UNIVERSITAT ROVIRA I VIRGILI

INNOVATION, MARKET STRUCTURE, AND COOPERATIVE R&D STRATEGIES

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Innovation, Market Structure, and Cooperative R&D Strategies

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We STATE that the present study, entitled "Innovation, Market Structure, and Cooperative R&D Strategies", presented by Guiomar Ibáñez Zárate for the degree of Doctor of Philosophy in Economics, has been carried out under our supervision at the Department of Economics of this University, and that it fulfils the requirements to receive the International Doctorate Distinction.

Reus, April 22th, 2015.

The doctoral thesis supervisor | The doctoral thesis co-supervisor

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Introduction

It is widely recognized that innovation is a key issue for firms' competitiveness and countries economic growth. The European Union (EU) includes research and innovation as fundamental aspects of 'smart, sustainable and inclusive growth' in the Horizon 2020 strategy (European Commission, 2014), and the American Strategy for Innovation reckons that the America's future economic growth and international competitiveness depend on their capacity to innovate (White House, 2014). In this context, and given the growing competition environment, and innovation risks and costs, frequently, firms consider collaborative strategies to innovate. These collaborative strategies can take different forms, as research joint ventures (RJVs), vertical and horizontal mergers, acquisitions, among others. Nevertheless, these kind of agreements constitute a major concern for competition authorities, since cooperative behaviour may have undesirable repercussions on market competition and, therefore, on consumer welfare. Hence, my research interests are focused on industrial organization and economics of innovation, particularly in the analysis of cooperative innovation strategies and market structure.

The first chapter, entitled "Domestic and International Research Joint Ventures: The Effect of Collusion" (joint with Ricardo Flores-Fillol and Bernd Theilen),[1] analyses the effect of RJVs on consumer welfare in an international context, considering the threat that RJVs can be used to reach collusive agreements in the product market. The main novelty of our analysis is to study the differentiated effect of domestic and international RJVs, since this kind of agreements can be used as a subterfuge to sustain tacit collusion agreements in the product market, the effect of collusion may differ between domestic and international agreements. 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

[1] This chapter is published in *Economics Letters* 122 (2014), 79-83.

between domestic and international RJVs and, in certain cases, be more benevolent with international RJVs.

The second chapter, "Innovation and Horizontal Mergers in a Vertically Related Industry" analyses the effects of horizontal mergers on innovation and consumer welfare in a vertically related industry. Firms often argue that mergers and acquisitions (M&A) constitute leverage for innovation. However, M&A may reduce competition, especially horizontal mergers. Therefore, it is relevant to understand and assess the consequences of horizontal mergers for the innovative potential of firms. This paper analyses the effects of horizontal mergers on innovation and consumer welfare in a vertically related industry context, in which downstream firms compete for customers with a differentiated final good and can undertake R&D activities to reduce their unit costs. Upstream and downstream horizontal mergers can take place. The results suggest that competition authorities aiming to promote innovation and consumer welfare should treat upstream and downstream mergers differently, since horizontal mergers between upstream firms are detrimental to innovation and consumer welfare. By contrast, it is shown that downstream horizontal mergers can be both innovation and consumer welfare enhancing in sufficiently small markets. Thus, policy makers should evaluate the market characteristics under downstream integration.

Finally, in the third chapter, entitled "The Determinants of Partner Choice for Cooperative Innovation: The Effect of Competition", is analysed empirically the effect of competition intensity as a determinant of cooperative partner choice. To the best of our knowledge, this is the first attempt to study the relationship between research and development (R&D) cooperation and direct measures of competition intensity. Competition intensity is measured by the number of competitors in the firm's core market and the price elasticity reported by firms. Using information from German firms for 2011, our results show that competition intensity is a determinant for different types of collaborative innovation (e.g., with customers, suppliers, competitors, universities, or firms of the same group). Overall, the effect of competition is negative for cooperation with universities, customers and firms of the same group, and positive for cooperation with suppliers and competitors (and ambiguous for cooperation with consultants). Competition negatively affects partnerships with customers and universities, which look for radical innovation and involve high risks of disclosure. By contrast, competition positively influences partnerships with suppliers and competitors, which pursue incremental innovation and which involve a symmetric risk of information disclosure.

Contents

Chapter 1

Domestic and International Research Joint Ventures: The Effect of Collusion

Jointly written with Ricardo Flores-Fillol and Bernd Theilen. A shorter version of this chapter is published in the *Economics Letters 122 (2014), 79-83.*

This chapter benefited from valuable comments and suggestions from Nikolaos Georgantzís, Rafael Moner-Colonques, Jo Seldeslachts, and an anonymous referee. Discussions during the congresses *XXVII Jornadas de Economía Industrial* at Universidad de Murcia (Spain), and during our seminar at Universitat Rovira i Virgili in Reus (Spain) also helped to improve this chapter.

1.1 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]

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

[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.

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

[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.

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 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

[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.

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 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

[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).

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.

1.2 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.,

$$q_j = h_j + e_l = h_{1j} + h_{2j} + e_{1l} + e_{2l}, \qquad (1.2.1)$$

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

$$CT_{ij} = \left[c - x_{ij} - \beta x_{kj} - \lambda\beta \sum_{i=1,2} x_{il} \right] (h_{ij} + e_{ij}) + \gamma x_{ij}^2/2, \tag{1.2.2}$$

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 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.[8] Thus, the profits of a firm i located in country j are given by

$$\pi_{ij} = p_j h_{ij} + p_l e_{ij} - CT_{ij} - te_{ij}. \tag{1.2.3}$$

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. (1.2.3). The

[6] This threshold ensures compliance with second-order and stability conditions. These conditions are thoroughly analyzed in the Appendix 1.6.

[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.

[8] In this paper we assume internationalization costs to be entirely exogenous. Though, as pointed out by an anonymous referee, some of these costs could be endogenous such as some tariffs and other artificial trade barriers.

