j$. Firms can undertake R&D to look for cost reducing innovations. Moreover, firms can collaborate in R&D by forming an information sharing RJV. Given the decisions of collaborating or not in R&D and given the R&D research outputs $\{e_1, e_2\}$, the marginal cost of production for each firm becomes

$$\begin{array}{ll} c_i = \overline{c} - \ e_i - e_j \ , i \neq j & \text{if RJV} \\ c_i = \overline{c} - \ e_i - \phi \cdot e_j \ , i \neq j & \text{if no RJV} \end{array} \tag{2}$$

where research knowledge is fully absorbed if firms form an RJV but is only partially absorbed if there is no RJV between firms. [6] Partial absorption of research knowledge is expressed through a public spillover parameter $\phi \in [0, 1)$. Given a level $e_i \in [0, \overline{c}]$ of effort, the cost of R&D investment is $(e_i)^2$. Then, firm $i$'s profits can be written as

$$\Pi_i = (P_i - \ c_i)X_{ii} + (P_j - \ c_i - T_j)X_{ij} - (e_i)^2,\ i, j = 1, 2,\ i \neq j. \tag{3}$$

where $T_j$ is the unit tariff that country $j$ levies on import of goods from country $i$. Remember that we assume $T_j = 0$ if country $j$ chooses to unilaterally liberalize trade. The consumer surplus is given by

$$CS_i = \frac{(X_i)^2}{2} \text{ with } X_i \equiv X_{1i} + X_{2i}. \tag{4}$$

The tariff revenue collected by country $i$ from import is given by $TR_i = T_i \cdot X_{ji}$. Then, social welfare of country $i$ is given by $SW_i = \Pi_i + CS_i + TR_i$. Let $SW$ denote the global social welfare: $SW = SW_i + SW_j$.

[6] In the terminology of Kamien, Muller and Zang (1992), our model is an Research Joint Venture competition type, where firms forming a collaboration commit to completely share the R&D results arising from research efforts decided unilaterally.

We develop a four-stage game. In stage one, each government simultaneously decides whether to liberalize trade ($T = 0$) or to fix a tariff on its imports ($T > 0$), in order to maximize the social welfare level. Notice that if both countries choose to liberalize trade, then a "free-trade" regime is observed. In stage two, firms choose whether or not to collaborate in R&D by forming an RJV. In order to have an RJV we need mutual agreement between firms. This stage may have a multiplicity of Nash equilibria since both firms choosing not to collaborate in R&D is always a Nash equilibrium. To overcome this issue we will restrict to the reasonable Nash equilibria, namely the coalition-proof Nash equilibria.[7] In stage three, each firm chooses simultaneously its R&D effort. Finally, in stage four, each firm chooses simultaneously its output levels for the separate product markets. The model is solved backwards.

# 3 The Analysis

We distinguish six different situations: (1) both countries liberalize trade and both firms have incentives to form an RJV (denoted $(0, 0; C)$); (2) both countries liberalize and both firms do not have incentive to form an RJV (denoted $(0, 0; N)$); (3) only one country liberalizes and both firms have incentives to form an RJV (denoted $(0, T; C)$ or $(T, 0; C)$); (4) only one country liberalizes and both firms do not have incentives to form an RJV (denoted $(0, T; N)$ or $(T, 0; N)$); (5) both countries do not liberalize and both firms have incentives to form an RJV (denoted $(T, T; C)$); (6) both countries do not liberalize and both firms do not have incentives to form an RJV (denoted $(T, T; N)$). Before looking for the equilibrium and efficiency of the four-stage game, we fully derive for the benchmark setting, namely $(T, T; N)$, the equilibrium R&D efforts, quantities, profits, consumer surplus and social welfare levels (see the appendix for details and all equilibrium values for the six different situations). The profit of firm $i$ at the last stage of the game is given by

$$\Pi_i = (P_i - (\bar{c} - \ e_i - \phi e_j)\ )X_{ii} + (P_j - (\bar{c} - \ e_i - \phi e_j) - T_j)X_{ij} - (e_i)^2, i \neq j. \quad (5)$$

Under Cournot competition the firms compete by simultaneously choosing their outputs to maximize profits with price adjusting to clear the market. Then, the Nash equilibrium outputs are given by

$$X_{ii} = \frac{(a - \bar{c}) + 2e_i - e_j + T_i - \phi e_i + 2\phi e_j}{3}, \quad (6)$$

$$X_{ij} = \frac{(a - \bar{c}) - e_j + 2e_i - 2T_j + 2\phi e_j - \phi e_i}{3}, \ i, j = 1, 2, \ i \neq j. \quad (7)$$

[7] A Nash equilibrium strategy profile is a coalition-proof Nash equilibrium if no coalition of players could form a self-enforcing agreement to deviate from it.

Let $k \equiv a - \overline{c}$. Then, we obtain the profits as function of R&D outputs and tariffs:

$$\Pi_i = \tfrac{1}{9}[2k^2 + 2kT_i + T_i^2 - 4kT_j + 4T_j^2 + 2e_j^2(1-2\phi)^2 + 2e_j(2k + T_i - 2T_j)(2\phi - 1) + e_i^2(-1 + 2(\phi-4)\phi) - 2e_i(\phi-2)(2k + T_i - 2T_j + e_j(4\phi - 2))],\ i,j = 1,2,\ i \neq j. \quad \text{.................(8)}$$

In the third stage, the firms choose simultaneously their research outputs to maximize profits. The unique (symmetric) Nash equilibrium of this stage game is

$$e_i = \frac{(2-\phi)(2T_j(1+\phi) + 2k(1+2(\phi-3)\phi) + T_i(-3-2(\phi-2)\phi))}{(1+2(\phi-3)\phi)(5+2(\phi-1)\phi)}. \quad \text{...................(9)}$$

Then, we obtain the profit of each firm and the social welfare of each country as a function of tariffs:

$$\begin{aligned}\Pi_i \;=\; & \frac{1}{36}\left(2(T_i+2T_j)^2 + \frac{9(T_i-T_j)^2(1+\phi)}{(1+2(\phi-3)\phi)^2} + \frac{9(T_i-T_j)(T_j-2k)}{1+2(\phi-3)\phi}\right. \\ & \left. + \frac{27(T_i+T_j-4k)^2(1+\phi)}{(5+2(\phi-1)\phi)^2} - \frac{9(4k-T_i-T_j)(2k-2T_i+T_j)}{5+2(\phi-1)\phi}\right)\end{aligned} \quad \text{..................(10)}$$

$$\begin{aligned}SW_i \;=\; & \frac{1}{72}\left(17T_j^2 - 19T_i^2 + 2T_iT_j + \frac{18(T_i-T_j)^2(1+\phi)}{(1+2(\phi-3)\phi)^2} + \frac{18(T_i-T_j)(-2k+3T_i+T_j)}{1+2(\phi-3)\phi}\right. \\ & \left. + \frac{27(T_i+T_j-4k)^2(5+2\phi)}{(5+2(\phi-1)\phi)^2} - \frac{36(4k-T_i-T_j)(k-2T_i)}{5+2(\phi-1)\phi}\right)\end{aligned} \quad \text{.................(11)}$$

Notice that we are considering a situation where in the second stage firms do not collaborate in R&D. In the first stage, the governments choose simultaneously their own strategically optimal tariffs to maximize its own national social welfare. If public spillovers are not too small ($\phi > 0.031$), then the unique (symmetric) Nash equilibrium of this stage game is[8]

$$T_i^* = \frac{k(-5 + 2\phi(-25 + \phi(51 + 8(\phi-5)\phi)))}{-5 + \phi(-119 + 2(\phi-2)\phi(-37 + \phi(17 + 2(\phi-3)\phi)))}$$

One can easily obtain the equilibrium R&D outputs, quantities produced, profits, consumer surplus and social welfare:

$$e_i^* = -\frac{k(\phi-2)(-1 + 2\phi(-19 + 2\phi(6 + (\phi-4)\phi)))}{-5 + \phi(-119 + 2(\phi-2)\phi(-37 + \phi(17 + 2(\phi-3)\phi)))},$$

[8] When both governments choose their own strategically optimal tariff, for $\phi \in (0, 0.031)$, the (symmetric) Nash equilibrium tariff is prohibitively high, leading to an autarky situation, which is not of our interests.

