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Document de treball n.07 - 2013

DEPARTAMENT D'ECONOMIA – CREIP
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UNIVERSITAT
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Edita:

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www.fcee.urv.es/departaments/economia/public_html/index.html
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Adreçar comentaris al Departament d'Economia / CREIP

Dipòsit Legal: T - 484 - 2013

ISSN edició en paper: 1576 - 3382
ISSN edició electrònica: 1988 - 0820

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Domestic and International Research Joint Ventures: The Effect of Collusion

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March 2013

Abstract

We analyze the effect of research joint ventures (RJVs) on consumer welfare in an international context when collusion can occur. The main novelty of our analysis is to study the differentiated effect of domestic and international RJVs. The recent literature shows that RJVs with collusion harm consumers. However, our results introduce a qualification to this statement: international RJVs with collusion might be beneficial for consumers when internationalization costs are high. The EU and US competition policy advises against RJVs that facilitate collusion on the grounds of their expected negative effects. Our results suggest that antitrust authorities should distinguish between domestic and international RJVs and, in certain cases, be more benevolent with international RJVs.

Keywords: collusion; domestic research joint venture; international research joint venture

JEL Classification Numbers: K21, L24, L44, O32

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1 Introduction

Cooperative R&D among enterprises is common practice in all sectors of the economy, particularly in the high-tech sector. These cooperation agreements in the form of research joint ventures (RJVs) enable firms to exploit synergies, share individual risks, internalize R&D spillovers, increase efficiencies, and promote innovation. As a consequence, new products become available and existing products are produced at lower prices, which benefits consumers and raises social welfare. For this reason and regardless of the characteristics of each RJV, regulatory agencies have mainly ruled in favor of these agreements. RJVs are typically exempted from restrictive antitrust rules, in both the United States (US) and the European Union (EU) (Carree *et al.*, 2010; White, 2010). However, there are two reasons that call into question the common practice when assessing the effects of RJVs. First, there is increasing evidence that cooperation in R&D is used to facilitate collusion in the product market (Duso *et al.*, forthcoming; Goeree and Helland, 2010; Oxley *et al.*, 2009; Martin, 1995). Second, with the globalization of the economy, an increasing number of RJVs bring together firms located in different countries (Uphoff and Gilman, 2010). Such international RJVs have different effects than domestic RJVs. The objective of this paper is to analyze the effect of RJVs in an international context, considering the threat that they can be used to reach collusive agreements in the product market.

Current regulatory practice regarding RJVs in the US is based on the Sherman Antitrust Act, embodied in the US Code. Initially, under this code, guidelines were developed to permit mergers or to impose conditions on them, as well as to identify and prohibit cartels due to their clear detriment to competition. Nowadays, it also acts as the legal framework for regulatory authorities to determine whether a joint venture undermines market competition. The 'Report and Recommendations' of the Antitrust Modernization Commission (2007, pp. 378) identified over 30 statutory or judicial exemptions (or partial exemptions) from the antitrust laws, including cooperative RJVs (White, 2010). In the EU, the legality of joint ventures is also determined by general rules of competition under the EU Competition Law. More precisely, article 101 (3) of *The Treaty on the Functioning of the EU* (2010) facilitates the creation of joint ventures with the aim of fostering technical and economic progress. As in the US, RJVs in the EU are generally exempted from antitrust regulations (Gugler and Siebert, 2004).[1]

[1] In the first half of the 1980s, multiple block exemption regulations were issued, including RJVs (Carree *et al.*, 2010). However, over the past two decades, EU antitrust and merger policies have placed a greater emphasis on consumer welfare, particularly through a tighter economic analysis.

In the past, the scope of RJVs has only been limited when they have been proved to favor collusive practices in the product market. In these cases, antitrust legislation procedures have been applied to penalize these anticompetitive practices. In the US, a rule of reason is applied. Fact-finders are required to balance the potential adverse and positive effects of RJVs to determine whether their net effect is likely to be beneficial or harmful to consumers (Piriano, 2008).[2] Because of their detrimental competitive effects, suits have been brought against the following RJVs: (*i*) *CITGO Petroleum and Motiva* (in 2006), an RJV between Shell, Texaco, and Saudi Refining, and (*ii*) *Equilon Enterprises* (in 2007), another RJV between Texaco and Shell. However, in both cases the application of the rule of reason led to the dismissal of the suits (Goeree and Helland, 2010). In the EU, in the period 1964-2004, suits have been brought only against two joint ventures (Carree *et al.*, 2010). However, in both cases the agreements were not found to have infringed article 101, and neither decision was appealed. To the best of our knowledge, there is no case in which anticompetitive practices were reported for RJVs.

Current industrial policy tends to favor domestic RJVs as compared to international RJVs. For example, US domestic RJVs are accorded more lenient antitrust treatment by the National Cooperative Research Act (NCRA) to give American firms a cooperative advantage over foreign firms. While some authors defend the creation of "national champions" (Marvel, 1980; Krugman, 1984; Chou, 1986), others defend free competition and equal treatment for domestic and international firms (Ray, 1981; Sakakibara and Porter, 2001; Hollis, 2003). The majority of empirical studies support the latter rationale (Clougherty and Zhang, 2008). In this paper, we assess the possibility of giving a different treatment to domestic and international RJVs.

Using different methodologies, three recent empirical papers show that RJVs are often used as a subterfuge to sustain tacit collusion agreements in the product market. First, using US data, Duso *et al.* (forthcoming) show that RJVs involving direct competitors can lead to collusion in the product market. The authors conclude that RJVs have led to a significant reduction in market output in 29% of the cases included in their sample. By contrast, RJVs among non-competitors are found to be welfare-enhancing. Second, also using US data, Goeree and Helland (2010) examine the potential use of RJVs as a vehicle to facilitate collusion. They exploit a recent change in US leniency policy aimed at making collusive agreements less sustainable and examine its effects on RJV formation. They find that the number of RJVs has fallen significantly since this policy change, suggesting illegal practices associated to these agreements. On average, the probability of joining a RJV has fallen by 34% among

[2] The rule of reason has been applied on a regular basis since the Dagher case in 2005. This rule of reason approach requires an inquiry into all the characteristics of the relevant market.

telecommunications firms, by 33% among computer and semiconductor manufacturers, and by 27% among petroleum refining firms. Finally, Oxley *et al.* (2009) analyze how R&D-related alliances in the telecommunications equipment and electronics industries affect the stock market's evaluation of rival firms. If an alliance is expected to enhance the resource portfolio of partner firms, i.e., making them stronger competitors, this should lead to negative abnormal returns for rivals when the alliance is announced. If an alliance is expected to facilitate a reduction in competitive intensity, then this should lead to positive abnormal returns for rivals because they will also benefit from the attenuation of competitive pressures. The authors find evidence that some alliances are indeed expected to soften competition, especially in the case of horizontal alliances in concentrated industries. However, their results show that cross-border alliances appear to have a procompetitive effect[3]. Our analysis of international RJVs reinforces this result.