Cournot-Nash equilibrium values of this stage game (conditional on R&D decisions) are

$$h_{ij}^{02} = \frac{1}{5}\left[a - c + 2t - (1+\beta-3\lambda\beta)\sum_{i=1,2,j=A,B} x_{ij}\right] + (1-\beta\lambda)\,x_{ij} + (1-\lambda)\,\beta x_{kj} \tag{1.2.4}$$

and

$$e_{ij}^{02} = \frac{1}{5}\left[a - c - 3t - (1+\beta-3\lambda\beta)\sum_{i=1,2,j=A,B} x_{ij}\right] + (1-\beta\lambda)\,x_{ij} + (1-\lambda)\,\beta x_{kj}, \tag{1.2.5}$$

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. (1.2.1), 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. (1.2.3), we obtain the stage-1 profit function that firms maximize through their choices of R&D

$$\pi_{ij} = \left(h_{ij}^{02}\right)^2 + \left(e_{ij}^{02}\right)^2 - \gamma x_{ij}^2/2. \tag{1.2.6}$$

The SPNE total quantity is given by

$$q_j^0 = 10\gamma\frac{2\,(a-c)-t}{25\,(\gamma-1)+(2\beta+4\beta\lambda-3)^2}, \tag{1.2.7}$$

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.[9] With linear demand functions, this is tantamount to comparing quantities. As pointed out by d'Aspremont and Jacquemin (1988), the 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.[10]

1.3 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 R&D activities does not extend to the realm of production. Since

[9] In this paper, we do not include an equilibrium analysis to assess eventual conflicts between private and public interests. The reason is that, as pointed out by an anonymous referee, RJVs are also motivated by fixed-costs savings. Naturally, including fixed costs in the analysis would benefit RJV formation. Therefore, any equilibrium analysis would strongly depend on the size of these fixed costs. By contrast, consumer welfare is independent of fixed costs. However, we have performed an equilibrium analysis for the case where there are no fixed costs, which is the *least favorable* case for RJV formation. This analysis can be found in the Complementary Appendix 1.7.

[10] 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.* (2014), have also used this criterion.

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

$$\max_{x_{1j},x_{2j}} \sum_{i=1,2} \pi_{ij} = \sum_{i=1,2} \left[\left(h_{ij}^{02}\right)^2 + \left(e_{ij}^{02}\right)^2 - \gamma x_{ij}^2/2 \right], \tag{1.3.1}$$

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

$$\max_{x_{iA},x_{iB}} \sum_{j=A,B} \pi_{ij} = \sum_{j=A,B} \left[\left(h_{ij}^{02}\right)^2 + \left(e_{ij}^{02}\right)^2 - \gamma x_{ij}^2/2 \right]. \tag{1.3.2}$$

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,[11] which are

$$q_j^D = 10\gamma \frac{2(a-c)-t}{25\gamma - 12 - 4\beta\left[2(3+\lambda) + \beta(1+2\lambda)(3-4\lambda)\right]} \tag{1.3.3}$$

and

$$q_j^I = 10\gamma \frac{2(a-c)-t}{25\gamma - 12 - 4\beta\left[1 + 7\lambda - \beta(1+2\lambda)(2-\lambda)\right]}, \tag{1.3.4}$$

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. (1.2.7), (1.3.3), and (1.3.4), 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.

[11] 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. 1.1 below.

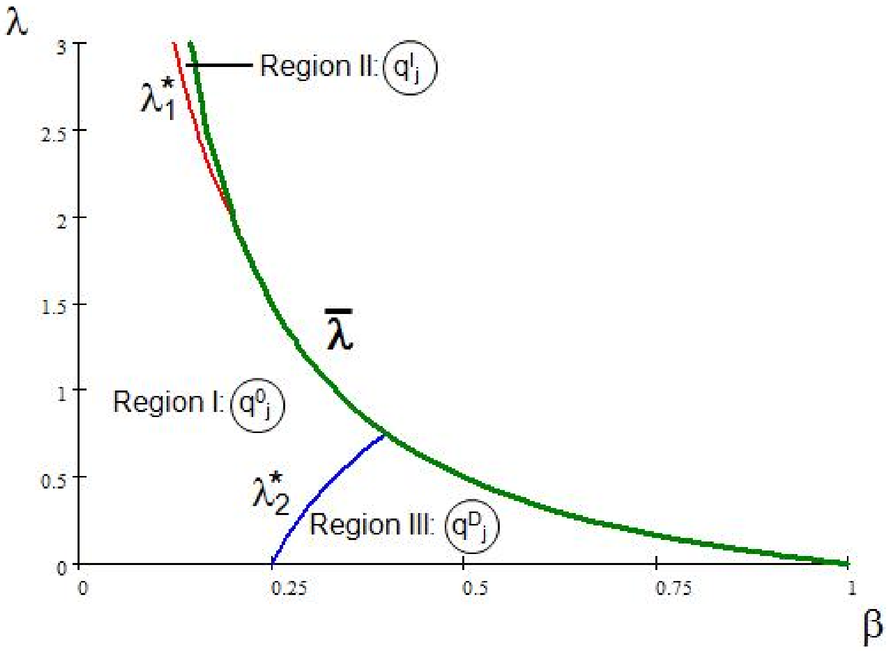

Fig.1.1. Socially preferred RJVs without collusion.

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. 1.1). Similarly, we find that the international RJVs are consumer welfare-enhancing when international spillovers are sufficiently high (which corresponds to moving to the north-east in Fig. 1.1). Moreover, a necessary condition for international RJVs to be more profitable than the domestic RJVs requires international spillovers to be larger than domestic ones ($\lambda > 1$ in Fig. 1.1). The policy implications of these findings are that each type of RJVs should be allowed when the corresponding spillovers are sufficiently large.[12]

[12] The comparison between the consumer welfare and the equilibrium analyses yields the following result (details can be found in the Complementary Appendix 1.7). We observe that (i) in Region II, international RJVs maximize the consumer welfare but firms prefer domestic RJVs, (ii) in Region I,

1.4 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.[13] In this case, we assume that partner firms share the market 50/50, so that the RJV behaves as a *merger of equals*.[14]

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

$$\max_{h_{ij},e_{ij}} \sum_{i=1,2} \pi_{ij} = \sum_{i=1,2} \left[p_j h_{ij} + p_l e_{ij} - CT_{ij} - te_{ij}\right], \tag{1.4.1}$$

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

$$\max_{h_{ij}} \sum_{j=A,B} \pi_{ij} = \sum_{j=A,B} \left[p_j h_{ij} - CT_{ij}\right]. \tag{1.4.2}$$

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

$$q_j^{DC} = 3\gamma \frac{2(a-c)-t}{9\gamma - 4 - 4\beta\left[2+\lambda+\beta(1+2\lambda)(1-\lambda)\right]} \tag{1.4.3}$$

no RJV maximizes the consumer welfare but firms prefer RJVs (international RJVs for $\lambda \geq 1$ and domestic RJVs for $\lambda \leq 1$) and, (iii) in Region III, domestic RJVs maximize the consumer welfare but firms prefer international RJVs. The reason for these conflicts to arise is the following. When domestic (international) RJVs are socially desirable, firms prefer international (domestic) RJVs because firms use RJVs as a device to internalize the externalities stemming from other firms' R&D. Therefore, when domestic (international) spillovers are large, domestic (international) RJVs are not observed in equilibrium because firms already benefit from the other firms' R&D.

[13] In a different setting, Martin (1995) studies the impact of RJVs on the stability of product-market collusion.

[14] 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.

and

$$q_j^{IC} = h_j^{IC} = 6\gamma \frac{(a-c)}{9\gamma - 4 - 2\beta\left[1 + 5\lambda - \beta\left(1 + 2\lambda\right)\left(1 - \lambda\right)\right]}, \tag{1.4.4}$$

where the superscripts DC and IC denote equilibrium values under domestic and international RJV in the presence of collusion, respectively.[15] 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. (1.4.4). From a pairwise comparison of Eqs. (1.2.7), (1.4.3), and (1.4.4), the following proposition arises.