$$
\begin{aligned}
X_{ii}^* &= \frac{k(-4+\phi(-82+\phi(87+2\phi(7\phi-32))))}{-5+\phi(-119+2(\phi-2)\phi(-37+\phi(17+2(\phi-3)\phi)))}, \\
X_{ji}^* &= -\frac{k(1+\phi)(-1+\phi(33+2(\phi-9)\phi))}{-5+\phi(-119+2(\phi-2)\phi(-37+\phi(17+2(\phi-3)\phi)))},
\end{aligned}
$$

$$
\begin{aligned}
\Pi_i^* &= -\frac{k^2(1+\phi)}{\Theta^2}\left[(-13+\phi(-279+2\phi(-731+\phi(775+4\phi(-375+\right. \\
&\left.\phi(446+\phi(-319+\phi(129+2(-13+\phi)\phi)))))))\right],
\end{aligned}
$$

$$
CS_i^* = \frac{9k^2(1+2\phi(19-2\phi(6+(\phi-4)\phi)))^2}{2\Theta^2},
$$

$$
\begin{aligned}
SW_i^* &= -\frac{k^2(-1+2\phi(-19+2\phi(6+(\phi-4)\phi)))}{2\Theta^2}\cdot \\
&\quad [25+2\phi(269+2\phi(-61+\phi(33+2\phi(11+(\phi-8)\phi))))],
\end{aligned}
$$

$$
\begin{aligned}
SW^* &= -\frac{k^2}{\Theta^2}\left[-1+2\phi(-19+2\phi(6+(\phi-4)\phi)))(25+2\phi(269+\right. \\
&\quad \left. 2\phi(-61+\phi(33+2\phi(11+(\phi-8)\phi))))\right].
\end{aligned}
$$

where $\Theta = -5+\phi(-119+2(\phi-2)\phi(-37+\phi(17+2(\phi-3)\phi)))$. If public spillovers are very small ($\phi < 0.031$), then the (symmetric) Nash equilibrium tariff is prohibitively high, leading to an autarky situation where the equilibrium R&D outputs, quantities produced, profits, consumer surplus and social welfare are given by

$$
e_i^* = \frac{k}{3-\phi},
$$

$$
X_{ii}^* = \frac{2k}{3-\phi} \text{ and } X_{ji}^* = 0,
$$

$$
\Pi_i^* = \frac{3k^2}{(3-\phi)^2},
$$

$$
CS_i^* = \frac{2k^2}{(3-\phi)^2},
$$

$$
SW_i^* = \frac{5k^2}{(3-\phi)^2},
$$

$$
SW^* = \frac{10k^2}{(3-\phi)^2}.
$$

Now we investigate firms' incentive to form R&D collaboration, by checking the profits difference for each firm between collaboration and non-collaboration. Notice that when firms collaborate in R&D, the spillover rate is increased to the maximum level, i.e., $\phi = 1$. Therefore, the profit function Eq. 10 becomes

$$\Pi_i' = \frac{2}{225}(63k^2 + 8T_i^2 + 21k(T_i - 4T_j) + 11T_iT_j + 53T_j^2) \tag{10'}$$

**Lemma 1** *Suppose that both governments take the same trade policy, i.e., either both governments liberalize trade or both do not liberalize trade and choose their own strategically optimal tariffs. Then, both firms have incentive to collaborate in R&D by forming an RJV if and only if public spillovers are not too large,i.e., $\phi < 0.808$.*

**Proof:**(Case 1) Suppose that both governments liberalize trade ($T_i = 0$ ). Then, firms will collaborate if and only if $\Pi_i(0, 0; C) \geq \Pi_i(0, 0; N)$. We have that

$$\Pi_i(0, 0; C) = \frac{14k^2}{25} > -\frac{2k^2(-1 + 2(\phi - 4)\phi)}{(5 + 2(\phi - 1)\phi)^2} = \Pi_i(0, 0; N)$$

if and only if $\phi < 0.808$. So, both firms have incentives to collaborate in R&D by forming an RJV if and only if public spillovers are not too large, i.e., $\phi < 0.808$.

(Case 2) Suppose that both governments do not liberalize trade and choose their own strategically optimal tariffs. Then, both firms have incentives to collaborate if and only if $\Pi_i(T, T; C) \geq \Pi_i(T, T; N)$. We have $\Pi_i(T, T; N) = \frac{3k^2}{(3-\phi)^2}$ if public spillovers are very small ($\phi < 0.031$), and

$$\begin{aligned}\Pi_i(T, T; N) \quad = \quad & \frac{1}{36}\Bigg(2(T_i + 2T_j)^2 + \frac{9(T_i - T_j)^2(1 + \phi)}{(1 + 2(\phi - 3)\phi)^2} + \frac{9(T_i - T_j)(T_j - 2k)}{1 + 2(\phi - 3)\phi} \\ & + \frac{27(T_i + T_j - 4k)^2(1 + \phi)}{(5 + 2(\phi - 1)\phi)^2} - \frac{9(4k - T_i - T_j)(2k - 2T_i + T_j)}{5 + 2(\phi - 1)\phi}\Bigg)\end{aligned}$$

otherwise ($\phi > 0.031$). Indeed, when spillovers are extremely small, each government will choose their own strategically optimal tariffs that lead to an autarky situation. Thus, we distinguish two cases.

(a) If spillovers are extremely small ($\phi < 0.031$), since in this symmetric setting, in the equilibrium, both countries must take the same level of tariff, i.e., $T_i = T_j$, we have that

$$\Pi_i(T, T; C) = \frac{2}{225}(63k^2 + 8T_i^2 + 21k(T_i - 4T_j) + 11T_iT_j + 53T_j^2) > \Pi_i(T, T; N) = \frac{3k^2}{(3 - \phi)^2} \tag{8}$$

for $\phi \in [0, 0.031)$ and all $T_i = T_j > \widehat{T}$, where $\widehat{T} = \frac{3k}{4+(\phi-1)\phi}$ is the threshold value of tariff leading to the autarky situation.[9]

(b) If spillovers are not too small ($\phi > 0.031$) we have that

[9] It will be shown late that in this case each government will not choose a tariff lower than $\widehat{T}$.

$\Delta\Pi_i = \Pi_i(T,T;C) - \Pi_i(T,T;N) = \frac{7}{450}(6k + T_i - 4T_j)^2 - \frac{(T_i - T_j)^2(1+\phi)}{4(1+2(\phi-3)\phi)^2} - \frac{(T_i - T_j)(T_j - 2k)}{4(1+2(\phi-3)\phi)}$ -3$(\mathrm{T}_i + T_j - 4k)^2(1+\phi)\frac{}{4(5+2(\phi-1)\phi)^2 + \frac{(4k - T_i - T_j)(2k - 2T_i + T_j)}{4(5+2(\phi-1)\phi)}}$ Since in this symmetric setting, in the equilibrium, both countries must take the same level of tariffs, i.e., $T_i = T_j$, then $\Delta\Pi_i = \frac{(T-2k)^2(\phi-1)(-75+\phi(95+14(\phi-1)\phi))}{25(5+2(\phi-1)\phi)^2} \gtrless 0$ *iff* $\phi \lesseqgtr 0.808$.[10] So, both firms have incentives to collaborate in RD by forming an RJV if and only if public spillovers are not too large, i.e., $\phi < 0.808$.

When both governments liberalize trade or both do not liberalize trade and choose their own strategically optimal tariff, firms will collaborate in R&D by forming an RJV if and only if public spillovers are not too large. Only if public spillovers are sufficiently large, firms will not collaborate in R&D. There are two effects at work when two firms collaborate in R&D by forming an RJV. First, the perfect sharing of knowledge between both firms (as if $\phi = 1$) will help both firms to improve profits. Second, each firm tends to make less R&D efforts, which likely reduces profits. When public spillovers are sufficiently small, the first effect dominates the second one. As public spillovers increase, firms are absorbing more and more research knowledge from each other even in the absence of R&D collaboration. Thus, when public spillovers are sufficiently large, the second effect overturns the first one, and firms have no incentives to collaborate in R&D.

Now we study the settings in which one country (say country $i$) does not liberalizes trade and chooses its own strategically optimal tariff while another country (say country $j$) liberalizes trade. We distinguish two regimes. One normal regime under which country $i$ sets a low tariff and there is two-way trade occurs between country $i$ and country $j$. Another quasi-autarky one under which country $i$ chooses such a high level of tariff that one firm stops exporting while another one could still export. It is worthy highlighting that in this setting, the public spillover plays a very puzzling role in firms' behavior. As usually expected, for most levels of public spillover ($0.177 < \phi < 1$), with the increase of the unilateral tariff levied by country $i$ on import from firm $j$ located in country $j$, it becomes more and more difficult for firm $j$ to export to the market in country $i$ and eventually no export when the tariff is sufficiently high ($T_i > \frac{9k(1+2(\phi-3)\phi)}{-4+\phi(-41+4\phi(6+(-4+\phi)\phi))}$, $0.177 < \phi < 1$), at which the regime switches from two-way trade to quasi-autarky. While for sufficiently low spillover level ($\phi < 0.177$), firm $j$ in country $j$ intensively increases its cost-reducing R&D investment, much more than firm $i$ in country $i$, to offset (indeed "over-offset") its disadvantage due to the unilateral tariff barrier imposed by country $i$. Therefore, firm $j$ outperforms firm $i$ and eventually drives it out of the market in country $j$ when tariff is sufficiently high ($T_i > \frac{9k(1+2(\phi-3)\phi)}{(\phi-2)(-8+\phi(13+2(\phi-2)\phi))}$, $\phi < 0.177$), at which the

[10] Tariffs should be bounded above, i.e., $T_i \leqslant 9k/11$, otherwise, there is no trade between countries in all possible settings. Therefore $T - 2k \neq 0$.

quasi-autarky regime occurs.