We propose a theoretical model of RJV formation in an international context when collusion can occur. The main novelty of our analysis is to study the effect of international RJVs with collusion. The effect of RJVs and collusion is analyzed in the seminal paper by d'Aspremont and Jacquemin (1988), which shows that RJVs can be welfare-enhancing when the spillovers are large enough. In a setting without collusion, Suzumura (1992) and Kamien *et al.* (1992) extend the model described in d'Aspremont and Jacquemin (1988) to more general forms of R&D cooperation and market structures.[4] Martin (1995) considers tacit collusion in the product market in a Cournot duopoly model where firms can cooperate in R&D, showing that RJVs are used to sustain collusion. This effect can jeopardize the welfare advantage of RJVs. Given that RJVs lead to collusion in the product market, Faulí-Oller *et al.* (2012) use a rich and general setting to show that a consumer-surplus maximizing antitrust authority should almost always prohibit RJVs.[5] Using a different approach, some papers have analyzed RJVs in an international context without collusion. Spencer and Brander (1983) consider government intervention through subsidies and taxes on exports and R&D, and conclude that countries do

[3]Duso *et al.* (2011) use a similar approach to assess the effectiveness of European merger control.

[4]Amir (2000) thoroughly compares the models in d'Aspremont and Jacquemin (1988) and Kamien *et al.* (2000) concluding that the real tests for their appropriateness would ultimately have to be empirical, although the Kamien *et al.* (2000) model seems a priori more appropriate for universal use. However, collusion in the product market has the same negative effect in both models. For the purposes of our analysis, the choice of a specific model is therefore not essential because our focus is on the effect of collusion in both domestic and international RJVs.

[5]Other papers have focused on the effect of RJVs in the presence of cost asymmetries (Petit and Tolwinski, 1999), product differentiation (Rosenkranz, 1995, and Lambertini *et al.*, 2002), asymmetric spillovers (Amir and Wooders, 1999), and technology differentiation (Gil-Molto *et al.*, 2005).

not subsidize R&D when export subsidies are available. Neary and O'Sullivan (1999) analyze the effect of export subsidies in a model where domestic and foreign firms choose R&D either independently or cooperatively and compete in the product market. These subsidies produce different welfare effects depending on the existence of a government commitment to support export subsidies.

We analyze the effect of RJVs on consumer welfare in an international context when firms can collude. RJVs can be used as a subterfuge to sustain tacit collusion agreements in the product market, and the effect of collusion may differ between domestic and international agreements. Our analysis is based on a model that extends the study of d'Aspremont and Jacquemin (1988) to a context with international trade. There are two countries with four firms - two in each country. We assume the technological spillovers between domestic and foreign firms to be different. Strategic decision making by firms is modeled as a two-stage game. In stage one, firms decide whether or not to form a RJV with another firm, either domestic or foreign. In stage two, firms choose the quantity to produce. Once a RJV has been formed, it is possible to distinguish two scenarios. Either firms decide on production levels non-cooperatively, or they use the RJV to collude in the production stage. We limit our attention to symmetric outcomes where either two domestic or two international RJVs are formed, along with the base case in which no RJV is formed. In addition to the base case, we thus have four different scenarios: (*i*) domestic and (*ii*) international RJVs with no collusion in the production stage, and (*iii*) domestic and (*iv*) international RJVs with collusion in the production stage.

Our main findings can be summarized as follows. In the absence of collusion, both domestic and international RJVs are consumer welfare-enhancing when the spillovers are sufficiently large. The relative magnitude of each spillover effect (domestic and international) determines which of the two types of RJV is more beneficial. In the presence of collusion, domestic RJVs are unambiguously welfare-reducing whereas international RJVs can be welfare-enhancing. While collusion in domestic RJVs yields a *competition-reduction effect*, under international RJVs there is an additional *efficiency-gains effect* since the specialization in domestic markets allows partner firms to save internationalization costs. International RJVs therefore increase consumer welfare when the latter positive effect of collusion predominates over the former negative effect. Naturally, when internationalization costs are low, collusion typically reduces consumer welfare (for both domestic and international RJVs).

In general, RJVs with collusion harm consumers. However, our results introduce a qualification to this statement: international RJVs with collusion might be beneficial for consumers when internationalization costs are high. The EU and US competition policy advises against RJVs that facilitate collusion on the grounds of their expected negative effects. Our results suggest that antitrust authorities should distinguish between domestic and international RJVs and, in certain cases, be more benevolent with international RJVs.

The paper is organized as follows. Section 2 presents the model and the equilibrium (both in production and R&D) in the base case where no RJVs are observed. Section 3 analyzes domestic and international RJVs in the absence of collusion at the production stage. Section 4 assesses the effect of collusion. Finally, a brief concluding section closes the paper. All the proofs can be consulted in the Appendix.

2 The model

Consider an industry with four firms located in two countries that produce a homogeneous good. Two firms are located in country A and two firms are located in country B. Each firm i decides on the quantity to produce for the domestic market (h_{ij}) and for the foreign market (e_{ij}), with $i = 1, 2$ and $j = A, B$. Thus, the total quantity traded in country j consists of domestic production and imports, i.e.,

$$q_j = h_j + e_l = h_{1j} + h_{2j} + e_{1l} + e_{2l}, \tag{1}$$

where $j, l = A, B$ and $j \neq l$. Firms face a linear inverse demand function $p_j = a - q_j$ and compete in quantities (à la Cournot).

Production costs are assumed to be linear in the firm's total output. Firms can reduce their marginal production costs by undertaking R&D activities, x_{ij}, at cost $\gamma x_{ij}^2/2$ with $\gamma \geq \underline{\gamma} \equiv 9.6$.[6] R&D efforts exerted by an individual firm produce a positive spillover that benefits other firms. These spillovers may have an asymmetric impact on the domestic and the foreign markets. Let us denote by β and $\lambda\beta$ the intensity of spillovers at the domestic and international levels, respectively. Thus, total production cost for firm i in country j is given by

$$CT_{ij} = \left[c - x_{ij} - \beta x_{kj} - \lambda\beta \sum_{i=1,2} x_{il} \right] (h_{ij} + e_{ij}) + \gamma x_{ij}^2/2, \tag{2}$$

where $i, k = 1, 2$ with $i \neq k$ and $a > c > 0$. At this point, it seems sensible to assume $0 \leqslant \lambda \leqslant \overline{\lambda} \equiv (1-\beta)/2\beta$ so that the own marginal return to R&D effort is larger than the

[6] This condition ensures compliance with second-order and stability conditions. The proof is in the Appendix.

absorbed one. This cost structure builds on the one proposed in d'Aspremont and Jacquemin (1988), adapting it to a framework with international trade.[7]

In addition, selling abroad makes firms incur an additional *internationalization cost,* te_{ij}. This term accounts for learning costs on how to adapt the product to a foreign market, the costs for complying with different legal requirements, higher transportation costs, or the payment of tariffs levied by the foreign country. Thus, the profits of a firm i located in country j are given by

$$\pi_{ij} = p_j h_{ij} + p_l e_{ij} - CT_{ij} - te_{ij}. \tag{3}$$

Now, consider the base case in which firms behave non-cooperatively in both stages of the game, i.e., firms neither engage in RJVs nor collude in production. In stage 2, firms choose quantities h_{ij} and e_{ij} to maximize profits in Eq. (3). The Cournot-Nash equilibrium values of this stage game (conditional on R&D decisions) are

$$h_{ij}^{02} = \frac{1}{5}\left[a - c + 2t - (1 + \beta - 3\lambda\beta) \sum_{i=1,2,j=A,B} x_{ij}\right] + (1 - \beta\lambda) x_{ij} + (1 - \lambda) \beta x_{kj} \tag{4}$$

and

$$e_{ij}^{02} = \frac{1}{5}\left[a - c - 3t - (1 + \beta - 3\lambda\beta) \sum_{i=1,2,j=A,B} x_{ij}\right] + (1 - \beta\lambda) x_{ij} + (1 - \lambda) \beta x_{kj}, \tag{5}$$

where the superscript 02 denotes stage-2 equilibrium values in the base case. The sole difference between home and foreign production quantities is found in the effect of the internationalization cost, which benefits domestic production. By looking at these expressions along with Eq. (1), we can verify that the existence of internationalization costs reduces total production in both countries. We can also confirm that both h_{ij}^{02} and e_{ij}^{02} increase with x_{ij}, which constitutes a natural firm reaction to a lower marginal production cost.