Proposition 2 *Let $\underline{\gamma} \leqslant \gamma$, $0 \leqslant \lambda \leqslant \overline{\lambda}$, and $0 \leqslant t \leqslant \overline{t}$. 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.

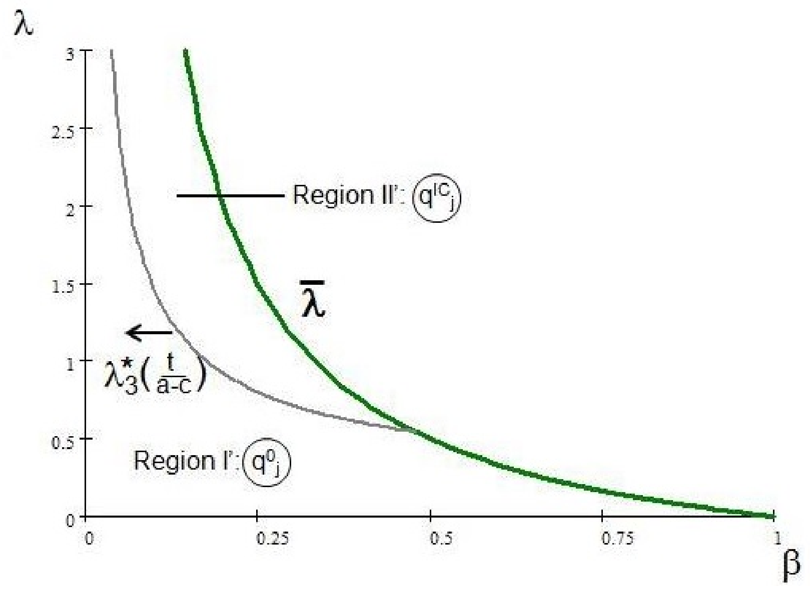

Fig. 1.2. Socially preferred RJVs with collusion.

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

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. 1.1 does not appear in Fig. 1.2. 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 $q_j^{IC} = h_j^{IC}$).[16] The higher the internationalization cost, the grater this *efficiency-gains effect* of collusion. As a consequence, region II' in Fig. 1.2 expands (shrinks) as t increases (decreases) and may become larger (smaller) than region II in Fig 1.1. When t is very low, region II' disappears from Fig. 1.2 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.[17]

1.5 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

[16] As a result, firms only absorb spillovers through their domestic production (see Eq. (1.2.2)).

[17] The equilibrium analysis yields the following result: a multiple equilibrium of the type {(Form, Form)^I, (No Form, No Form)} appears in Region II' and in the western part of Region I'; and the unique equilibrium in the eastern part of Region I is (Form, Form)^I (details in the Complementary Appendix: Equilibrium Analysis). From the comparison between the consumer welfare and the equilibrium analyses, we observe that (i) in Region II', there is no private–public conflict when the equilibrium is of the type (Form, Form)^I but there is a conflict when the equilibrium is (No form, No form) because consumer welfare is maximized under international RJVs, (ii) in the western part of Region I', there is no private–public conflict when the equilibrium is of the type (No Form, No Form) but there is a conflict when the equilibrium is (Form, Form)^I because consumer welfare is maximized in the absence of RJVs, and (iii) in the eastern part of Region I', there is a conflict because no RJVs maximize consumer welfare but firms prefer international RJVs. In conclusion, while both consumers and firms dislike domestic RJVs, international RJV formation is always an equilibrium because they are formed as a device to save internationalization costs.

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.[18] 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.

[18] 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).

1.6 Appendix

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.*

1.6.1 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. (1.2.6)) we obtain

$$\gamma > \gamma_1 \equiv \frac{4}{25} \left[4 - \beta \left(1 + 2\lambda\right)\right]^2 . \tag{1.6.1}$$

A sufficient condition for Eq. (1.6.1) 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

$$\gamma > \gamma_2 \equiv \frac{4}{25} \left[17 + \beta \left(17\beta - 16 - 12\lambda \left(1 + \beta\right) + 8\lambda^2 \beta\right)\right], \tag{1.6.2}$$

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

$$\gamma > \gamma_3 \equiv \max \left\{4 \left(\beta - 1\right)^2, \frac{4}{25} \left[\beta \left(4\lambda - 3\right) - 3\right]^2 \right\}. \tag{1.6.3}$$

A sufficient condition for Eqs. (1.6.2) and (1.6.3) 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 $\partial^2 (\pi_{iA} + \pi_{iB}) / \partial x_{iA}^2 < 0$ and $\partial^2 (\pi_{iA} + \pi_{iB}) / \partial x_{iB}^2 < 0$ (see Eq. (1.3.2)) we obtain

$$\gamma > \gamma_4 \equiv \frac{4}{25} \{17 + \beta [\beta (2 + \lambda (13\lambda - 2)) - 22\lambda - 6]\}, \tag{1.6.4}$$

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

$$\gamma > \gamma_5 \equiv \max \left\{ 4 (\lambda\beta - 1)^2, \frac{4}{25} [\beta (\lambda - 2) + 3]^2 \right\}. \tag{1.6.5}$$

A sufficient condition for Eqs. (1.6.4) and (1.6.5) to be true, is that $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_4 \equiv \gamma_4^\lambda = \frac{4}{25} \left(2\beta^2 - 6\beta + 17\right)$ and $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_5 \equiv \gamma_5^\lambda = \max \left\{4, \frac{1}{25} (7 - 5\beta)^2\right\} = 4$, 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 $\partial^2 (\pi_{1j} + \pi_{2j}) / \partial x_{1j}^2 < 0$ and $\partial^2 (\pi_{1j} + \pi_{2j}) / \partial x_{2j}^2 < 0$ we obtain

$$\gamma > \gamma_6 \equiv \frac{4}{9} [\beta (\lambda - 1) - 1]^2, \tag{1.6.6}$$

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

$$\gamma > \gamma_7 \equiv 2\gamma_6. \tag{1.6.7}$$

A sufficient condition for Eqs. (1.6.6) and (1.6.7) to be true, is that $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_6 \equiv \gamma_6^\lambda \equiv \frac{4}{9} (\beta + 1)^2$ and $\gamma > \max_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_7 \equiv \gamma_7^\lambda = 2\gamma_6^\lambda$, 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 $\partial^2 (\pi_{iA} + \pi_{iB}) / \partial x_{iA}^2 < 0$ and $\partial^2 (\pi_{iA} + \pi_{iB}) / \partial x_{iB}^2 < 0$ we obtain

$$\gamma > \gamma_8 \equiv \frac{1}{9} \left\{ 8 + 2\beta \left[\beta \left(1 + \lambda^2 \right) - 4 \right] \right\}, \tag{1.6.8}$$

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

$$\gamma > \gamma_9 \equiv \frac{2}{9} \left[\beta (\lambda - 1) + 2 \right]^2. \tag{1.6.9}$$

A sufficient condition for Eqs. (1.6.8) and (1.6.9) 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 $\gamma > \max\limits_{0 \leqslant \lambda \leqslant \overline{\lambda}} \gamma_9 \equiv \gamma_9^{\lambda} \equiv \frac{1}{18} (5 - 3\beta)^2$, 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:[19]

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

1.6.2 Stability conditions

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

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

[19] 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., $4 (\beta - 1)^2 < 4$.