In the normal regime, when firms collaborate in R&D

$$\Pi_i(T_i, 0; C) = \frac{2}{225}(63k^2 + 21kT_i + 8T_i^2)$$

and when firms do not collaborate

$$\begin{aligned}\Pi_i(T_i, 0; N) &= \frac{1}{\Psi}(-18k^2(-1 + 2(\phi - 4)\phi)(1 + 2(\phi - 3)\phi)^2 + \\ &\quad 18kT_i(-1 + 2(\phi - 4)\phi)(1 + 2(\phi - 3)\phi)(3 + 2(\phi - 2)\phi) + T_i^2(1 + \phi) \bullet \\ &\quad (53 + \phi(3 + 2\phi(-95 + \phi(247 + 2\phi(-121 + \phi(65 + 2(\phi - 9)\phi)))))))\end{aligned}$$

where $\Psi = 9(1+2(\phi-3)\phi)^2(5+2(\phi-1)\phi)^2$. Then firm $i$ located in country $i$ has incentive to collaborate in R&D by forming an RJV with firm $j$ located in country $j$ if and only if $\Pi_i(T_i, 0; C) > \Pi_i(T_i, 0; N)$, that is

$$\begin{aligned}\Delta\Pi_i &= \Pi_i(T_i, 0; C) - \Pi_i(T_i, 0; N) = \frac{7}{450}(6k + T_i)^2 - \frac{(T_i)^2(1 + \phi)}{4(1 + 2(\phi - 3)\phi)^2} \\ &\quad + \frac{T_i k}{2 + 4(\phi - 3)\phi} - \frac{3(T_i - 4k)^2(1 + \phi)}{4(5 + 2(\phi - 1)\phi)^2} + \frac{4k^2 - 5kT_i + 5T_i^2}{10 + 4(\phi - 1)\phi} > 0\end{aligned}$$

Clearly the comparison of profit under collaboration and non-collaboration depends on such parameters as effective demand $k$, tariff level $T_i$ and public spillover rate $\phi$. Taking the tariff restriction imposed by two-way exportation into account, one can easily show that, in this regime, we have $\Delta\Pi_i > 0$ if and only if $T_i < \frac{9k(1+2(\phi-3)\phi)}{(\phi-2)(-8+\phi(13+2(\phi-2)\phi))}$ if public spillovers are very small ($\phi < 0.177$), and

$$\begin{aligned}T_i &< \frac{1}{\Upsilon}(-30\sqrt{7(-k^2(5 - 4\phi)^2(-1 + 2(\phi - 4)\phi)(1 + 2(\phi - 3)\phi)^2(5 + 2(\phi - 1)\phi)^2} \\ &\quad -6k(1 + 2(\phi - 3)\phi)(-200 + \phi(-355 + 4\phi(79 + \phi(22 + 7(\phi - 4)\phi)))))\end{aligned}$$

where $\Upsilon = (925 + \phi(7445 + 2\phi(-8727 + \phi(8641 + 2\phi(-2177 + \phi(519 + 14(\phi - 7)\phi))))))$, otherwise ($\phi > 0.177$).

Accordingly, we have the tariff condition for firm $i$'s R&D collaboration decision for the quasi-autarky regime. We have $\Delta\Pi_i > 0$ if and only if

$$\begin{aligned}T_i &< \frac{1}{\Gamma}(k(-23799 - 6\phi(-23941 + \phi(22673 + \phi(-7487 + 2\phi(-277 + \phi(-1582 + \\ &\quad \phi(1219 + 28(\phi - 11)\phi))))))) - 15k(13 + 2\phi(37 + \phi(-24 + (11 - 2\phi)\phi)))\sqrt{\Lambda})\end{aligned}$$

where $\Gamma = (-88421 + \phi(119884 + \phi(62473 + 8\phi(-2341 + \phi(19687 + 2\phi(-4504 + \phi(1093 + 16(\phi - 11)\phi)))))))$, and $\Lambda = -(-53947 + 2\phi(51612 + \phi(-2325 + 2\phi(-30176 + \phi(28222 + \phi(-11360 + \phi(2255 + 28(\phi - 11)\phi)))))))$, if public spillovers are very small ($\phi < 0.177$); and for extremely high level of tariff $T_i$ otherwise ($\phi > 0.177$), that means the condition is never binding. The economic intuition is clear here. In this quasi-autarky regime, when $\phi > 0.177$, firm $j$ could not export to the market in country $i$ if firms do not collaborate in R&D, while it could export if firms collaborate, which worsens firm $i$'s competitive position, although by collaborating firm $i$ gains as well by further reducing its marginal production cost, which helps improve its competitiveness. As the first (negative) effect dominates the second (positive) effect, firm $i$ has no incentive to collaborate with firm $j$. But for very low public spillover ($\phi < 0.177$), it is firm $i$ that could not export to the market in country $j$ if firms do not collaborate, while it could export if firms collaborate. Therefore firm $i$ is willing to collaborate. While it should be noted that even in this case, the tariff $T_i$ should be bounded from above, for that with further increase of the tariff, firm $i$ can not enter market $j$ even when firms collaborate in R&D, while collaboration always improves the competitiveness of its rival (firm $j$) in its domestic market $i$, thence firm $i$ looses incentive for collaboration for extremely high level of tariff.

As clearly the comparison of profits (and social welfare for the decision at the government's level) under collaboration and non-collaboration depends on such parameters as effective demand $k$, tariff level $T_i$ and public spillover rate $\phi$, it is not easy to have sharp prediction about the equilibrium outcomes. We confine ourselves in the following analysis to some discrete levels of public spillover, i.e., no public spillover ($\phi = 0$), low public spillover ($\phi = 0.25$), intermediate public spillover ($\phi = 0.5$), intermediate-high public spillover ($\phi = 0.6$), high public spillover ($\phi = 0.75$) and very high public spillover ($\phi = 0.85$). [11]

**Lemma 2** *Suppose that country 1 does not liberalize trade and chooses its own strategically optimal tariff, while country 2 liberalizes trade. Then, for different levels of public spillover, the firm located in country 1 has incentive to collaborate in R&D by forming an RJV with the firm located in country 2 if and only if*

| *Spillover* $\phi$ | *Collaboration* |
|---|---|
| 0 | $0 < T_1 < 0.781k$ |
| 0.25 | $0 < T_1 < 0.171k$ |
| 0.5 | $0 < T_1 < 0.391k$ |
| 0.6 | $0 < T_1 < 0.351k$ |
| 0.75 | $0 < T_1 < 0.141k$ |
| 0.85 | *Never* |

When one country (say country 1) does not liberalize trade and chooses its own strategically optimal tariff while the other country (say country 2) liberalizes trade, the firm

[11] We do analysis for many other levels of public spillover, and select these representative levels of analytical interests.

(say firm 1) located in that country has strong incentive to collaborate in R&D by forming an RJV with the firm (ay firm 2) located in the other country when the public spillover is sufficiently low (and it suffers from a competitive disadvantage). When the public is not so small, its incentive of collaborating in R&D becomes much lower and displays a non-monotonic property with respect to the public spillover, first it increases and then decreases.

**Lemma 3** *Suppose that country 1 does not liberalize trade and chooses its own strategically optimal tariff while country 2 liberalizes trade. Then, for different levels of public spillover, the firm located in country 2 has incentive to collaborate in RD by forming an RJV with the firm located in country 1 if and only if.*

| *Spillover* $\phi$ | *Collaboration* |
|---|---|
| 0 | $0 < T_1 < 0.563k$ |
| 0.25 | *Always* |
| 0.5 | *Always* |
| 0.6 | *Always* |
| 0.75 | *Always* |
| 0.85 | $0 < T_1 < 0.817k$ |

When one country (say country 1) does not liberalize trade and chooses its optimal tariff while the other country (say country 2)liberalizes trade, the firm (say firm 2) located in the country (say country 2) that does liberalize trade is always more willing to collaborate in R&D by forming an RJV than the firm (say firm 1) located in the country (say country 1) that does not liberalize trade, except for sufficiently low level of public spillover. It is worthy mentioning that, as explained above, when there is no spillover ($\phi = 0$), firm 2 only has incentive to collaborate for the normal regime ($0 < T_1 < 0.563k$ if $\phi = 0$) and has no incentive to collaborate for the quasi-autarky regime ($T_1 > 0.563k$ if $\phi = 0$). While firm 1 has incentive to collaborate for the normal regime and the quasi-autarky regime given the tariff is not extremely high. Henceforth, in the case of no spillover ($\phi = 0$), firm 1 is more willing to collaborate in R&D for given tariff than firm 2. It should also be noted that if public spillovers are not very small ($\phi > 0.177$), while firm 1 becomes less and less willing to collaborate, firm 2 is always willing to collaborate to offsets its competitive disadvantage due to the unilateral tariff barrier imposed by country 1, except if public spillover is very high ($\phi = 0.85$) and tariff is sufficiently high ($T_1 > 0.817k$), in which firm 2 can not make export even if collaborate with firm 1.

Proofs of Lemma 3 and Lemma 4 follow the same procedure as those of Lemma 1 or Lemma 2, with additional consideration on the regime-switching scenario, and are left to the reader. It should be mentioned that in order to have Lemma 3 and Lemma 4, one needs to integrate the results of the two regimes: the normal regime and the quasi-autarky regime. Using Lemma 3 and Lemma 4 we have that, if one country (say country 1) does not liberalize trade and chooses its own strategically optimal tariff while the other country (say country 2) liberalizes trade, then firms will collaborate in R&D by forming an RJV if and only if tariff and public spillovers are such that as follows.

| Spillover $\phi$ | R&D Collaboration |
|---|---|
| 0 | $0 < T_1 < 0.563k$ |
| 0.25 | $0 < T_1 < 0.177k$ |
| 0.5 | $0 < T_1 < 0.391k$ |
| 0.6 | $0 < T_1 < 0.351k$ |
| 0.75 | $0 < T_1 < 0.141k$ |
| 0.85 | Never |

Thus, if one country does not liberalize trade and chooses its own strategically optimal tariff while the other country liberalizes trade, there are two conclusions can be made here. First, the threshold value of tariff for firms to collaborate in R&D varies non-monotonically with respect to the public spillover, it unilaterally decreases in the public spillover for $\phi \in (0, 0.177)$, and it is approximately an inverted U-shape centering the point $\phi = 0.5$ for $\phi \in (0.177, 1)$. Second, and the more important one, the likelihood that firms will collaborate in R&D is significantly reduced compared to the symmetric situation where both governments take the same trade policies(i.e., either both liberalize trade or both do not liberalize trade and simultaneously choose their own strategically optimal tariff.). This reduction in the likelihood of collaborating in R&D is largely due to the endogenized asymmetry between firms from different countries, in that the firm from the country applying its optimal tariff and the firm from the country liberalizing trade are willing to collaborate in R&D for different values of tariffs given a fix public spillover (alternatively it could be interpreted as for different values of public spillovers given a fix tariff), whereas collaborating in R&D requires mutual acceptance. Moreover, the firm from the country liberalizing trade has more incentives, except for the case of no public spillover ($\phi = 0$), to collaborate in cost-reducing R&D to improve its competitiveness. This is because it suffers from competitive disadvantages as a consequence of the opening of its domestic market to its rival while the foreign market is hard to enter due to tariff barrier imposed by foreign government.