Plugging these values into Eq. (3), we obtain the stage-1 profit function that firms maximize through their choices of R&D

$$\pi_{ij} = \left(h_{ij}^{02}\right)^2 + \left(e_{ij}^{02}\right)^2 - \gamma x_{ij}^2/2. \tag{6}$$

[7] Kamien and Zang (2000) extend the d'Aspremont and Jacquemin (1988) model to allow for absorptive capacity. In their model, the extent to which a firm can benefit from R&D carried on by other firms depends on its own R&D investment. As compared to the case with costless spillovers, they find that absorptive capacity yields larger R&D spending. Introducing absorptive capacity in our analysis would not change the results qualitatively while complicating the model substantially.

The SPNE total quantity is given by

$$q_j^0 = 10\gamma \frac{2(a-c)-t}{25(\gamma-1)+(2\beta+4\beta\lambda-3)^2}, \tag{7}$$

where the superscript 0 denotes equilibrium values in the base case. These expressions corroborate the inefficiency associated to the presence of internationalization costs. At this point, we need to impose an upper bound to the marginal internationalization cost to ensure non-negative equilibrium values, which is given by $0 \leqslant t \leqslant \bar{t} \equiv 2(a-c)$.

We compare consumer surplus under all the scenarios considered, since competition and antitrust authorities use this criterion to assess the welfare effects of RJVs, mergers, and other agreements among firms. With linear demand functions, this is tantamount to comparing quantities. As pointed out by d'Aspremont and Jacquemin (1988), comparison of R&D efforts could yield a different ordering than comparison of quantities. However, our analysis focuses exclusively on the comparison of quantities (and not R&D spending) because competition and antitrust authorities do not take into account the potential (but uncertain) future gains of different R&D efforts when assessing possible anticompetitive practices.[8]

3 RJVs without collusion at the production stage

D'Aspremont and Jacquemin (1988) conclude that (domestic) RJVs without collusion at the production stage are socially profitable for sufficiently large spillover levels. In this section we test this result in a more general context of international competition where both domestic and international RJVs are possible and can have different spillover effects. As mentioned above, research spillovers (synergies, risk sharing, efficiency gains, innovation diffusion, etc.) constitute the main argument for antitrust authorities when assessing RJVs. However, these authorities apparently do not distinguish between domestic and international RJVs, even though the spillovers they generate may be substantially different.

Having explained the base case, our attention now shifts to RJV formation, at both the domestic and international levels. In this section, we assume that firms' collaboration on

[8] As pointed out in Banal-Estañol *et al.* (2008), "this is consistent with the current standards used both in the US and the EU to assess mergers. In the US, the 'substantial lessening of competition' test (SLC) has been interpreted such that a merger is unlawful if it is likely that it will lead to an increase in price (i.e., to a decrease in consumer surplus). In the EU, the Horizontal Merger Guidelines state that the Commission should take into account, above all, the interests of consumers when considering efficiency claims of merging firms (art. 79-81)." Subsequent papers, such as Duso *et al.* (forthcoming), have also used this criterion.

R&D activities does not extend to the realm of production. Since partner firms behave non-cooperatively when choosing their optimal production levels, stage-2 equilibrium values remain the same as in the base case. However, in stage 1, partner firms determine their R&D efforts jointly.

Therefore, in the case of a *domestic RJV*, partner firms solve

$$\max_{x_{1j},x_{2j}} \sum_{i=1,2} \pi_{ij} = \sum_{i=1,2} \left[\left(h_{ij}^{02}\right)^2 + \left(e_{ij}^{02}\right)^2 - \gamma x_{ij}^2/2 \right], \tag{8}$$

and in the case of an *international RJV*, partner firms solve

$$\max_{x_{iA},x_{iB}} \sum_{j=A,B} \pi_{ij} = \sum_{j=A,B} \left[\left(h_{ij}^{02}\right)^2 + \left(e_{ij}^{02}\right)^2 - \gamma x_{ij}^2/2 \right]. \tag{9}$$

Since the main goal of this paper is to understand the welfare implications of RJVs, in the analysis that follows we will directly present the equilibrium total quantities,[9] which are

$$q_j^D = 10\gamma \frac{2(a-c)-t}{25\gamma - 12 - 4\beta\left[2(3+\lambda) + \beta(1+2\lambda)(3-4\lambda)\right]} \tag{10}$$

and

$$q_j^I = 10\gamma \frac{2(a-c)-t}{25\gamma - 12 - 4\beta\left[1 + 7\lambda - \beta(1+2\lambda)(2-\lambda)\right]}, \tag{11}$$

where the superscripts D and I, respectively, denote equilibrium values in the domestic and international RJV cases in the absence of collusion. The difference between the two expressions lies in the value of the denominator, which depends on the intensity of domestic and international spillovers (i.e., β and λ).

Based on a pairwise comparison of equilibrium quantities under domestic and international RJVs along with the base case where no RJVs are formed, i.e., comparing Eqs. (7), (10), and (11), the following proposition arises.

Proposition 1 *Let* $\underline{\gamma} \leqslant \gamma$, $0 \leqslant \lambda \leqslant \overline{\lambda}$, *and* $0 \leqslant t \leqslant \overline{t}$. *When partner firms in a RJV do not collude, consumer welfare is maximized*
i) under international RJVs if $\lambda\beta$ *is sufficiently high,*
ii) under domestic RJVs if λ *is low and* β *is sufficiently high,*
iii) when no RJVs are formed, otherwise.

[9] More information on the computations is available from the authors on request.

Naturally, each type of RJV requires a minimum level of spillovers' intensity to yield an overall positive effect. The results in Proposition 1 are represented in Fig. 1 below.