The Jacobian of first derivatives is negative definite if

$$\begin{aligned} A &< 0, & (1.6.10)\\ (A-B)(A+B) &> 0, & (1.6.11)\\ 2BCD + A\left(A^2 - B^2 - C^2 - D^2\right) &< 0, & (1.6.12)\\ \left[(A+B)^2 - (C+D)^2\right]\left[(A-B)^2 - (C-D)^2\right] &> 0. & (1.6.13) \end{aligned}$$

The condition in Eq. (1.6.10) is already guaranteed by second-order conditions.

Claim 2 *Conditions in Eqs. (1.6.11)-(1.6.13) are satisfied iff*

$$\begin{aligned} A-B &< 0, & (1.6.14)\\ A+B &< 0, & (1.6.15)\\ (A+B)^2 - (C+D)^2 &> 0, & (1.6.16)\\ (A-B)^2 - (C-D)^2 &> 0. & (1.6.17) \end{aligned}$$

Proof. First, note that Eqs. (1.6.14) and (1.6.15) guarantee that Eq. (1.6.11) holds and Eqs. (1.6.16) and (1.6.17) guarantee that Eq. (1.6.13) holds. Finally, Eq. (1.6.12) can be rewritten as:

$$(A-B)^2\left(2A(A+B) - (C+D)^2\right) > (C-D)^2 (A-B)(A+B). \qquad (1.6.18)$$

Under Eq. (1.6.17), Eq. (1.6.18) holds iff

$$\begin{aligned} 2A(A+B) - (C+D)^2 &> (A-B)(A+B)\text{, or} & (1.6.19)\\ (A+B)^2 - (C+D)^2 &> 0, & (1.6.20) \end{aligned}$$

which is Eq. (1.6.16). ■

♦ *Base case (no RJVs)*

In this scenario

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

Thus, Eq. (1.6.17) holds directly and Eqs. (1.6.14)-(1.6.16) become

$$\gamma > \gamma_{10} \equiv \frac{4}{5}(1-\beta)[4-\beta(1+2\lambda)], \tag{1.6.21}$$

$$\gamma > \gamma_{11} \equiv \frac{4}{25}[4-\beta(1+2\lambda)][3+\beta(3-4\lambda)], \tag{1.6.22}$$

$$\gamma > \gamma_{12} \equiv \max\left\{\frac{4}{5}[4-\beta(1+2\lambda)](1+\beta-2\beta\lambda), \frac{4}{25}[4-\beta(1+2\lambda)](1+\beta+2\beta\lambda)\right\}. \tag{1.6.23}$$

A sufficient condition for Eqs. (1.6.21)-(1.6.23) to be true is that $\gamma > \max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{10} \equiv \gamma_{10}^{\lambda} \equiv \frac{4}{5}(4-\beta)(1-\beta)$, $\gamma > \max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{11} \equiv \gamma_{11}^{\lambda} = \frac{12}{25}(4-\beta)(1+\beta)$, and $\gamma > \max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{12} \equiv \gamma_{12}^{\lambda} = \max\left\{\frac{4}{5}(4-\beta)(1+\beta), \frac{24}{25}\right\} = \frac{4}{5}(4-\beta)(1+\beta)$, respectively.

♦ *Domestic RJVs without collusion at the production stage*

In this scenario

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

for $i = 1, 2$ and $j, l = A, B$. Thus, Eq. (1.6.17) holds directly and Eqs. (1.6.14)-(1.6.16) become

$$\begin{aligned} \gamma &> \gamma_{13} \equiv 4 (1 - \beta)^2, & (1.6.24) \\ \gamma &> \gamma_{14} \equiv \frac{4}{25} \left[3 + \beta (3 - 4\lambda) \right]^2, & (1.6.25) \\ \gamma &> \gamma_{15} \equiv \max \left\{ \frac{4}{5} \left[3 + \beta (3 - 4\lambda) \right] (1 + \beta - 2\beta\lambda), \right. \\ & \left. \frac{4}{25} \left[3 + \beta (3 - 4\lambda) \right] (1 + \beta + 2\beta\lambda) \right\}. & (1.6.26) \end{aligned}$$

A sufficient condition for Eqs. (1.6.24)-(1.6.26) to be true is that $\gamma > \max_{0 \leqslant \lambda \leqslant \bar{\lambda}} \gamma_{13} \equiv \gamma_{13}^{\lambda} \equiv 4 (1 - \beta)^2$, $\gamma > \max_{0 \leqslant \lambda \leqslant \bar{\lambda}} \gamma_{14} \equiv \gamma_{14}^{\lambda} = \frac{36}{25} (1 + \beta)^2$, and $\gamma > \max_{0 \leqslant \lambda \leqslant \bar{\lambda}} \gamma_{15} \equiv \gamma_{15}^{\lambda} = \max \left\{ \frac{12}{5} (1 + \beta)^2, \frac{1}{2} (1 + \beta)^2 \right\} = \frac{12}{5} (1 + \beta)^2$, respectively.

♦ *International RJVs without collusion at the production stage*

In this scenario

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

for $i,k=1,2$, $k\neq i$ and $j,l=A,B$, $l\neq j$. Thus, Eqs. (1.6.14)-(1.6.17) become

$$
\begin{aligned}
\gamma &> \gamma_{16}\equiv 4\left(1-\beta\lambda\right)^2, && (1.6.27)\\
\gamma &> \gamma_{17}\equiv \frac{4}{25}\left[3-\beta\left(2-\lambda\right)\right]^2, && (1.6.28)\\
\gamma &> \gamma_{18}\equiv \max\left\{\frac{4}{5}\left(1-\beta\right)\left[3-\beta\left(2-\lambda\right)\right],\frac{4}{25}\left[3-\beta\left(2-\lambda\right)\right]\left[1+\beta\left(1+2\lambda\right)\right]\right\}, && (1.6.29)\\
\gamma &> \gamma_{19}\equiv \max\left\{4\left(1-\beta\right)\left(1-\beta\lambda\right),4\left(1-\beta\lambda\right)\left[1+\beta\left(1-2\lambda\right)\right]\right\}. && (1.6.30)
\end{aligned}
$$

A sufficient condition for Eqs. (1.6.27)-(1.6.30) to be true is that $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{16}\equiv\gamma_{16}^{\lambda}\equiv 4$, $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{17}\equiv\gamma_{17}^{\lambda}=\frac{1}{25}\left(7-5\beta\right)^2$, $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{18}\equiv\gamma_{18}^{\lambda}=$
$\max\left\{\frac{2}{5}\left(7-5\beta\right)\left(1-\beta\right),\frac{4}{25}\left(7-5\beta\right)\right\}$,
and $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{19}\equiv\gamma_{19}^{\lambda}=\max\left\{4\left(1-\beta\right),4\left(1+\beta\right)\right\}=4\left(1+\beta\right)$, respectively.