To summarize, firms will collaborate in R&D if and only if (i) both government do not liberalize and $\phi < 0.808$, (ii) one government (say government 1) liberalizes trade while the other (say government 2) does not and $0 < T_1 < 0.563k$ if $\phi = 0$, $0 < T_1 <$

| Spillovers $\phi$ | Ranking on social welfare for country 1 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| 0 | $(T, 0; C)$ | $(0, 0; C)$ | $(T, T; C)$ | $(0, T; C)$ |
| 0.25 | $(T, 0; N)$ | $(0, 0; C)$ | $(T, T; C)$ | $(0, T; N)$ |
| 0.5 | $(T, 0; N)$ | $(0, 0; C)$ | $(T, T; C)$ | $(0, T; N)$ |
| 0.6 | $(T, 0; N)$ | $(0, 0; C)$ | $(T, T; C)$ | $(0, T; N)$ |
| 0.75 | $(T, 0; N)$ | $(0, 0; C)$ | $(0, T; N)$ | $(T, T; C)$ |
| 0.85 | $(T, 0; N)$ | $(0, 0; N)$ | $(T, T; N)$ | $(0, T; N)$ |

Table 1: Ranking on social welfare

| Spillovers $\phi$ | Ranking on social welfare for country 2 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| 0 | $(0, T; C)$ | $(0, 0; C)$ | $(T, T; C)$ | $(T, 0; C)$ |
| 0.25 | $(0, T; N)$ | $(0, 0; C)$ | $(T, T; C)$ | $(T, 0; N)$ |
| 0.5 | $(0, T; N)$ | $(0, 0; C)$ | $(T, T; C)$ | $(T, 0; N)$ |
| 0.6 | $(0, T; N)$ | $(0, 0; C)$ | $(T, T; C)$ | $(T, 0; N)$ |
| 0.75 | $(0, T; N)$ | $(0, 0; C)$ | $(T, 0; N)$ | $(T, T; C)$ |
| 0.85 | $(0, T; N)$ | $(0, 0; N)$ | $(T, T; N)$ | $(T, 0; N)$ |

Table 2: Ranking on social welfare

$0.171k$ if $\phi = 0.25$, $0 < T_1 < 0.391k$ if $\phi = 0.5$, $0 < T_1 < 0.351k$ if $\phi = 0.6$,and $0 < T_1 < 0.141k$ if $\phi = 0.75$, (iii) both government liberalize trade and $\phi < 0.808$. In stage one, each government make decision by choosing between liberalizing trade or imposing a tariff on imports from foreign country, anticipating the decision of firms in terms of R&D collaborations at the subsequent stage. At the sequent stage, firms make decisions on RD collaboration, given the choices of governments on trade regime. For each value of public spillovers and given the optimal decisions of firms, the preferences of country 1 are given in Table 1 and the preferences of country 2 are given in Table 2.

Then, we are able to characterize the Nash equilibrium of the game.[12]

**Proposition 1** *The subgame perfect Nash equilibrium outcomes for each possible value of*

[12]Indeed, it does not only characterize the Nash equilibrium of stage one, but also stage two. The game involves 4 players, the two governments and the two firms. Governments decide on trade liberalization, firms on RD collaboration. Governments take action first, anticipating the decision of firms at the subsequent stage.

*public spillovers are*

| *Spillovers* $\phi$ | *SPE outcome* |
|---|---|
| 0 | $(T,T;C)$ |
| 0.25 | $(T,T;C)$ |
| 0.5 | $(T,T;C)$ |
| 0.6 | $(T,T;C)$ |
| 0.75 | $(T,0;N)$ *or* $(0,T;N)$ |
| 0.85 | $(T,T;N)$ |

**Proof:**(i) For $\phi = 0$, anticipating the optimal behavior of firms (firms are going to collaborate in R&D), we have $SW_i(T,0;C) > SW_i(0,0;C) > SW_i(T,T;C) > SW_i(0,T;C)$ and $SW_j(0,T;C) > SW_j(0,0;C) > SW_j(T,T;C) > SW_j(T,0;C)$. If country $i$ chooses to liberalize $(T = 0)$, it is optimal for country $j$ to not liberalize trade $(T_j \neq 0)$; if country $j$ chooses to not liberalize trade $(T_j \neq 0\ )$, it is optimal for country $i$ to not liberalize trade. Thus, $(0,T;C)$, $(T,0;C)$ and $(0,0;C)$ cannot be an equilibrium. If country $i$ chooses to not liberalize trade $(T_i \neq 0)$, it is optimal for country $j$ to not liberalize trade $(T_j \neq 0)$; if country $j$ chooses to not liberalize trade $(T_j \neq 0)$, it is optimal for country $i$ to not liberalize trade. Thus, $(T,T;C)$ is the unique equilibrium outcome when $\phi = 0$.
(ii),(iii),(iv) For $\phi = 0.25$, 0.5, 0.6, anticipating the optimal behavior of firms (firms are going to collaborate in R&D if both governments choose either $(T,T)$ or $(0,0)$, and not collaborate if governments chooses either $(T,0)$ or $(0,T)$), we have $SW_i(T,0;N) > SW_i(0,0;C) > SW_i(T,T;C) > SW_i(0,T;N)$ and $SW_j(0,T;N) > SW_j(0,0;C) > SW_j(T,T;C) > SW_j(T,0;N)$. If country $i$ chooses to liberalize $(T_i = 0)$, it is optimal for country $j$ to not liberalize trade $(T_j \neq 0)$; if country $j$ chooses to not liberalize trade $(T_j \neq 0)$, it is optimal for country $i$ to not liberalize trade. Thus, $(0,T;N)$, $(T,0;N)$ and $(0,0;C)$ cannot be an equilibrium. If country $i$ chooses to not liberalize trade $(T_i \neq 0)$, it is optimal for country $j$ to not liberalize trade $(T_j \neq 0)$; if country $j$ chooses to not liberalize trade $(T_j \neq 0\ )$, it is optimal for country $i$ to not liberalize trade. Thus, $(T,T;C)$ is the unique equilibrium outcome when $\phi = 0.25$, 0.5, 0.6.
(iv) For $\phi = 0.75$, anticipating the optimal behavior of firms (firms are going to collaborate in R&D if both governments choose either $(T,T)$ or $(0,0)$, and not collaborate if governments chooses either $(T,0)$ or $(0,T)$), we have $SW_i(T,0;N) > SW_i(0,0;C) > SW_i(0,T;N) > SW_i(T,T;C)$ and $SW_j(0,T;N) > SW_j(0,0;C) > SW_j(T,0;N) > SW_j(T,T;C)$. If country $i$ chooses to liberalize $(T_i = 0)$, it is optimal for country $j$ to not liberalize trade $(T_j \neq 0)$; if country $j$ chooses to not liberalize trade $(T_j \neq 0)$, it is optimal for country $i$ to liberalize trade $(T_i = 0)$. Thus, $(0,T;N)$ and $(T,0;N)$ are equilibrium outcomes when $\phi = 0.75$; and $(0,0;C)$, $(T,T;C)$ are not equilibrium outcomes.

(v) For $\phi = 0.85$, anticipating the optimal behavior of firms (firms are not going to collaborate in R&D for all governments choices), we have $SW_i(T, 0; N) > SW_i(0, 0; N) > SW_i(T, T; N) > SW_i(0, T; N)$ and $SW_j(0, T; N) > SW_j(0, 0; N) > SW_j(T, T; N) > SW_j(T, 0; N)$. If country $i$ chooses to not liberalize ($T_i \neq 0$), it is optimal for country $j$ to not liberalize trade ($T_j \neq 0$); if country $j$ chooses to not liberalize trade ($T_j \neq 0$), it is optimal for country $i$ to not liberalize trade ($T_j \neq 0$ ). Thus, $(T, T; N)$ is an equilibrium outcome when $\phi = 0.85$; and $(0, T; N)$ , $(T, 0; N)$ cannot be an equilibrium. The outcome $(0, 0; N)$ is not equilibrium outcome because if country $i$ chooses to liberalize trade ($T_i = 0$ ), it is optimal for country $j$ to not liberalize trade ($T_j \neq 0$).

Proposition 1 gives us the equilibrium outcomes of the whole game as a function of public spillovers. The most striking result is that, even if countries are symmetric, an asymmetric outcome where one country liberalizes trade and the other does not is likely to occur when public spillovers are large. Precisely, (i) In the cases of no public spillover ($\phi = 0$), low level of public spillover ($\phi = 0.25$), intermediate level of public spillover ($\phi = 0.5$), and intermediate-high level of public spillover ($\phi = 0.6$), governments will not liberalize trade but firms will collaborate in R&D by forming an international RJV; (ii) when public spillovers are large ($\phi = 0.75$), we observe an asymmetric equilibrium outcome: one government liberalizes trade while the other country does not, and firms stop collaborating in R&D; (iii) when public spillovers are very large ($\phi = 0.85$), both governments will not liberalize trade and firms do not collaborate in R&D. This result contrasts with Cordella (1993) who has shown that if two countries play a non-cooperative game in trade policies, free trade (equivalent to a situation where both countries liberalize trade) is not an equilibrium of the game. Some comments are worth mentioning with respect to the equilibrium outcomes. On one hand, firms always form R&D collaboration if public spillovers are low and do not collaborate if public spillover are large enough. On the other hand, each country prefers to apply its optimal tariff against its rival, except for large public spillover ($\phi = 0.75$). Finally, notice that the asymmetric situation, where one country liberalizes trade while the other does not, only occurs at the turning point at which the firms switch from collaborating in R&D to non-collaborating at all.