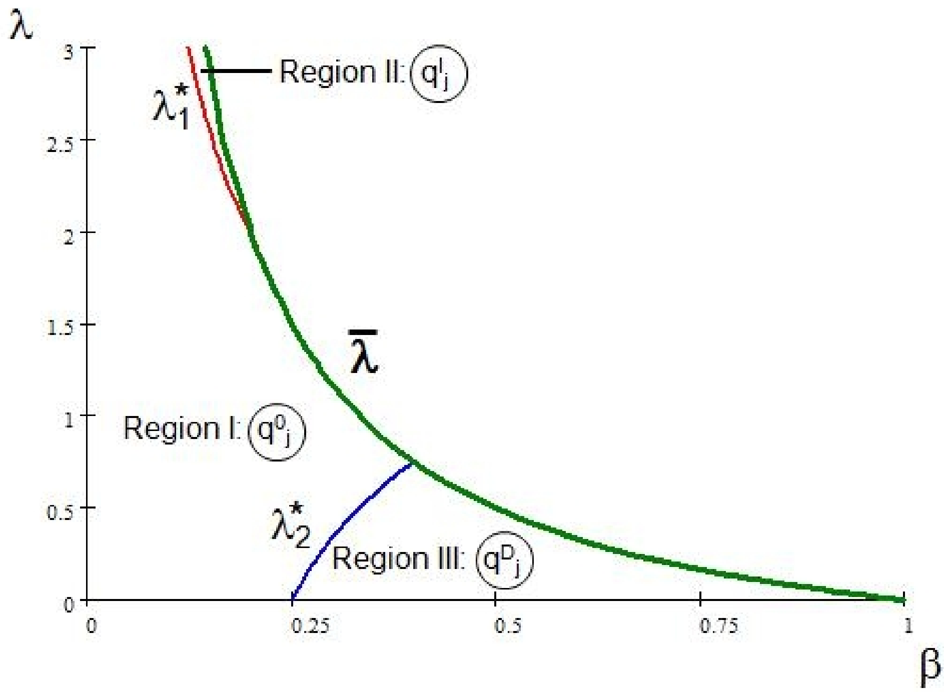

Fig. 1: Socially preferred RJVs without collusion.

Proposition 1(ii) confirms the result reported by d'Aspremont and Jacquemin (1988) which points out that (domestic) RJVs are socially preferred when (domestic) spillovers are large enough (which corresponds to moving to the east in Fig. 1). Similarly, we find that international RJVs are consumer welfare-enhancing when international spillovers are sufficiently high (which corresponds to moving to the north-east in Fig. 1). Moreover, a necessary condition for international RJVs to be more profitable than domestic RJVs requires international spillovers to be larger than domestic ones ($\lambda > 1$ in Fig. 1). The policy implications of these findings are that each type of RJVs should be allowed when the corresponding spillovers are sufficiently large.

4 RJVs with collusion at the production stage

As mentioned in the introduction, RJVs can be employed to facilitate collusion in the product market. Of course, this means that the potential positive effect of RJVs on consumer welfare is more questionable. In this section, we analyze the consequences of domestic and international RJVs when they involve collusive behavior. In this case, we assume that partner firms share the market 50/50, so that the RJV behaves as a "merger of equals".[10]

In the case of a *domestic RJV*, stage-2 production levels are therefore determined by solving

$$\max_{h_{ij},e_{ij}} \sum_{i=1,2} \pi_{ij} = \sum_{i=1,2} \left[p_j h_{ij} + p_l e_{ij} - CT_{ij} - t e_{ij} \right], \tag{12}$$

where $h_{ij} = h_j/2$ and $e_{ij} = e_j/2$. In the case of an *international RJV*, a straightforward efficiency argument suggests that partner firms specialize in their respective domestic markets and avoid exporting to save internationalization costs. As a consequence, $e_{ij} = 0$ and stage-2 production levels are determined by solving

$$\max_{h_{ij}} \sum_{j=A,B} \pi_{ij} = \sum_{j=A,B} \left[p_j h_{ij} - CT_{ij} \right]. \tag{13}$$

Having obtained the results for production, partner firms jointly determine their R&D efforts in stage 1, which yields

$$q_j^{DC} = 3\gamma \frac{2(a-c) - t}{9\gamma - 4 - 4\beta \left[2 + \lambda + \beta (1 + 2\lambda)(1 - \lambda) \right]} \tag{14}$$

and

$$q_j^{IC} = h_j^{IC} = 6\gamma \frac{(a-c)}{9\gamma - 4 - 2\beta \left[1 + 5\lambda - \beta (1 + 2\lambda)(1 - \lambda) \right]}, \tag{15}$$

where the superscripts DC and IC denote equilibrium values under domestic and international RJV in the presence of collusion, respectively.[11] As in the case without collusion, these equilibrium expressions differ in the intensity of the domestic and international spillovers that affect the denominator of the expressions. Additionally, collusive international RJVs also benefit from being exempt from internationalization costs. Consequently, t does not appear in Eq. (15). From a pairwise comparison of Eqs. (7), (14), and (15), the following proposition arises.

Proposition 2 *Let $\underline{\gamma} \leqslant \gamma$, $0 \leqslant \lambda \leqslant \overline{\lambda}$, and $0 \leqslant t \leqslant \bar{t}$. When partner firms in a RJV collude, consumer welfare is maximized*
i) under international RJVs if $t/(a-c)$ and $\lambda\beta$ are high,
ii) when no RJVs are formed if $t/(a-c)$ and $\lambda\beta$ are low.
Domestic RJVs never maximize consumer welfare.

[10] It could be argued that concentrating all the production in a single firm could be more efficient. However, capacity constrains and the tacit nature of the collusion agreement between symmetric firms argue in favor of the 50/50 assumption.

[11] More information on the computations is available from the authors on request.

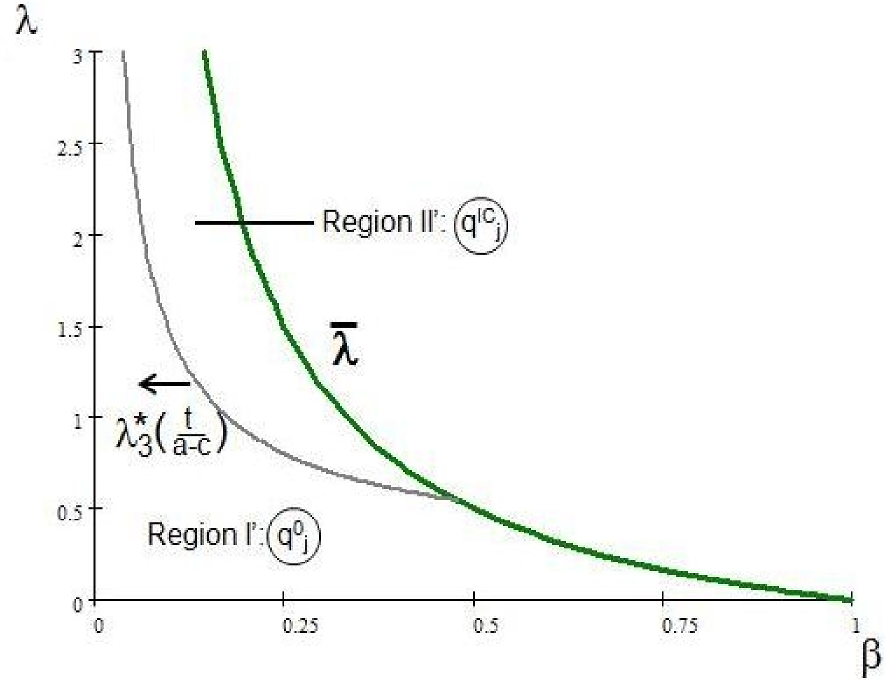

Fig. 2: Socially preferred RJVs with collusion for $\gamma = 10$ and $\frac{t}{(a-c)} = \frac{4}{11}$.
The arrow denote the movement of λ_3^* as $\frac{t}{(a-c)}$ increases.