♦ *Domestic RJVs with collusion at the production stage*

In this scenario

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

for $i=1,2$ and $j,l=A,B$. Thus, Eq. (1.6.17) holds directly and Eqs. (1.6.14)-(1.6.16) become

$$
\begin{aligned}
\gamma &> 0, && (1.6.31)\\
\gamma &> \gamma_{20}\equiv\frac{8}{9}\left[1+\beta\left(1-\lambda\right)\right]^2, && (1.6.32)\\
\gamma &> \gamma_{21}\equiv\max\left\{\frac{4}{9}\left[1+\beta\left(1-\lambda\right)\right]\left[1+\beta\left(1+2\lambda\right)\right],\right.\\
&\qquad\left.\left\{\frac{4}{3}\left[1+\beta\left(1-\lambda\right)\right]\left[1+\beta\left(1-2\lambda\right)\right]\right\}\right\}. && (1.6.33)
\end{aligned}
$$

Eq. (1.6.31) holds by construction. A sufficient condition for Eqs. (1.6.32) and (1.6.33) to be true is that $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{20}\equiv\gamma_{20}^{\lambda}\equiv\frac{8}{9}\left(1+\beta\right)^2$ and $\gamma>\max\limits_{0\leqslant\lambda\leqslant\overline{\lambda}}\gamma_{21}\equiv$

$\gamma_{21}^{\lambda} = \max\left\{\frac{1}{2}(1+\beta)^2, \frac{4}{3}(1+\beta)^2\right\} = \frac{4}{3}(1+\beta)^2$, 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. (1.6.14)-(1.6.17) become

$$\gamma > \gamma_{22} \equiv \frac{2}{9}\left[2-\beta(1+\lambda)\right]^2, \tag{1.6.34}$$

$$\gamma > \gamma_{23} \equiv \frac{2}{9}\left[2-\beta(1-\lambda)\right]^2, \tag{1.6.35}$$

$$\gamma > \gamma_{24} \equiv \max\left\{\frac{2}{3}(1-\beta)\left[2-\beta(1-\lambda)\right], \frac{2}{9}\left[2-\beta(1-\lambda)\right]\left[1+\beta(1+2\lambda)\right]\right\}, \tag{1.6.36}$$

$$\gamma > \gamma_{25} \equiv \max\left\{\frac{2}{3}(1-\beta)\left[2-\beta(1+\lambda)\right], \frac{2}{9}\left[2-\beta(1+\lambda)\right]\left[1+\beta(1-2\lambda)\right]\right\}. \tag{1.6.37}$$

A sufficient condition for Eqs. (1.6.34)-(1.6.37) 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:[20]

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

[20] 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 $\gamma_{25}^{\lambda} < 4/3$.

1.6.3 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. 1.1. Then $q_j^0 \geqslant q_j^I$ for $\lambda \leqslant \lambda_1^*$ (regions I and III in Fig. 1.1) and $q_j^0 > q_j^I$ for $\lambda > \lambda_1^*$ (region II in Fig. 1.1).

From $q_j^0 - q_j^D = 0$ we obtain $\lambda_2^* = \frac{1}{2\beta}(4\beta - 1)$, which is plotted in Fig. 1.1. Then $q_j^0 > q_j^D$ for $\lambda > \lambda_2^*$ (regions I and II in Fig. 1.1) and $q_j^0 \leqslant q_j^D$ for $\lambda \leqslant \lambda_2^*$ (region III in Fig. 1.1).

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.

In the base case, maximization of the stage-1 profit function (i.e., Eq. (3)) yields the following SPNE values

$$x_{ij}^0 = \frac{2(4-\beta-2\beta\lambda)(2(a-c)-t)}{25\gamma + 2(\beta+2\beta\lambda-4)(2\beta+4\beta\lambda+2)}, \tag{1.6.38}$$

$$h_{ij}^0 = \frac{5}{2}\gamma\frac{2(a-c)-t}{25\gamma+4(\beta+2\beta\lambda-4)(\beta+2\beta\lambda+1)} + \frac{t}{2}, \tag{1.6.39}$$

$$e_{ij}^0 = \frac{5}{2}\gamma\frac{2(a-c)-t}{25\gamma+4(\beta+2\beta\lambda-4)(\beta+2\beta\lambda+1)} - \frac{t}{2}, \tag{1.6.40}$$

$$q_j^0 = 10\gamma\frac{2(a-c)-t}{25(\gamma-1)+(2\beta+4\beta\lambda-3)^2}, \tag{1.6.41}$$

$$\pi_{ij}^0 = \left\{\left(\frac{25\gamma^2}{2} - \frac{\gamma(2(4-\beta-2\beta\lambda))^2}{2}\right)\left(\frac{2(a-c)-t}{25\gamma+4(\beta+2\beta\lambda-4)(\beta+2\beta\lambda+1)}\right)^2 + \frac{t^2}{2}\right\}. \tag{1.6.42}$$

In the case of a domestic RJV, maximization of the stage-1 profit function (i.e., Eq.

(8)) yields the following SPNE values

$$x_{ij}^{D} = \frac{2(3\beta - 4\beta\lambda + 3)(2(a-c)-t)}{25\gamma - 2(2\beta + 4\beta\lambda + 2)(3\beta - 4\beta\lambda + 3)}, \tag{1.6.43}$$

$$h_{ij}^{D} = \frac{5}{2}\gamma \frac{2a - 2c - t}{25\gamma - 2(2\beta + 4\beta\lambda + 2)(3\beta - 4\beta\lambda + 3)} + \frac{t}{2}, \tag{1.6.44}$$

$$e_{ij}^{D} = \frac{5}{2}\gamma \frac{2a - 2c - t}{25\gamma - 2(2\beta + 4\beta\lambda + 2)(3\beta - 4\beta\lambda + 3)} - \frac{t}{2}, \tag{1.6.45}$$

$$q_{j}^{D} = 10\gamma \frac{2(a-c)-t}{25\gamma - 12 - 4\beta(2(3+\lambda) + \beta(1+2\lambda)(3-4\lambda))}, \tag{1.6.46}$$

$$\pi_{ij}^{D} = \left(\frac{25\gamma^2}{2} - \frac{\gamma(2(3\beta - 4\beta\lambda + 3))^2}{2}\right)\left(\frac{2(a-c)-t}{25\gamma - 2(2\beta + 4\beta\lambda + 2)(3\beta - 4\beta\lambda + 3)}\right)^2 \\ .. + \frac{t^2}{2}. \tag{1.6.47}$$