We now examine the global social welfare. In table 3 we rank the global welfare for the six different situations: (1) both countries liberalize trade and firms form an RJV (denoted $(0, 0; C)$); (2) both countries liberalize and firms do not form an RJV (denoted $(0, 0; N)$); (3) only one country liberalizes and firms form an RJV (denoted $(0, T; C)$ or $(T, 0; C)$); (4) only one country liberalizes and firms do not form an RJV (denoted $(0, T; N)$ or $(T, 0; N)$); (5) both countries do not liberalize and firms form an RJV (denoted $(T, T; C)$); (6) both countries do not liberalize and firms do not form an RJV (denoted $(T, T; N)$).

| Spillovers | Ranking on global welfare | | | | | |
|---|---|---|---|---|---|---|
| $\phi$ | 1st | 2nd | 3rd | 4th | 5th | 6th |
| 0 | $(0,0;C)$ | $(0,T;C)$ | $(T,T;C)$ | $(0,0;N)$ | $(0,T;N)$ | $(T,T;N)$ |
| 0.25 | $(0,0;C)$ | $(0,T;C)$ | $(0,T;N)$ | $(T,T;C)$ | $(0,0;N)$ | $(T,T;N)$ |
| 0.5 | $(0,0;N)$ | $(0,0;C)$ | $(0,T;N)$ | $(0,T;C)$ | $(T,T;C)$ | $(T,T;N)$ |
| 0.6 | $(0,0;N)$ | $(0,0;C)$ | $(0,T;N)$ | $(0,T;C)$ | $(T,T;N)$ | $(T,T;C)$ |
| 0.75 | $(0,0;N)$ | $(0,T;N)$ | $(0,0;C)$ | $(T,T;N)$ | $(0,T;C)$ | $(T,T;C)$ |
| 0.85 | $(0,0;N)$ | $(0,T;N)$ | $(0,0;C)$ | $(0,T;C)$ | $(T,T;N)$ | $(T,T;C)$ |

Table 3: Ranking on global welfare

**Proposition 2** *The efficient outcome is* $(0,0;C)$ *for small public spillovers, (*$\phi = 0$*,0.25), and* $(0,0;N)$ *for large public spillovers, (*$\phi = 0.5$*, 0.6, 0.75, 0.85).*

Proposition 2 tells us that $(0,0;C)$ is the efficient outcome for small public spillovers while $(0,0;N)$ is the efficient outcome for large public spillovers. From Proposition 1 and Proposition 2, we have that in general we should observe a conflict between the equilibrium outcome and the efficient one.

We now discuss whether it is sometimes possible to improve global welfare by jointly implementing trade and industrial policies. Beside trade policies (tariffs or trade liberalization), governments could also some implement industrial policies (taxes or subsidies on R&D) that will affect firms' costs. Let us consider one extreme intervention policy consisting of imposing a ban on international R&D collaborations. Suppose that international R&D collaborations are banned, then one can show that the subgame perfect Nash equilibrium outcomes for each possible value of public spillovers are: $(0,0;N)$ for $\phi = 0$ and $(T,T;N)$ for $\phi = 0.25$, 0.5, 0.6, 0.75, 0.85. While banning international R&D collaboration helps to reach free trade equilibrium in the situations of very low public spillover (e.g., the extreme case $\phi = 0$), the global welfare is deteriorated in such situations. One can easily show that, only when public spillovers is in the very narrow domain of intermediate-high level (say $\phi = 0.6$), the global welfare may be slightly improved by banning international R&D collaborations. Otherwise, banning is far from helping countries to reach the outcome that maximizes the global welfare.

# 4 Concluding comments

The main contribution of this paper is to have shown that in an international trade model with symmetric countries and symmetric firms, an asymmetric outcome where one country unilaterally liberalizes trade while the other does not, and firms do not form an RJV is likely to occur. We also discuss that while banning international R&D collaboration may help to reach free trade equilibrium in certain situation, it is far from helping countries to reach the outcome that maximizes the global welfare.

# Appendix

First we give the values for quantities produced, R&D outputs, profits and national social welfare under the six different situations and for each possible value of public spillovers and tariff.

| | $(0,0;C)$ | $(0,0;N)$ | $(T,T;C)$ |
|---|---|---|---|
| $X_{11}$ | $\frac{3k}{5}$ | $\frac{3k}{5+2(\phi-1)\phi}$ | $\frac{(9k+4T_1-T_2)}{15}$ |
| $X_{12}$ | $\frac{3k}{5}$ | $\frac{3k}{5+2(\phi-1)\phi}$ | $\frac{(9k-11T_2-T_1)}{15}$ |
| $X_{21}$ | $\frac{3k}{5}$ | $\frac{3k}{5+2(\phi-1)\phi}$ | $\frac{(9k-11T_1-T_2)}{15}$ |
| $X_{22}$ | $\frac{3k}{5}$ | $\frac{3k}{5+2(\phi-1)\phi}$ | $\frac{(9k+4T_2-T_1)}{15}$ |
| $e_1$ | $\frac{2k}{5}$ | $-\frac{2k(\phi-2)}{5+2(\phi-1)\phi}$ | $\frac{(6k+T_1-4T_2)}{15}$ |
| $e_2$ | $\frac{2k}{5}$ | $-\frac{2k(\phi-2)}{5+2(\phi-1)\phi}$ | $\frac{(6k+T_2-4T_1)}{15}$ |
| $\Pi_1$ | $\frac{14k^2}{25}$ | $-\frac{2k^2(-1+2(\phi-4)\phi)}{(5+2(\phi-1)\phi)^2}$ | $\frac{2(63k^2+8T_1^2+21k(T_1-4T_2)+11T_1T_2+53T_2^2)}{225}$ |
| $\Pi_2$ | $\frac{14k^2}{25}$ | $-\frac{2k^2(-1+2(\phi-4)\phi)}{(5+2(\phi-1)\phi)^2}$ | $\frac{2(63k^2+8T_2^2+21k(T_2-4T_1)+11T_1T_2+53T_1^2)}{225}$ |
| $SW_1$ | $\frac{32k^2}{25}$ | $-\frac{4k^2(\phi-5)(1+\phi)}{(5+2(\phi-1)\phi)^2}$ | $\frac{(192k^2-83T_1^2+34k(T_1-4T_2)+14T_1T_2+72T_2^2)}{150}$ |
| $SW_2$ | $\frac{32k^2}{25}$ | $-\frac{4k^2(\phi-5)(1+\phi)}{(5+2(\phi-1)\phi)^2}$ | $\frac{(192k^2-83T_2^2+34k(T_2-4T_1)+14T_1T_2+72T_1^2)}{150}$ |

For the situation $(T,0;C)$ we distinguish two cases.

(a) Under the normal regime ( the tariff $T_1 < \frac{9k(1+2(\phi-3)\phi)}{(\phi-2)(-8+\phi(13+2(\phi-2)\phi))}$ if $\phi < 0.177$ and $T_1 < \frac{9k(1+2(\phi-3)\phi)}{-4+\phi(-41+4\phi(6+(-4+\phi)\phi))}$ if $\phi > 0.177$):

$X_{11} = \frac{3k}{5} + \frac{4T_1}{15}$;

$X_{12} = \frac{3k}{5} - \frac{T_1}{15}$;

$X_{21} = \frac{3k}{5} - \frac{11T_1}{15}$;

$X_{22} = \frac{3k}{5} - \frac{T_1}{15}$;

$e_1 = \frac{(6k+T_1)}{15}$;

$e_2 = \frac{2(3k-2T_1)}{15}$;

$\Pi_1 = \frac{2(63k^2+21kT_1+8T_1^2)}{225}$;

$\Pi_2 = \frac{2(63k^2-84kT_1+53T_1^2)}{225}$.

$SW_1 = \frac{(192k^2+34kT_1-83T_1^2)}{150}$;

$SW_2 = \frac{4(24k^2-17kT_1+9T_1^2)}{75}$

(b) Under the quasi-autarky regime ( the tariff $T_1 > \frac{9k(1+2(\phi-3)\phi)}{(\phi-2)(-8+\phi(13+2(\phi-2)\phi))}$ if $\phi < 0.177$ and $T_1 > \frac{9k(1+2(\phi-3)\phi)}{-4+\phi(-41+4\phi(6+(-4+\phi)\phi))}$ if $\phi > 0.177$):

$X_{11} = \frac{18k}{19}$;

$X_{12} = \frac{12k}{19}$;

$X_{21} = 0$;

$X_{22} = \frac{12k}{19}$;

$e_1 = \frac{13k}{19}$;

$e_2 = \frac{4k}{19}$;

$\Pi_1 = \frac{299k^2}{361}$;

$\Pi_2 = \frac{128k^2}{361}$.

$SW_1 = \frac{461k^2}{361}$;

$SW_2 = \frac{416k^2}{361}$.

Notice that the situation $(0, T; C)$ is identical to $(T, 0; C)$ with the roles of players inverted.

For the situation $(T, 0; N)$ we distinguish three cases.