Comparing Propositions 1 and 2, we find that collusion has a differentiated effect on consumer welfare under domestic and international RJVs. First, collusion reduces consumer welfare under domestic RJVs. This *competition-reduction effect* of collusion under RJVs has also been obtained by d'Aspremont and Jacquemin (1988) and Martin (1995) in related models. Thus, Region III in Fig. 1 does not appear in Fig. 2. Second, under international RJVs, an additional effect of collusion is that it allows partner firms to save internationalization costs since they specialize in domestic markets and do not export (i.e., $e_{ij} = 0$ and $q_j^{IC} = h_j^{IC}$).[12] The higher the internationalization cost, the grater this *efficiency-gains effect* of collusion. As a consequence, region II' in Fig. 2 expands (shrinks) as t increases (decreases) and may become larger (smaller) than region II in Fig 1. When t is very low, region II' disappears from Fig. 2 and, thus, international RJVs are never the best option in terms of consumer welfare. Similarly, for a sufficiently high t, international RJVs maximize consumer welfare even in the absence of spillovers. As a consequence, spillovers are needed to make international RJVs consumer welfare-enhancing for moderate values of t.

[12] As a result, firms only absorb spillovers through their domestic production (see Eq. (2)).

5 Policy implications and concluding remarks

The results in this paper can be generalized in different directions. Considering heterogeneous products, the social profitability of international RJVs in the presence of collusion would be somewhat diluted. This is because the domestic specialization associated to collusion under international RJVs would also entail a loss of product variety for consumers. Another generalization of the paper would is the extension to different competitive environments: enlarging the number of firms would downplay the negative effect of collusion, whereas assuming price competition would exacerbate it.

The policy implications of this paper are as follows. In industries characterized by a low probability of collusion, RJVs (both domestic and international) should be allowed when the spillovers are large enough.[13] This recommendation is consistent with the findings in d'Aspremont and Jacquemin (1988). However, in industries where RJVs are likely to be used as a subterfuge to sustain a tacit collusion agreement, domestic RJVs should always be forbidden, regardless of the intensity of spillovers. By contrast, international RJVs should be allowed in high-spillover environments as long as the efficiency gains stemming from savings on internationalization costs are large enough. This means that international RJVs should be treated more favorably than domestic RJVs under these circumstances.

[13] Industries are characterized by a low probability of collusion when firms do not interact repeatedly, there is a large number of participants, or there are low barriers to entry. In addition, collusion is more difficult in declining markets (Ivaldi *et al.*, 2007); and in advertising-intensive and low capital-intensive industries (Symeonidis, 2003).

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A Appendix: Second-order and stability conditions

In this appendix, we elucidate the conditions that ensure positive quantities and compliance with second-order and stability conditions in all the scenarios considered, i.e., we prove the following claim.

Claim 1 *Imposing* $\gamma \geqslant \underline{\gamma} = 9.6$ *is sufficient to ensure compliance with second-order and stability conditions.*

A.1 Second-order conditions

♦ *Base case (no RJVs)*

It can be verified that second-order conditions at the production stage (stage 1) are always satisfied. At the R&D stage (stage 2), from $\partial^2 \pi_{ij} / \partial x_{ij}^2 < 0$ (see Eq. (6)) we obtain

$$\gamma > \gamma_1 \equiv \frac{4}{25} \left[4 - \beta \left(1 + 2\lambda\right)\right]^2 . \tag{16}$$

A sufficient condition for Eq. (16) to be true, is that $\gamma > \max\limits_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_1 \equiv \gamma_1^{\lambda} = \frac{4}{25} \left(4 - \beta\right)^2$.

♦ *Domestic RJVs without collusion at the production stage*

It can be confirmed that second-order conditions at the production stage (stage 1) are always satisfied. At the R&D stage (stage 2), from $\partial^2 \left(\pi_{1j} + \pi_{2j}\right) / \partial x_{1j}^2 < 0$ and $\partial^2 \left(\pi_{1j} + \pi_{2j}\right) / \partial x_{2j}^2 < 0$ (see Eq. (8)) we obtain

$$\gamma > \gamma_2 \equiv \frac{4}{25} \left[17 + \beta \left(17\beta - 16 - 12\lambda \left(1 + \beta\right) + 8\lambda^2 \beta\right)\right] , \tag{17}$$

and positivity of the determinant requires $\left(\gamma_2 - \gamma\right)^2 - \left\{ \frac{8}{25} \left[1 + 2\beta \left(\lambda - 2\right)\right] \left[\beta \left(1 + 2\lambda\right) - 4\right] \right\}^2 > 0$, which is observed when

$$\gamma > \gamma_3 \equiv \max \left\{ 4 \left(\beta - 1\right)^2 , \frac{4}{25} \left[\beta \left(4\lambda - 3\right) - 3\right]^2 \right\} . \tag{18}$$

A sufficient condition for Eqs. (17) and (18) to be true, is that $\gamma > \max\limits_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_2 \equiv \gamma_2^{\lambda} = \frac{4}{25} \left(17\beta^2 - 16\beta + 17\right)$ and $\gamma > \max\limits_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_3 \equiv \gamma_3^{\lambda} = \max\{4 \left(\beta - 1\right)^2 , \frac{36}{25} \left(\beta + 1\right)^2\}$, respectively.

♦ *International RJVs without collusion at the production stage*

It can be verified that second-order conditions at the production stage (stage 1) are always satisfied. At the R&D stage (stage 2), from $\partial^2 \left(\pi_{iA} + \pi_{iB}\right) / \partial x_{iA}^2 < 0$ and $\partial^2 \left(\pi_{iA} + \pi_{iB}\right) / \partial x_{iB}^2 < 0$ (see Eq. (9)) we obtain

$$\gamma > \gamma_4 \equiv \frac{4}{25} \left\{17 + \beta \left[\beta \left(2 + \lambda \left(13\lambda - 2\right)\right) - 22\lambda - 6\right]\right\} , \tag{19}$$

and positivity of the determinant requires $(\gamma_4-\gamma)^2-\left\{\frac{8}{25}\left[1-\beta\left(3\lambda-1\right)\right]\left[\beta\left(1+2\lambda\right)-4\right]\right\}^2>0$, which is observed when

$$\gamma>\gamma_5\equiv\max\left\{4\left(\lambda\beta-1\right)^2,\frac{4}{25}\left[\beta\left(\lambda-2\right)+3\right]^2\right\}. \tag{20}$$

A sufficient condition for Eqs. (19) and (20) to be true, is that $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_4\equiv\gamma_4^\lambda=\frac{4}{25}\left(2\beta^2-6\beta+17\right)$ and $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_5\equiv\gamma_5^\lambda=\max\left\{4,\frac{1}{25}\left(7-5\beta\right)^2\right\}=4$, respectively.