In the case of an international RJV, maximization of the stage-1 profit function (i.e., Eq. (9)) yields the following SPNE values

$$x_{ij}^{I} = \frac{2(3 - 2\beta + \beta\lambda)(2(a-c)-t)}{25\gamma - 2(3 - 2\beta + \beta\lambda)(2\beta + 4\beta\lambda + 2)}, \tag{1.6.48}$$

$$h_{ij}^{I} = \frac{5}{2}\gamma \frac{2a - 2c - t}{25\gamma - 2(3 - 2\beta + \beta\lambda)(2\beta + 4\beta\lambda + 2)} + \frac{t}{2}, \tag{1.6.49}$$

$$e_{ij}^{I} = \frac{5}{2}\gamma \frac{2a - 2c - t}{25\gamma - 2(3 - 2\beta + \beta\lambda)(2\beta + 4\beta\lambda + 2)} - \frac{t}{2}, \tag{1.6.50}$$

$$q_{j}^{I} = 10\gamma \frac{2(a-c)-t}{25\gamma - 2(3 - 2\beta + \beta\lambda)(2\beta + 4\beta\lambda + 2)}, \tag{1.6.51}$$

$$\pi_{ij}^{I} = \left(\frac{25\gamma^2}{2} - \frac{\gamma(2(3 - 2\beta + \beta\lambda))^2}{2}\right)\left(\frac{2(a-c)-t}{25\gamma - 2(3 - 2\beta + \beta\lambda)(2\beta + 4\beta\lambda + 2)}\right)^2 \\ + \frac{t^2}{2}. \tag{1.6.52}$$

A comparison between Eqs. (1.6.38)-(1.6.42) and Eqs. (1.6.43)-(1.6.47) yields directly $q_j^0 > q_j^D$, $h_{ij}^0 > h_{ij}^D$, $e_{ij}^0 > e_{ij}^D$, $x_{ij}^0 > x_{ij}^D$, $\pi_{ij}^0 < \pi_{ij}^D$ for $\lambda > \frac{4\beta-1}{2\beta} \equiv \lambda_2^*$; and $q_j^0 \leq q_j^D$, $h_{ij}^0 \leq h_{ij}^D$, $e_{ij}^0 \leq e_{ij}^D$, $x_{ij}^0 \leq x_{ij}^D$, $\pi_{ij}^0 \geq \pi_{ij}^D$ for $\lambda \leq \lambda_2^*$.
A comparison between Eqs. (1.6.38)-(1.6.42) and Eqs. (1.6.48)-(1.6.52) yields directly $q_j^0 > q_j^I$, $h_{ij}^0 > h_{ij}^I$, $e_{ij}^0 > e_{ij}^I$, $x_{ij}^0 > x_{ij}^I$, $\pi_{ij}^0 < \pi_{ij}^I$ for $\lambda < \frac{1+\beta}{3\beta} \equiv \lambda_1^*$; and $q_j^0 \leq q_j^I$, $h_{ij}^0 \leq h_{ij}^I$, $e_{ij}^0 \leq e_{ij}^I$, $x_{ij}^0 \leq x_{ij}^I$, $\pi_{ij}^0 \geq \pi_{ij}^I$ for $\lambda \geq \lambda_1^*$.
Finally, a comparison between Eqs. (1.6.43)-(1.6.47) and Eqs. (1.6.48)-(1.6.52) yields

directly $q_j^D > q_j^I$, $h_{ij}^D > h_{ij}^I$, $e_{ij}^D > e_{ij}^I$, $x_{ij}^D > x_{ij}^I$, $\pi_{ij}^D < \pi_{ij}^I$ for $\lambda < 1$; and $q_j^D \leq q_j^I$, $h_{ij}^D \leq h_{ij}^I$, $e_{ij}^D \leq e_{ij}^I$, $x_{ij}^D \leq x_{ij}^I$, $\pi_{ij}^D \geq \pi_{ij}^I$ for $\lambda \geq 1$.
As a consequence, regarding the comparison of quantities in Fig. 1.1, we have $q_j^0 > q_j^I$ 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. Regarding the comparison of profits, we have: $\pi_{ij}^D > \pi_{ij}^I > \pi_{ij}^0$ in region I (in Fig. 1.1) for $\lambda > 1$; $\pi_{ij}^I > \pi_{ij}^D > \pi_{ij}^0$ in region I for $\lambda < 1$; $\pi_{ij}^D > \pi_{ij}^0 > \pi_{ij}^I$ in region II; and $\pi_{ij}^I > \pi_{ij}^0 > \pi_{ij}^D$ in region III. These results will be used in the Complementary Appendix 1.7. ■

1.6.4 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. 1.2) and $q_j^0 \leqslant q_j^{IC}$ (region II' in Fig. 1.2) 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. 1.2 expands), which proves Proposition 2(i) and (ii). ■

1.7 Complementary Appendix: Equilibrium Analysis

In this appendix, we perform an equilibrium analysis. The purpose of this analysis is twofold. On the one hand, it justifies the symmetric cases considered in the consumer welfare analysis (where either two domestic or two international RJVs are formed) since no asymmetric outcomes occur in equilibrium (i.e., where only one RJV is formed). On the other hand, it allows us to compare private and social interests and to derive some policy implications out of this comparison. The complexity of the analysis requires to include some simplifying assumptions to get conclusive results. More precisely, the exercise is performed for the parameter values considered in Fig. 1.2, i.e., $\gamma = 10$ and $\frac{t}{(a-c)} = \frac{4}{11}$, to make easier the comparison between private and social incentives. Although the analysis is not exhaustive, it is appropriate for a moderate range of these parameter values and reveals some interesting insights. In addition, changes in γ and t affect simultaneously both the private and the social profitability of RJVs.[21]

1.7.1 RJVs without collusion at the production stage

First, we consider two games in which two-partner RJVs can be formed. In the *domestic game*, the (two) domestic firms in each of the (two) countries decide whether or not to form a RJV. In the *international game*, there are two couples of international partners that decide whether or not to form a RJV. These games can be represented in normal form (where players, strategies, and payoffs are displayed) in the following way,

Domestic game

	Form	No form
Form	(π^D, π^D)	(π^{DN}, π^{ND})
No form	(π^{ND}, π^{DN})	(π^0, π^0)

International game

	Form	No form
Form	(π^I, π^I)	(π^{IN}, π^{NI})
No form	(π^{NI}, π^{IN})	(π^0, π^0)

[21] An increase in γ makes R&D more costly and discourages RJVs. An increase in t makes international RJVs with collusion more profitable (both privately and socially).

where firm-market subscripts are omitted such that π^D refers to π^D_{ij}, etc. After computing the equilibrium of these two games,[22] we need to consider them jointly to obtain the final equilibrium outcome, given that domestic and international RJVs cannot occur simultaneously in our setting.