(a) For the normal regime, ( the tariff $T_1 < \frac{9k(1+2(\phi-3)\phi)}{(\phi-2)(-8+\phi(13+2(\phi-2)\phi))}$ if $\phi < 0.177$ and $T_1 < \frac{9k(1+2(\phi-3)\phi)}{-4+\phi(-41+4\phi(6+(-4+\phi)\phi))}$ if $\phi > 0.177$), we have:

$X_{11} = \frac{1}{6}T_1 - \frac{3T_1)}{4(1+2(\phi-3)\phi)} - \frac{3(T_1-4k)}{4(5+2(\phi-1)\phi)}$

$X_{22} = \frac{T_1}{3} + \frac{3T_1}{4(1+2(\phi-3)\phi)} - \frac{3(T_1-4k)}{4(5+2(\phi-1)\phi)}$

$X_{12} = -\frac{T_1}{6} - \frac{3T_1}{4(1+2(\phi-3)\phi)} - \frac{3(T_1-4k)}{4(5+2(\phi-1)\phi)}$

$X_{21} = -\frac{1}{6}(T_2 + 2T_1) + \frac{3(T_1-T_2)}{4(1+2(\phi-3)\phi)} - \frac{3(T_1+T_2-4k)}{4(5+2(\phi-1)\phi)}$

$e_1 = -\frac{(\phi-2)(2k(1+2(\phi-3)\phi)+T_1(-3-2(\phi-2)\phi))}{(1+2(\phi-3)\phi)(5+2(\phi-1)\phi)}$

$e_2 = -\frac{2(\phi-2)(T_1(1+\phi)+k(1+2(\phi-3)\phi))}{(1+2(\phi-3)\phi)(5+2(\phi-1)\phi)}$

$\Pi_1 = \frac{1}{\Omega}(-18k^2(-1 + 2(\phi - 4)\phi)(1 + 2(\phi - 3)\phi)^2+$
$18kT_1(-1 + 2(\phi - 4)\phi(1 + 2(\phi - 3)\phi)(3 + 2(\phi - 2)\phi)+$
$T_1^2(1 + \phi)(53 + \phi(3 + 2\phi(-95 + \phi(247 + 2\phi(-121 + \phi(65 + 2(\phi - 9)\phi)))))))$

$\Pi_2 = \frac{1}{\Omega}(2(-18T_1k(1 + \phi)(-1 + 2(\phi - 4)\phi)(1 + 2(\phi - 3)\phi)-$
$9k^2(-1 + 2(\phi - 4)\phi)(1 + 2(\phi - 3)\phi)^2 + T_1^2(34 + \phi(-230+$
$\phi(1399 + 2\phi(-830 + \phi(811 + 8\phi(-64 + \phi(28 + (\phi - 8)\phi)))))))))$

$SW_1 = \frac{1}{2\Omega}(-72k^2(\phi - 5)(1 + \phi)(1 + 2(\phi - 3)\phi)^2 + 18kT_1(1 + 2(\phi - 3)\phi)\bullet$
$(-5 + 2\phi(-25 + \phi(51 + 8(\phi - 5)\phi))) + T_1^2(275 - \phi(28 + \phi(6247+$
$\phi(-9298 + \phi(9311 + 4\phi(-1351 + \phi(541 + 19(\phi - 8)\phi))))))))$;

$SW_2 = \frac{1}{2\Omega}(-72k^2(\phi - 5)(1 + \phi)(1 + 2(\phi - 3)\phi)^2 + 36kT_1\phi(1 + \phi)\bullet$
$(29 + 2(\phi - 7)\phi(1 + 2(\phi - 3)\phi) + T_1^2(140 + \phi(-964 + \phi(5705+$
$\phi(-6542 + \phi(6313 + 4\phi(-1025 + \phi(467 + 17(\phi - 8)\phi))))))))$.

where $\Omega = 9(1 + 2(\phi - 3)\phi)^2(5 + 2(\phi - 1)\phi)^2$.

(b) If $\phi \in (0, 0.177)$, for the quasi-autarky regime (the tariff $T_1 > \frac{9k(1+2(\phi-3)\phi)}{(\phi-2)(-8+\phi(13+2(\phi-2)\phi))}$), we have:

$X_{11} = \frac{3(T_1(-9-4(\phi-2)\phi)+k(2-18\phi+4\phi^2))}{F}$

$X_{22} = \frac{2(9k(-1+(\phi-3)\phi)+T_1(\phi-2)^2(2+\phi^2))}{F}$

$X_{12} = 0$

$X_{21} = \frac{3(k(-7+\phi(-9+4\phi))+T_1(12+\phi(3+(\phi-2)\phi)))}{\mathsf{F}}$
$e_1 = \frac{(\phi-2)(T_1(9+4(\phi-2)\phi)+2k(-1+9\phi-2\phi^2))}{-108+2(\phi-2)(\phi-1)(1+\phi)(2\phi-7)+3(41+8(\phi-4)\phi)}$
$e_2 = \frac{T_1(\phi-2)(16+\phi)+k(51-12\phi+2(\phi-2)(\phi-1)(2\phi-7))}{108-2(\phi-2)(\phi-1)(1+\phi)(2\phi-7)-3(41+8(\phi-4)\phi)}$
$\Pi_1 = -\frac{(\phi-5)(1+\phi)(T_1(-9-4(\phi-2)\phi)+k(2-18\phi+4\phi^2))^2}{\mathsf{F}^2}$
$\Pi_2 = \frac{1}{\mathsf{F}^2}(k^2(236 + \phi(1330 + \phi(2245 - 16\phi(50 + \phi(32 + (\phi - 13)\phi)))))$
$+2kT_1(-308 + \phi(-843 + \phi(-136 + \phi(-131 + \phi(429 + 4\phi(-55 + 9\phi))))))+$
$T_1^2(528 + \phi(1032 + \phi(157 + \phi(-560 + \phi(553 + \phi(-292 + \phi(121 + 4(\phi - 8)\phi))))))))$
$SW_1 = -\frac{1}{2\mathsf{F}^2}(k^2(265 + \phi(1742 + \phi(8657 - 8\phi(308 + \phi(137 + 4(\phi - 13)\phi)))))$
$+2kT_1(-42 + \phi(2317 + \phi(-1773 + \phi(-337 + \phi(1459 + 4\phi(20\phi - 159))))))+$
$T_1^2(-45 + \phi(-5760 + \phi(3091 + \phi(-308 + \phi(-1230 + \phi(772 + \phi(24\phi - 203)))))))$
$SW_2 = \frac{1}{\mathsf{F}^2}(k^2(398 + \phi(2302 + \phi(3379 - 2\phi(886 + \phi(175 + 8(\phi - 13)\phi)))))$
$+2kT_1(-452 + \phi(-1131 + \phi(332 + \phi(-527 + \phi(735 - 346\phi + 54\phi^2)))))+$
$T_1^2(656 + \phi(776 + \phi(477 + \phi(-880 + \phi(785 + 3\phi(-140 + \phi(59 + 2(\phi - 8)\phi)))))))$
where $\mathsf{F} = -13 + 2\phi(-37 + \phi(24 + \phi(-11 + 2\phi)))$.

(c) If $\phi \in (0.177, 1)$, for the quasi-autarky regime (the tariff $T_1 > \frac{9k(1+2(\phi-3)\phi)}{-4+\phi(-41+4\phi(6+(-4+\phi)\phi))}$), we have:

$X_{11} = \frac{18k(-1+(\phi-3)\phi)}{\mathsf{F}}$
$X_{22} = \frac{6k(1+\phi(2\phi-9))}{\mathsf{F}}$
$X_{12} = \frac{3k(-7+\phi(4\phi-9))}{\mathsf{F}}$
$X_{21} = 0$
$e_1 = -\frac{k(23+2\phi(19+\phi(2\phi-13)))}{\mathsf{F}}$
$e_2 = -\frac{2k(\phi-2)(1+\phi(2\phi-9))}{\mathsf{F}}$
$\Pi_1 = -\frac{k^2(-236+\phi(-1330+\phi(-2245+16\phi(50+\phi(32+(\phi-13)\phi)))))}{\mathsf{F}^2}$
$\Pi_2 = -\frac{4k^2(\phi-5)(1+\phi)(1+\phi(2\phi-9))^2}{\mathsf{F}^2}$
$SW_1 = -\frac{1}{\mathsf{F}^2}(k^2(-398 + \phi(-2302 + \phi(-3379 + 2\phi(886 + \phi(175 + 8(\phi - 13)\phi))))))$
$SW_2 = -\frac{1}{2\mathsf{F}^2}(k^2(-265 + \phi(-1742 + \phi(-8657 + 8\phi(308 + \phi(137 + 4(\phi - 13)\phi))))))$
where $\mathsf{F} = -13 + 2\phi(-37 + \phi(24 + \phi(-11 + 2\phi)))$.

Notice that the situation $(T, 0; N)$ is identical to $(0, T; N)$ with the roles of players inverted.