♦ *Domestic RJVs with collusion at the production stage*

It can be confirmed that second-order conditions at the production stage (stage 1) are always satisfied. At the R&D stage (stage 2), from $\partial^2\left(\pi_{1j}+\pi_{2j}\right)/\partial x_{1j}^2<0$ and $\partial^2\left(\pi_{1j}+\pi_{2j}\right)/\partial x_{2j}^2<0$ we obtain

$$\gamma>\gamma_6\equiv\frac{4}{9}\left[\beta\left(\lambda-1\right)-1\right]^2, \tag{21}$$

and positivity of the determinant requires $(\gamma_6-\gamma)^2-\gamma_6^2>0$, which is observed when

$$\gamma>\gamma_7\equiv2\gamma_6. \tag{22}$$

A sufficient condition for Eqs. (21) and (22) to be true, is that $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_6\equiv\gamma_6^\lambda\equiv\frac{4}{9}\left(\beta+1\right)^2$ and $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_7\equiv\gamma_7^\lambda=2\gamma_6^\lambda$, respectively.

♦ *International RJVs with collusion at the production stage*

It can be verified that second-order conditions at the production stage (stage 1) are always satisfied. At the R&D stage (stage 2), from $\partial^2\left(\pi_{iA}+\pi_{iB}\right)/\partial x_{iA}^2<0$ and $\partial^2\left(\pi_{iA}+\pi_{iB}\right)/\partial x_{iB}^2<0$ we obtain

$$\gamma>\gamma_8\equiv\frac{1}{9}\left\{8+2\beta\left[\beta\left(1+\lambda^2\right)-4\right]\right\}, \tag{23}$$

and positivity of the determinant requires $(\gamma_8-\gamma)^2-\left[\frac{4}{9}\beta\lambda\left(2-\beta\right)\right]^2>0$, which is observed when

$$\gamma>\gamma_9\equiv\frac{2}{9}\left[\beta\left(\lambda-1\right)+2\right]^2. \tag{24}$$

A sufficient condition for Eqs. (23) and (24) to be true, is that $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_8\equiv\gamma_8^\lambda\equiv\frac{1}{18}\left(5\beta^2-18\beta+17\right)$ and $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_9\equiv\gamma_9^\lambda\equiv\frac{1}{18}\left(5-3\beta\right)^2$, respectively.

As a result of comparing the previous second-order conditions and using the bounds γ_h^λ for $h=1,...,9$, we compute the lower bound for γ as:[14]

$$\gamma\geqslant\max_{0\leq\beta\leq1}\{\gamma_1^\lambda,...,\gamma_9^\lambda\}=\max_{0\leq\beta\leq1}\{4,\frac{36}{25}\left(\beta+1\right)^2\}=5.76.\ \blacksquare$$

[14] It can be verified that $\gamma_1^\lambda<\gamma_5^\lambda$, $\gamma_2^\lambda<\gamma_5^\lambda$, $\gamma_4^\lambda<\gamma_5^\lambda$, $\gamma_6^\lambda<\gamma_7^\lambda<\gamma_5^\lambda$, and $\gamma_8^\lambda<\gamma_9^\lambda<\gamma_5^\lambda$. In addition, the first bound in γ_3^λ is also lower than γ_5^λ, i.e., $4\left(\beta-1\right)^2<4$.

A.2 Stability conditions

Stability of equilibria is ensured when the Jacobian of first derivatives of profits with respect to R&D investments is negative definite (see chapter 2 in Vives (2001) for further details). This matrix is symmetric with the following structure

$$\begin{pmatrix} A & B & C & D \\ B & A & D & C \\ C & D & A & B \\ D & C & B & A \end{pmatrix}.$$

The Jacobian of first derivatives is negative definite if

$$\begin{aligned} A &< 0, && (25) \\ (A-B)(A+B) &> 0, && (26) \\ 2BCD + A\left(A^2 - B^2 - C^2 - D^2\right) &< 0, && (27) \\ \left[(A+B)^2 - (C+D)^2\right]\left[(A-B)^2 - (C-D)^2\right] &> 0. && (28) \end{aligned}$$

The condition in Eq. (25) is already guaranteed by second-order conditions.

Claim 2 *Conditions in Eqs. (26)-(28) are satisfied iff*

$$\begin{aligned} A - B &< 0, && (29) \\ A + B &< 0, && (30) \\ (A+B)^2 - (C+D)^2 &> 0, && (31) \\ (A-B)^2 - (C-D)^2 &> 0. && (32) \end{aligned}$$

Proof. First, note that Eqs. (29) and (30) guarantee that Eq. (26) holds and Eqs. (31) and (32) guarantee that Eq. (28) holds. Finally, Eq. (27) can be rewritten as:

$$(A-B)^2 \left(2A(A+B) - (C+D)^2\right) > (C-D)^2 (A-B)(A+B). \quad (33)$$

Under Eq. (32), Eq. (33) holds iff

$$\begin{aligned} 2A(A+B) - (C+D)^2 &> (A-B)(A+B), \text{ or} && (34) \\ (A+B)^2 - (C+D)^2 &> 0, && (35) \end{aligned}$$

which is Eq. (31). ■

♦ *Base case (no RJVs)*

In this scenario

$$\begin{aligned}
A &\equiv \partial^2\pi_{ij}/\partial x_{ij}^2 = \frac{1}{25}\left\{64-25\gamma+4\beta\left[1+2\lambda\right]\left[-8+\beta\left(1+2\lambda\right)\right]\right\}, \\
B &\equiv \partial^2\pi_{ij}/\partial x_{ij}\partial x_{kj} = \frac{4}{25}\left[1-2\beta\left(2-\lambda\right)\right]\left[-4+\beta\left(1+2\lambda\right)\right], \text{ and} \\
C &= D \equiv \partial^2\pi_{ij}/\partial x_{ij}\partial x_{il} = \frac{4}{25}\left[-4+\beta\left(1+2\lambda\right)\right]\left[1+\beta\left(1-3\lambda\right)\right].
\end{aligned}$$

Thus, Eq. (32) holds directly and Eqs. (29)-(31) become

$$\gamma > \gamma_{10} \equiv \frac{4}{5}\left(1-\beta\right)\left[4-\beta\left(1+2\lambda\right)\right], \tag{36}$$

$$\gamma > \gamma_{11} \equiv \frac{4}{25}\left[4-\beta\left(1+2\lambda\right)\right]\left[3+\beta\left(3-4\lambda\right)\right], \tag{37}$$

$$\gamma > \gamma_{12} \equiv \max\left\{\frac{4}{5}\left[4-\beta\left(1+2\lambda\right)\right]\left(1+\beta-2\beta\lambda\right), \frac{4}{25}\left[4-\beta\left(1+2\lambda\right)\right]\left(1+\beta+2\beta\lambda\right)\right\} \tag{38}$$

A sufficient condition for Eqs. (36)-(38) to be true is that $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{10} \equiv \gamma_{10}^{\lambda} \equiv \frac{4}{5}\left(4-\beta\right)\left(1-\beta\right)$, $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{11} \equiv \gamma_{11}^{\lambda} = \frac{12}{25}\left(4-\beta\right)\left(1+\beta\right)$, and $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{12} \equiv \gamma_{12}^{\lambda} = \max\left\{\frac{4}{5}\left(4-\beta\right)\left(1+\beta\right), \frac{24}{25}\right\} = \frac{4}{5}\left(4-\beta\right)\left(1+\beta\right)$, respectively.