♦ *Domestic game*

The unilateral incentive to form a domestic RJV is derived from studying the best-reply of domestic firms given that the firms located in the other country do not form a RJV, i.e., computing $\pi^{DN} - \pi^0$. This exercise yields three areas depending on the sign of the difference, as depicted below.

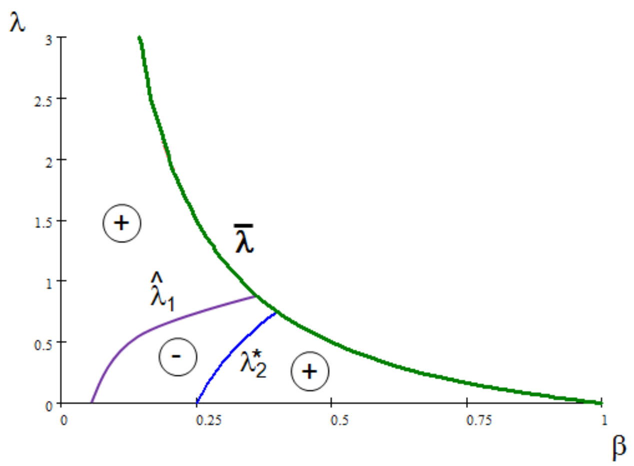

Fig. 1.$A1$: $\pi^{DN} - \pi^0$

The function λ_2^* is the same as in Fig. 1.1 and $\widehat{\lambda}_1$ is another threshold value.[23]

[22] The precise values these profit expressions are complex and are available from the authors on request.

[23] The precise value of $\widehat{\lambda}_1$ is complex and is available from the authors on request.

The best-reply of domestic firms given that the firms located in the other country form a RJV is obtained from the difference $\pi^D - \pi^{ND}$ and also yields three areas depending on the sign of the difference in the way displayed below.

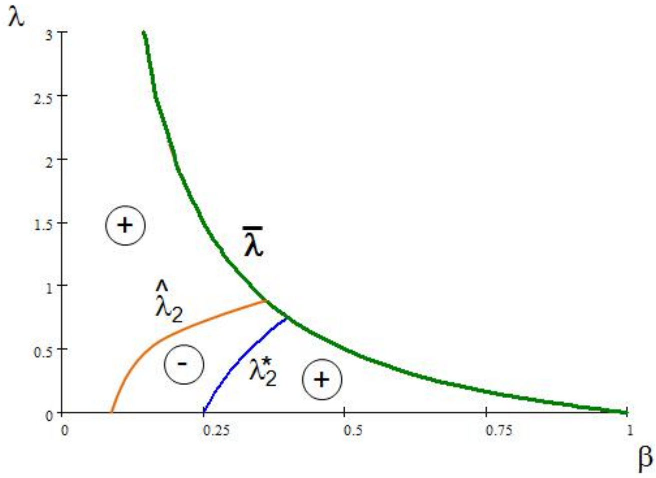

Fig. 1.$A2$: $\pi^D - \pi^{ND}$

The function λ_2^* is the same as in Fig. 1.1 and $\widehat{\lambda}_2$ is another threshold value.[24]

[24]The precise value of $\widehat{\lambda}_2$ is complex and is available from the authors on request.

Finally, the equilibrium arises from the joint analysis of Figs. 1.$A$1 and 1.$A$2, which is shown in the figure below.

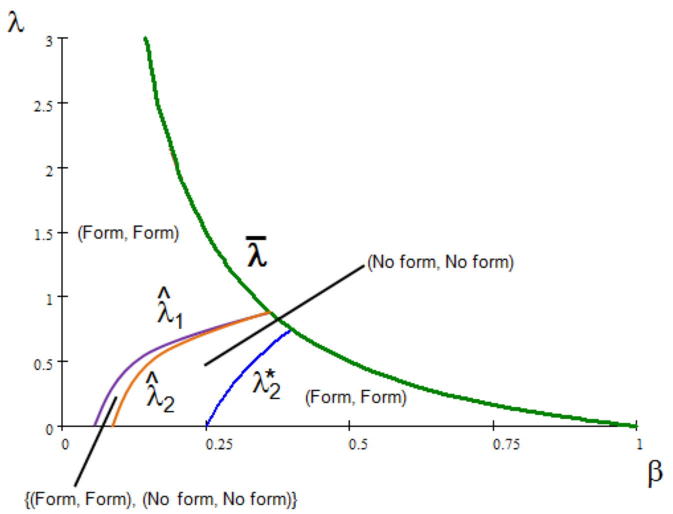

Fig. 1.$A$3: Equilibrium – domestic game without collusion.

The equilibrium always involves forming a domestic RJV, except for the central region delimited by functions λ_2^* and $\widehat{\lambda}_1$. More precisely, a multiple equilibrium arises in the region comprised between $\widehat{\lambda}_2$ and $\widehat{\lambda}_1$.

♦ *International game*

The unilateral incentive to form an international RJV is derived from studying the best-reply of two international partners given that the other firms do not form a RJV, i.e., computing $\pi^{IN} - \pi^0$. This exercise yields three areas depending on the sign of the difference, as depicted below.

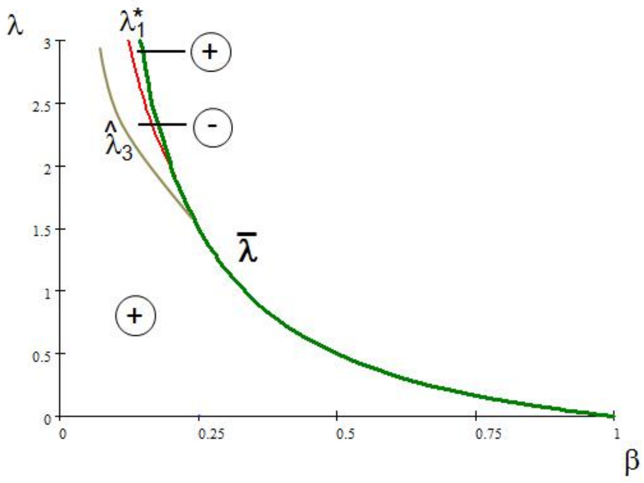

Fig. 1.$A4$: $\pi^{IN} - \pi^0$

The function λ_1^* is the same as in Fig. 1.1 and $\widehat{\lambda}_3$ is another threshold value.[25]

[25] The precise value of $\widehat{\lambda}_3$ is complex and is available from the authors on request.

The best-reply of two international partners given that the other firms form a RJV is obtained from the difference $\pi^I - \pi^{NI}$ and also yields three areas depending on the sign of the difference in the way displayed below.