For the situation $(T, T; N)$ we have:

(a) For the normal case ($\phi > 0.031$)

$X_{11} = \frac{1}{6}(T_1 + 2T_2) + \frac{3(T_2-T_1)}{4(1+2(\phi-3)\phi)} - \frac{3(T_1+T_2-4k)}{4(5+2(\phi-1)\phi)}$
$X_{22} = \frac{1}{6}(T_2 + 2T_1) + \frac{3(T_1-T_2)}{4(1+2(\phi-3)\phi)} - \frac{3(T_1+T_2-4k)}{4(5+2(\phi-1)\phi)}$
$X_{12} = -\frac{1}{6}(T_1 + 2T_2) + \frac{3(T_2-T_1)}{4(1+2(\phi-3)\phi)} - \frac{3(T_1+T_2-4k)}{4(5+2(\phi-1)\phi)}$
$X_{21} = -\frac{1}{6}(T_2 + 2T_1) + \frac{3(T_1-T_2)}{4(1+2(\phi-3)\phi)} - \frac{3(T_1+T_2-4k)}{4(5+2(\phi-1)\phi)}$

$e_1 = -\frac{(\phi-2)(2T_2(1+\phi)+2k(1+2(\phi-3)\phi)+T_1(-3-2(\phi-2)\phi))}{(1+2(\phi-3)\phi)(5+2(\phi-1)\phi)}$

$e_2 = -\frac{(\phi-2)(2T_1(1+\phi)+2k(1+2(\phi-3)\phi)+T_2(-3-2(\phi-2)\phi))}{(1+2(\phi-3)\phi)(5+2(\phi-1)\phi)}$

$\Pi_1 = \frac{1}{36}(2(T_1 + 2T_2)^2 + \frac{9(T_1-T_2)^2(1+\phi)}{(1+2(\phi-3)\phi)^2} + \frac{9(T_2-2k)(T_1-T_2)}{1+2(\phi-3)\phi} + \frac{27(T_1+T_2-4k)^2(1+\phi)}{(5+2(\phi-1)\phi)^2} - \frac{9(4k-T_1-T_2)(2k-2T_1+T_2)}{5+2(\phi-1)\phi})$

$\Pi_2 = \frac{1}{36}(2(T_2 + 2T_1)^2 + \frac{9(T_2-T_1)^2(1+\phi)}{(1+2(\phi-3)\phi)^2} + \frac{9(T_1-2k)(T_2-T_1)}{1+2(\phi-3)\phi} + \frac{27(T_1+T_2-4k)^2(1+\phi)}{(5+2(\phi-1)\phi)^2} - \frac{9(4k-T_1-T_2)(2k-2T_2+T_1)}{5+2(\phi-1)\phi})$

$SW_1 = \frac{1}{72}(-19T_1^2 + 2T_1T_2^2 + 17T_2^2 + \frac{18(T_1-T_2)^2(1+\phi)}{(1+2(\phi-3)\phi)^2} + \frac{18(3T_1+T_2-2k)(T_1-T_2)}{1+2(\phi-3)\phi} + \frac{27(T_1+T_2-4k)^2(5+2\phi)}{(5+2(\phi-1)\phi)^2} - \frac{36(4k-T_1-T_2)(k-2T_1)}{5+2(\phi-1)\phi})$

$SW_2 = \frac{1}{72}(-19T_2^2 + 2T_1T_2^2 + 17T_1^2 + \frac{18(T_1-T_2)^2(1+\phi)}{(1+2(\phi-3)\phi)^2} + \frac{18(3T_2+T_1-2k)(T_2-T_1)}{1+2(\phi-3)\phi} + \frac{27(T_1+T_2-4k)^2(5+2\phi)}{(5+2(\phi-1)\phi)^2} - \frac{36(4k-T_1-T_2)(k-2T_2)}{5+2(\phi-1)\phi})$

(a) For the quasi-autarky case ($\phi < 0.031$)

$X_{11} = X_{22} = \frac{2k}{3-\phi}$

$X_{12} = X_{21} = 0$

$e_1 = e_2 = \frac{k}{3-\phi}$

$\Pi_1 = \Pi_2 = \frac{3k^2}{(3-\phi)^2}$

$SW_1 = SW_2 = \frac{5k^2}{(3-\phi)^2}$

Now we give the equilibrium values under the six different situations.

Suppose that country 1 does not liberalize trade and chooses its optimal tariff while country 2 does liberalize trade.

(A)For $\phi = 0$, the threshold value of the tariff leading to the quasi-autarky situation is $T_1 = 0.563k$. While firm 1 prefers to collaborate for $T \in (0, 0.781k)$, firm 2 prefers to collaborate if and only if $T \in (0, 0.563k)$. As collaboration requires mutual acceptance, firm 1 and firm 2 collaborate if and only if $T \in (0, 0.563k)$. We have two sub-cases:

(a) For $T \in (0, 0.563k)$, firms collaborate, country 1's optimal tariff is $T_1 = 0.205k$, and the corresponding social welfare of country 1 $SW_1 = 1.303k^2$.

(b) For $T > 0.563k$, firms do not collaborate, country 1's optimal tariff is $T_1 = 0.563k$, and the corresponding social welfare of country 1 $SW_1 = 0.602k^2$.

In our setting, country 1 chooses the optimal tariff to maximize its national welfare, so it sets the tariff at $T_1 = 0.205k$, at which firms collaborate.

| | $(0,0;C)$ | $(T,0;C)$ | $(0,T;C)$ | $(T,T;C)$ |
|---|---|---|---|---|
| $X_{11}$ | $0.6k$ | $0.655k$ | $0.586k$ | $0.645k$ |
| $X_{12}$ | $0.6k$ | $0.586k$ | $0.450k$ | $0.421k$ |
| $X_{21}$ | $0.6k$ | $0.450k$ | $0.586k$ | $0.421k$ |
| $X_{22}$ | $0.6k$ | $0.586k$ | $0.655k$ | $0.645k$ |
| $e_1$ | $0.4k$ | $0.414k$ | $0.345k$ | $0.355k$ |
| $e_2$ | $0.4k$ | $0.345k$ | $0.414k$ | $0.355k$ |
| $\Pi_1$ | $0.56k^2$ | $0.601k^2$ | $0.427k^2$ | $0.467k^2$ |
| $\Pi_2$ | $0.56k$ | $0.427k^2$ | $0.601k^2$ | $0.467k^2$ |
| $CS_1$ | $0.72k^2$ | $0.610k^2$ | $0.688k^2$ | $0.568k^2$ |
| $CS_2$ | $0.72k$ | $0.688k^2$ | $0.610k^2$ | $0.568k^2$ |
| $SW_1$ | $1.28k^2$ | $1.303k^2$ | $1.114k^2$ | $1.129k^2$ |
| $SW_2$ | $1.28k^2$ | $1.114k^2$ | $1.303k^2$ | $1.129k^2$ |
| $SW$ | $2.56k^2$ | $2.418k^2$ | $2.418k^2$ | $2.258k^2$ |

(B)For $\phi = 0.25$, the threshold value of the tariff leading to the quasi-autarky situation is $T_1 = 0.260k$. While firm 1 prefers to collaborate for $T \in (0, 0.171k)$, firm 2 always prefers to collaborate. Therefore firm 1 and firm 2 collaborate if and only if $T \in (0, 0.171k)$. We have three sub-cases:

(a) For $T \in (0, 0.171k)$, firms collaborate, country 1's optimal tariff is $T_1 = 0.171k$, and the corresponding social welfare of country 1 $SW_1 = 1.303k^2$.

(b) For $T \in (0.171k, 0.260k)$, firms do not collaborate, country 1's optimal tariff is $T_1 = 0.260k$, and the corresponding social welfare of country 1 $SW_1 = 1.498k^2$.

(c) For $T > 0.260k$, firms do not collaborate, country 1's tariff is irrelevant (firm 2 exports no good to country 1), and the corresponding social welfare of country 1 $SW_1 = 1.391k^2$.

In our setting, country 1 chooses the optimal tariff to maximize its national welfare, so it sets the tariff at $T_1 = 0.260k$, at which firms do not collaborate.

| | $(0,0;C)$ | $(T,0;N)$ | $(0,T;N)$ | $(T,T;C)$ |
|---|---|---|---|---|
| $X_{11}$ | $0.6k$ | $1.170k$ | $0.173k$ | $0.645k$ |
| $X_{12}$ | $0.6k$ | $1.083k$ | $0$ | $0.421k$ |
| $X_{21}$ | $0.6k$ | $0$ | $1.083k$ | $0.421k$ |
| $X_{22}$ | $0.6k$ | $0.173k$ | $1.170k$ | $0.645k$ |
| $e_1$ | $0.4k$ | $1.314k$ | $0.101k$ | $0.355k$ |
| $e_2$ | $0.4k$ | $0.101k$ | $1.314k$ | $0.355k$ |
| $\Pi_1$ | $0.56k^2$ | $0.814k^2$ | $0.02k^2$ | $0.467k^2$ |
| $\Pi_2$ | $0.56k^2$ | $0.02k^2$ | $0.814k^2$ | $0.467k^2$ |
| $CS_1$ | $0.72k^2$ | $0.684k^2$ | $0.789k^2$ | $0.568k^2$ |
| $CS_2$ | $0.72k^2$ | $0.789k^2$ | $0.684k^2$ | $0.568k^2$ |
| $SW_1$ | $1.28k^2$ | $1.498k^2$ | $0.809k^2$ | $1.129k^2$ |
| $SW_2$ | $1.28k^2$ | $0.809k^2$ | $1.498k^2$ | $1.129k^2$ |
| $SW$ | $2.56k^2$ | $2.307k^2$ | $2.307k^2$ | $2.258k^2$ |

(C)For $\phi = 0.5$, the threshold value of the tariff leading to the quasi-autarky situation is $T_1 = 0.667k$. While firm 1 prefers to collaborate for $T \in (0, 0.391k)$, firm 2 always prefers to collaborate. Therefore firm 1 and firm 2 collaborate if and only if $T \in (0, 0.391k)$. We have three sub-cases:

(a) For $T \in (0, 0.391k)$, firms collaborate, country 1's optimal tariff is $T_1 = 0.205k$, and the corresponding social welfare of country 1 $SW_1 = 1.303k^2$.

(b) For $T \in (0.391k, 0.667k)$, firms do not collaborate, country 1's optimal tariff is $T_1 = 0.391k$, and the corresponding social welfare of country 1 $SW_1 = 1.399k^2$.

(c) For $T > 0.667k$, firms do not collaborate, country 1's tariff is irrelevant (firm 2 exports no good to country 1), and the corresponding social welfare of country 1 $SW_1 = 1.315k^2$.