♦ *Domestic RJVs without collusion at the production stage*

In this scenario

$$\begin{aligned}
A &\equiv \partial^2\left(\pi_{1j}+\pi_{2j}\right)/\partial x_{ij}^2 = \frac{1}{25}\left\{68-25\gamma+4\beta\left[-16+17\beta-12\lambda\left(1+\beta\right)+8\beta\lambda^2\right]\right\}, \\
B &\equiv \partial^2\left(\pi_{1j}+\pi_{2j}\right)/\partial x_{1j}\partial x_{2j} = \frac{8}{25}\left[1-2\beta\left(2-\lambda\right)\right]\left[-4+\beta\left(1+2\lambda\right)\right], \text{ and} \\
C &= D \equiv \partial^2\left(\pi_{1j}+\pi_{2j}\right)/\partial x_{1j}\partial x_{il} = \frac{4}{25}\left[-3+\beta\left(-3+4\lambda\right)\right]\left[1+\beta\left(1-3\lambda\right)\right],
\end{aligned}$$

for $i = 1, 2$ and $j, l = A, B$. Thus, Eq. (32) holds directly and Eqs. (29)-(31) become

$$\gamma > \gamma_{13} \equiv 4\left(1-\beta\right)^2, \tag{39}$$

$$\gamma > \gamma_{14} \equiv \frac{4}{25}\left[3+\beta\left(3-4\lambda\right)\right]^2, \tag{40}$$

$$\gamma > \gamma_{15} \equiv \max\left\{\frac{4}{5}\left[3+\beta\left(3-4\lambda\right)\right]\left(1+\beta-2\beta\lambda\right), \frac{4}{25}\left[3+\beta\left(3-4\lambda\right)\right]\left(1+\beta+2\beta\lambda\right)\right\} \tag{41}$$

A sufficient condition for Eqs. (39)-(41) to be true is that $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{13} \equiv \gamma_{13}^{\lambda} \equiv 4\left(1-\beta\right)^2$, $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{14} \equiv \gamma_{14}^{\lambda} = \frac{36}{25}\left(1+\beta\right)^2$, and $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{15} \equiv \gamma_{15}^{\lambda} = \max\left\{\frac{12}{5}\left(1+\beta\right)^2, \frac{1}{2}\left(1+\beta\right)^2\right\} = \frac{12}{5}\left(1+\beta\right)^2$, respectively.

♦ *International RJVs without collusion at the production stage*

In this scenario

$$\begin{aligned}
A &\equiv \partial^2 (\pi_{iA} + \pi_{iB}) / \partial x_{ij}^2 = \frac{1}{25} \{68 - 25\gamma + 4\beta [-6 - 22\lambda + \beta (2 + \lambda [13\lambda - 2])]\}, \\
B &\equiv \partial^2 (\pi_{iA} + \pi_{iB}) / \partial x_{iA} \partial x_{iB} = \frac{8}{25} [1 + \beta (1 - 3\lambda)] [-4 + \beta (1 + 2\lambda)], \\
C &\equiv \partial^2 (\pi_{iA} + \pi_{iB}) / \partial x_{ij} \partial x_{kj} = \frac{4}{25} \left[-3 + \beta \left(19 - 3\beta - 12\lambda (1 + \beta) + 13\beta\lambda^2\right)\right], \text{ and} \\
D &\equiv \partial^2 (\pi_{iA} + \pi_{iB}) / \partial x_{ij} \partial x_{kl} = \frac{4}{25} [1 + \beta (1 - 3\lambda)] [-3 - \beta (3 - 4\lambda)],
\end{aligned}$$

for $i, k = 1, 2$, $k \neq i$ and $j, l = A, B$, $l \neq j$. Thus, Eqs. (29)-(32) become

$$\begin{aligned}
\gamma &> \gamma_{16} \equiv 4 (1 - \beta\lambda)^2, && (42) \\
\gamma &> \gamma_{17} \equiv \frac{4}{25} [3 - \beta (2 - \lambda)]^2, && (43) \\
\gamma &> \gamma_{18} \equiv \max \left\{ \frac{4}{5} (1 - \beta) [3 - \beta (2 - \lambda)], \frac{4}{25} [3 - \beta (2 - \lambda)] [1 + \beta (1 + 2\lambda)] \right\}, && (44) \\
\gamma &> \gamma_{19} \equiv \max \{4 (1 - \beta) (1 - \beta\lambda), 4 (1 - \beta\lambda) [1 + \beta (1 - 2\lambda)]\}. && (45)
\end{aligned}$$

A sufficient condition for Eqs. (42)-(45) to be true is that $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_{16} \equiv \gamma_{16}^{\lambda} \equiv 4$, $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_{17} \equiv \gamma_{17}^{\lambda} = \frac{1}{25} (7 - 5\beta)^2$, $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_{18} \equiv \gamma_{18}^{\lambda} = \max \left\{ \frac{2}{5} (7 - 5\beta) (1 - \beta), \frac{4}{25} (7 - 5\beta) \right\}$, and $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_{19} \equiv \gamma_{19}^{\lambda} = \max \{4 (1 - \beta), 4 (1 + \beta)\} = 4 (1 + \beta)$, respectively.

♦ *Domestic RJVs with collusion at the production stage*

In this scenario

$$\begin{aligned}
A &\equiv \partial^2 (\pi_{1j} + \pi_{2j}) / \partial x_{ij}^2 = \frac{1}{9} \{4 - 9\gamma + 4\beta [2 + \beta (1 - \lambda)] [1 - \lambda]\}, \\
B &\equiv \partial^2 (\pi_{1j} + \pi_{2j}) / \partial x_{1j} \partial x_{2j} = \frac{4}{9} [1 + \beta (1 - \lambda)]^2, \text{ and} \\
C &= D \equiv \partial^2 (\pi_{1j} + \pi_{2j}) / \partial x_{1j} \partial x_{il} = \frac{2}{9} [1 + \beta (1 - \lambda)] [-1 + \beta (-1 + 4\lambda)],
\end{aligned}$$

for $i = 1, 2$ and $j, l = A, B$. Thus, Eq. (32) holds directly and Eqs. (29)-(31) become

$$\begin{aligned}
\gamma &> 0, && (46) \\
\gamma &> \gamma_{20} \equiv \frac{8}{9} [1 + \beta (1 - \lambda)]^2, && (47) \\
\gamma &> \gamma_{21} \equiv \max \left\{ \frac{4}{9} [1 + \beta (1 - \lambda)] [1 + \beta (1 + 2\lambda)], \frac{4}{3} [1 + \beta (1 - \lambda)] [1 + \beta (1 - 2\lambda)] \right\}. && (48)
\end{aligned}$$

Eq. (46) holds by construction. A sufficient condition for Eqs. (47) and (48) to be true is that $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_{20} \equiv \gamma_{20}^{\lambda} \equiv \frac{8}{9} (1 + \beta)^2$ and $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_{21} \equiv \gamma_{21}^{\lambda} = \max \left\{ \frac{1}{2} (1 + \beta)^2, \frac{4}{3} (1 + \beta)^2 \right\} =$

$\frac{4}{3}(1+\beta)^2$, respectively.