In our setting, country 1 chooses the optimal tariff to maximize its national welfare, so it sets the tariff at $T_1 = 0.391k$, at which firms do not collaborate.

| | $(0,0;C)$ | $(T,0;N)$ | $(0,T;N)$ | $(T,T;C)$ |
|---|---|---|---|---|
| $X_{11}$ | $0.6k$ | $0.862k$ | $0.536k$ | $0.645k$ |
| $X_{12}$ | $0.6k$ | $0.732k$ | $0.276$ | $0.421k$ |
| $X_{21}$ | $0.6k$ | $0.276$ | $0.732k$ | $0.421k$ |
| $X_{22}$ | $0.6k$ | $0.536k$ | $0.862k$ | $0.645k$ |
| $e_1$ | $0.4k$ | $0.797k$ | $0.406k$ | $0.355k$ |
| $e_2$ | $0.4k$ | $0.406k$ | $0.797k$ | $0.355k$ |
| $\Pi_1$ | $0.56k^2$ | $0.644k^2$ | $0.199k^2$ | $0.467k^2$ |
| $\Pi_2$ | $0.56k^2$ | $0.199k^2$ | $0.644k^2$ | $0.467k^2$ |
| $CS_1$ | $0.72k^2$ | $0.647k^2$ | $0.804k^2$ | $0.568k^2$ |
| $CS_2$ | $0.72k^2$ | $0.804k^2$ | $0.647k^2$ | $0.568k^2$ |
| $SW_1$ | $1.28k^2$ | $1.399k^2$ | $1.003k^2$ | $1.129k^2$ |
| $SW_2$ | $1.28k^2$ | $1.003k^2$ | $1.399k^2$ | $1.129k^2$ |
| $SW$ | $2.56k^2$ | $2.402k^2$ | $2.402k^2$ | $2.258k^2$ |

(D)For $\phi = 0.6$, the threshold value of the tariff leading to the quasi-autarky situation is $T_1 = 0.739k$. While firm 1 prefers to collaborate for $T \in (0, 0.351k)$, firm 2 always prefers to collaborate. Therefore firm 1 and firm 2 collaborate if and only if $T \in (0, 0.351k)$. We have three sub-cases:

(a) For $T \in (0, 0.351k)$, firms collaborate, country 1's optimal tariff is $T_1 = 0.205k$, and the corresponding social welfare of country 1 $SW_1 = 1.303k^2$.

(b) For $T \in (0.351k, 0.739k)$, firms do not collaborate, country 1's optimal tariff is $T_1 = 0.351k$, and the corresponding social welfare of country 1 $SW_1 = 1.399k^2$.

(c) For $T > 0.667k$, firms do not collaborate, country 1's tariff is irrelevant (firm 2 exports no good to country 1), and the corresponding social welfare of country 1 $SW_1 = 1.315k^2$.

In our setting, country 1 chooses the optimal tariff to maximize its national welfare, so it sets the tariff at $T_1 = 0.351k$, at which firms do not collaborate.

| | $(0,0;C)$ | $(T,0;N)$ | $(0,T;N)$ | $(T,T;C)$ |
|---|---|---|---|---|
| $X_{11}$ | $0.6k$ | $0.804k$ | $0.582k$ | $0.645k$ |
| $X_{12}$ | $0.6k$ | $0.687k$ | $0.348k$ | $0.421k$ |
| $X_{21}$ | $0.6k$ | $0.348k$ | $0.687k$ | $0.421k$ |
| $X_{22}$ | $0.6k$ | $0.582k$ | $0.804k$ | $0.645k$ |
| $e_1$ | $0.4k$ | $0.696k$ | $0.434k$ | $0.355k$ |
| $e_2$ | $0.4k$ | $0.434k$ | $0.696k$ | $0.355k$ |
| $\Pi_1$ | $0.56k^2$ | $0.634k^2$ | $0.272k^2$ | $0.467k^2$ |
| $\Pi_2$ | $0.56k^2$ | $0.272k^2$ | $0.634k^2$ | $0.467k^2$ |
| $CS_1$ | $0.72k^2$ | $0.664k^2$ | $0.806k^2$ | $0.568k^2$ |
| $CS_2$ | $0.72k^2$ | $0.806k^2$ | $0.664k^2$ | $0.568k^2$ |
| $SW_1$ | $1.28k^2$ | $1.421k^2$ | $1.078k^2$ | $1.129k^2$ |
| $SW_2$ | $1.28k^2$ | $1.078k^2$ | $1.421k^2$ | $1.129k^2$ |
| $SW$ | $2.56k^2$ | $2.498k^2$ | $2.498k^2$ | $2.258k^2$ |

(E)For $\phi = 0.75$, the threshold value of the tariff leading to the quasi-autarky situation is $T_1 = 0.800k$. While firm 1 prefers to collaborate for $T \in (0, 0.141k)$, firm 2 always prefers to collaborate. Therefore firm 1 and firm 2 collaborate if and only if $T \in (0, 0.141k)$. We have three sub-cases:

(a) For $T \in (0, 0.141k)$, firms collaborate, country 1's optimal tariff is $T_1 = 0.141k$, and the corresponding social welfare of country 1 $SW_1 = 1.301k^2$.

(b) For $T \in (0.141k, 0.800k)$, firms do not collaborate, country 1's optimal tariff is $T_1 = 0.225k$, and the corresponding social welfare of country 1 $SW_1 = 1.421k^2$.

(c) For $T > 0.800k$, firms do not collaborate, country 1's tariff is irrelevant (firm 2 exports no good to country 1), and the corresponding social welfare of country 1 $SW_1 = 1.311k^2$.

In our setting, country 1 chooses the optimal tariff to maximize its national welfare, so it sets tariff at $T_1 = 0.225k$, at which firms do not collaborate.

|  | $(0,0;C)$ | $(T,0;N)$ | $(0,T;N)$ | $(T,T;C)$ |
|---|---|---|---|---|
| $X_{11}$ | $0.6k$ | $0.721k$ | $0.616k$ | $0.645k$ |
| $X_{12}$ | $0.6k$ | $0.646k$ | $0.466k$ | $0.421k$ |
| $X_{21}$ | $0.6k$ | $0.466k$ | $0.646k$ | $0.421k$ |
| $X_{22}$ | $0.6k$ | $0.616k$ | $0.721k$ | $0.645k$ |
| $e_1$ | $0.4k$ | $0.569k$ | $0.451k$ | $0.355k$ |
| $e_2$ | $0.4k$ | $0.451k$ | $0.569k$ | $0.355k$ |
| $\Pi_1$ | $0.56k^2$ | $0.612k^2$ | $0.394k^2$ | $0.467k^2$ |
| $\Pi_2$ | $0.56k^2$ | $0.394k^2$ | $0.612k^2$ | $0.467k^2$ |
| $CS_1$ | $0.72k^2$ | $0.704k^2$ | $0.796k^2$ | $0.568k^2$ |
| $CS_2$ | $0.72k^2$ | $0.796k^2$ | $0.704k^2$ | $0.568k^2$ |
| $SW_1$ | $1.28k^2$ | $1.421k^2$ | $1.190k^2$ | $1.129k^2$ |
| $SW_2$ | $1.28k^2$ | $1.190k^2$ | $1.421k^2$ | $1.129k^2$ |
| $SW$ | $2.56k^2$ | $2.611k^2$ | $2.611k^2$ | $2.258k^2$ |

(F)For $\phi = 0.85$, the threshold value of the tariff leading to the quasi-autarky situation is $T_1 = 0.817k$. While firm 1 never prefers to collaborate, firm 2 prefers to collaborate for $T \in (0, 0.817k)$. Therefore firm 1 and firm 2 never collaborate. We have two sub-cases:

(a) For $T \in (0, 0.817k)$, firms do not collaborate, country 1's optimal tariff is $T_1 = 0.210k$, and the corresponding social welfare of country 1 $SW_1 = 1.390k^2$.

(b) For $T > 0.817k$, firms do not collaborate, country 1's tariff is irrelevant (firm 2 exports no good to country 1), and the corresponding social welfare of country 1 $SW_1 = 1.303k^2$.

In our setting, country 1 chooses the optimal tariff to maximize its national welfare, so it sets tariff at $T_1 = 0.210k$, at which firms do not collaborate.

| | $(0,0;N)$ | $(T,0;N)$ | $(0,T;N)$ | $(T,T;N)$ |
|---|---|---|---|---|
| $X_{11}$ | $0.632\,k$ | $0.693k$ | $0.610k$ | $0.674k$ |
| $X_{12}$ | $0.632\,k$ | $0.623k$ | $0.470k$ | $0.445k$ |
| $X_{21}$ | $0.632\,k$ | $0.470k$ | $0.623k$ | $0.445k$ |
| $X_{22}$ | $0.632\,k$ | $0.610k$ | $0.693k$ | $0.674k$ |
| $e_1$ | $0.485k$ | $0.505k$ | $0.414k$ | $0.429k$ |
| $e_2$ | $0.485k$ | $0.414k$ | $0.505k$ | $0.429k$ |
| $\Pi_1$ | $0.565k^2$ | $0.615k^2$ | $0.421k^2$ | $0.469k^2$ |
| $\Pi_2$ | $0.565k^2$ | $0.421k^2$ | $0.615k^2$ | $0.469k^2$ |
| $CS_1$ | $0.799k^2$ | $0.676k^2$ | $0.760k^2$ | $0.626k^2$ |
| $CS_2$ | $0.799k^2$ | $0.760k^2$ | $0.676k^2$ | $0.626k^2$ |
| $SW_1$ | $1.364k^2$ | $1.390k^2$ | $1.181k^2$ | $1.197k^2$ |
| $SW_2$ | $1.364k^2$ | $1.181k^2$ | $1.390k^2$ | $1.197k^2$ |
| $SW$ | $2.728k^2$ | $2.571k^2$ | $2.571k^2$ | $2.395k^2$ |

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