♦ *International RJVs with collusion at the production stage*
In this scenario

$$\begin{aligned}
A &\equiv \partial^2(\pi_{iA}+\pi_{iB})/\partial x_{ij}^2 = \frac{1}{9}\left\{8-9\gamma-2\beta\left[4-\beta\left(1+\lambda^2\right)\right]\right\}, \\
B &\equiv \partial^2(\pi_{iA}+\pi_{iB})/\partial x_{iA}\partial x_{iB} = \frac{4}{9}\beta\lambda(2-\beta), \\
C &\equiv \partial^2(\pi_{iA}+\pi_{iB})/\partial x_{ij}\partial x_{kj} = \frac{2}{9}\left\{-2+\beta\left[5+\beta\left(-2+\lambda^2\right)\right]\right\}, \text{ and} \\
D &\equiv \partial^2(\pi_{iA}+\pi_{iB})/\partial x_{ij}\partial x_{kl} = \frac{2}{9}\beta\lambda(1+\beta),
\end{aligned}$$

for $i,k=1,2$, $k\neq i$ and $j,l=A,B$, $l\neq j$. Thus, Eqs. (29)-(32) become

$$\begin{aligned}
\gamma &> \gamma_{22} \equiv \frac{2}{9}\left[2-\beta(1+\lambda)\right]^2, && (49)\\
\gamma &> \gamma_{23} \equiv \frac{2}{9}\left[2-\beta(1-\lambda)\right]^2, && (50)\\
\gamma &> \gamma_{24} \equiv \max\left\{\frac{2}{3}(1-\beta)\left[2-\beta(1-\lambda)\right], \frac{2}{9}\left[2-\beta(1-\lambda)\right]\left[1+\beta(1+2\lambda)\right]\right\}, && (51)\\
\gamma &> \gamma_{25} \equiv \max\left\{\frac{2}{3}(1-\beta)\left[2-\beta(1+\lambda)\right], \frac{2}{9}\left[2-\beta(1+\lambda)\right]\left[1+\beta(1-2\lambda)\right]\right\}. && (52)
\end{aligned}$$

A sufficient condition for Eqs. (49)-(52) to be true is that $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{22} \equiv \gamma_{22}^{\lambda} \equiv \frac{2}{9}(2-\beta)^2$, $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{23} \equiv \gamma_{23}^{\lambda} = \frac{1}{18}(5-3\beta)^2$, $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{24} \equiv \gamma_{24}^{\lambda} = \max\left\{\frac{1}{3}(5-3\beta)(1-\beta), \frac{2}{9}(5-3\beta)\right\}$, and $\gamma > \max_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{25} \equiv \gamma_{25}^{\lambda} = \max\left\{\frac{2}{3}(1-\beta)(2-\beta), \frac{2}{9}(1+\beta)(2-\beta)\right\}$, respectively.
As a result of comparing the previous stability conditions and using the bounds γ_h^{λ} for $h = 10,...,25$, we compute the lower bound for γ as:[15]

$$\gamma \geqslant \underline{\gamma} \equiv \max_{0\leq\beta\leq 1}\{\gamma_{10}^{\lambda},...,\gamma_{25}^{\lambda}\} = 9.6. \blacksquare$$

B Appendix: Proof of Proposition 1

From $q_j^0 - q_j^I = 0$ we obtain $\lambda_1^* = \frac{1}{3\beta}(1+\beta)$, which is plotted in Fig. 1. Then $q_j^0 \geqslant q_j^I$ for $\lambda \leqslant \lambda_1^*$ (regions I and III in Fig. 1) and $q_j^0 > q_j^I$ for $\lambda > \lambda_1^*$ (region II in Fig. 1).
From $q_j^0 - q_j^D = 0$ we obtain $\lambda_2^* = \frac{1}{2\beta}(4\beta-1)$, which is plotted in Fig. 1. Then $q_j^0 > q_j^D$ for $\lambda > \lambda_2^*$ (regions I and II in Fig. 1) and $q_j^0 \leqslant q_j^D$ for $\lambda \leqslant \lambda_2^*$ (region III in Fig. 1).

[15] It can be confirmed that $\gamma_{10}^{\lambda} < \gamma_{12}^{\lambda}$, $\gamma_{11}^{\lambda} < \gamma_{12}^{\lambda} < 4.8$, $\gamma_{13}^{\lambda} < 4$, $\gamma_{14}^{\lambda} < \gamma_{15}^{\lambda} < 9.6$, $\gamma_{16}^{\lambda} < \gamma_{19}^{\lambda}$, $\gamma_{17}^{\lambda} < 1.96$, $\gamma_{18}^{\lambda} < 5.6$, $\gamma_{19}^{\lambda} < 8$, $\gamma_{20}^{\lambda} < \gamma_{21}^{\lambda} < 16/3$, $\gamma_{22}^{\lambda} < 8/9$, $\gamma_{23}^{\lambda} < 25/15$, $\gamma_{24}^{\lambda} < 2$, and $\gamma_{25}^{\lambda} < 4/3$.

From $q_j^D - q_j^I = 0$ we obtain $\lambda = 1$. Then $q_j^D \geqslant q_j^I$ for $\lambda \leqslant 1$ and $q_j^D < q_j^I$ for $\lambda > 1$.
As a consequence, $q_j^0 > q_j^I$ and $q_j^0 > q_j^D$ in region I; $q_j^I > q_j^0 > q_j^D$ (since $\lambda > 1$) in region II; and $q_j^D > q_j^0 > q_j^I$ (since $\lambda < 1$) in region III. ■

C Appendix: Proof of Proposition 2

First, we show that $q_j^0 > q_j^{DC}$ for $\gamma > \underline{\gamma} \equiv 9.6$. From $q_j^0 - q_j^{DC} > 0$, we get $\Omega(\lambda) \equiv 15\gamma - 44\beta + 32\beta\lambda - 52\beta^2 - 88\beta^2\lambda + 32\beta^2\lambda^2 + 8 > 0$. This function has a minimum at $\lambda_{MIN} = \frac{11\beta-4}{8\beta}$ and $\Omega(\lambda_{MIN}) = \frac{15}{2}\left(2\gamma - 15\beta^2\right)$. Therefore, $\Omega(\lambda_{MIN}) > 0$ for $\gamma > \underline{\gamma}$ and thus $\Omega > 0$ is always observed, proving the last statement in Proposition 2.
As a consequence of the previous claim, the comparison $q_j^0 - q_j^{IC}$ determines the outcome that maximizes consumer welfare, where both $q_j^0 > q_j^{IC}$ (region I' in Fig. 2) and $q_j^0 \leqslant q_j^{IC}$ (region II' in Fig. 2) can be observed. To analyze how the aforementioned regions change with $t/(a-c)$, let us implicitly define the function λ_3^* by $\Phi(\beta, \lambda, \gamma, t/(a-c)) \equiv q_j^0(\beta, \lambda, \gamma, t/(a-c)) - q_j^{IC}(\beta, \lambda, \gamma) = 0$ where $\partial q_j^0(\beta, \lambda, \gamma, t/(a-c))/\partial t/(a-c) < 0$. Thus, λ_3^* falls as $t/(a-c)$ rises and the area where $q_j^0 > q_j^{IC}$ becomes larger (i.e., region I' in Fig. 2 expands), which proves Proposition 2(i) and (ii). ■