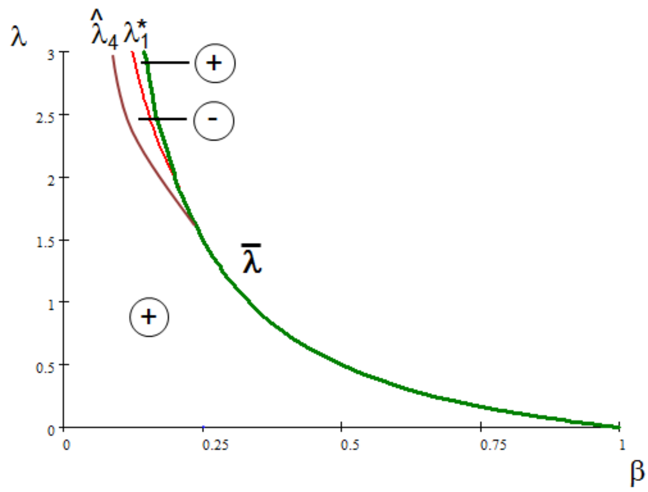

Fig. 1.$A5$: $\pi^I - \pi^{NI}$

The function λ_1^* is the same as in Fig. 1.1 and $\widehat{\lambda}_4$ is another threshold value.[26]

[26]The precise value of $\widehat{\lambda}_4$ is complex and is available from the authors on request.

Finally, the equilibrium arises from the joint analysis of Figs. 1.$A4$ and 1.$A5$, which is shown in the figure below.

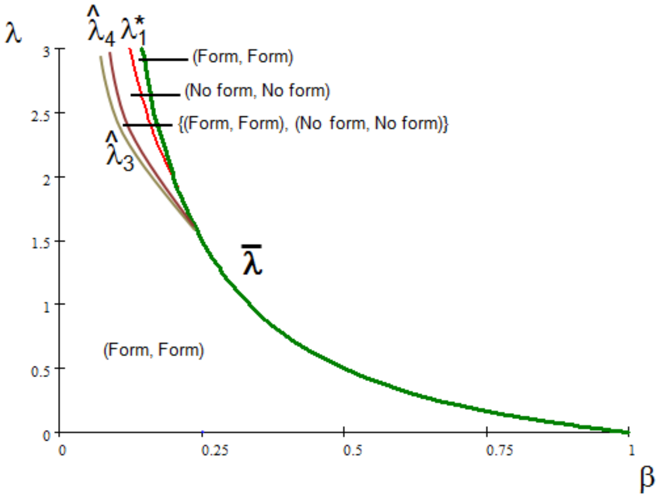

Fig. 1.$A6$: Equilibrium − international game without collusion.

The equilibrium always involves forming an international RJV, except for the central region delimited by functions $\widehat{\lambda}_3$ and λ_1^*. More precisely, a multiple equilibrium arises in the region comprised between $\widehat{\lambda}_3$ and $\widehat{\lambda}_4$.

♦ *Conclusion*

To be able to provide an accurate equilibrium prediction, we need to consider simultaneously the domestic and the international games, i.e., Figs. 1.$A3$ and 1.$A6$.

First, we need to compare (i) π^D and π^0 in the region $\lambda \in \left(\widehat{\lambda}_3, \lambda_1^*\right)$ because (Form, Form) is the equilibrium in the domestic game whereas (No form, No form) can be the equilibrium in the international game, and (ii) π^I and π^0 in the region $\lambda \in \left(\lambda_2^*, \widehat{\lambda}_1\right)$ because (No form, No form) can be the equilibrium in the domestic game whereas (Form, Form) is the equilibrium in the international game. From Complementary Appendix, we know that $\pi^D > \pi^0$ for $\lambda > \lambda_2^*$ and that $\pi^I > \pi^0$ for $\lambda < \lambda_1^*$. Therefore, in both cases (Form, Form) is the final equilibrium.

Second, we will assume that firms will form the *best* RJV in cases when both the domestic and the international can arise as an equilibrium outcome. Therefore, we need to compare π^I and π^D. From Complementary Appendix, we know that $\pi^I > \pi^D$ for $\lambda < 1$.

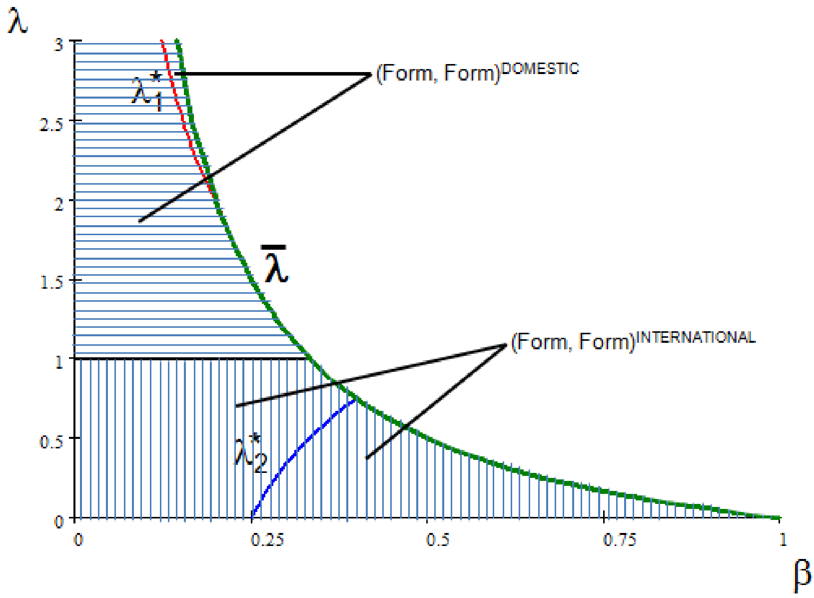

Fig. 1.$A7$: Equilibrium – domestic and international game without collusion.

Thus, in the absence of collusion, firms always engage in RJVs and the bound $\lambda \lessgtr 1$ determines the type of agreement. On the one hand, when international spillovers are small (i.e., $\lambda < 1$) firms use international RJVs to *internalize* the externalities stemming from cross-border cooperation agreements. On the other hand, when international spillovers are large (i.e., $\lambda > 1$), firms do not need cross-border agreements to benefit from foreign R&D and therefore they prefer domestic agreements. Comparing Figs. 1.1 and 1.$A7$, we observe that (i) in the northern region (i.e., above λ_1^*), international RJVs maximize consumer welfare but firms prefer domestic RJVs, (ii) in the upper central region (i.e., $\lambda \in (1, \lambda_1^*)$), no RJV maximizes consumer welfare but firms prefer domestic RJVs, (iii) in the lower central region (i.e., $\lambda \in (\max . \{0, \lambda_2^*\}, 1)$), no RJV maximizes consumer welfare but firms prefer international RJVs, and (iv) in the eastern region (i.e., on the right of λ_2^*), domestic RJVs maximize consumer welfare but firms prefer international RJVs. Therefore, there is an important conflict between private and public incentives: although domestic (international) RJVs are socially desirable when domestic (international) spillovers are large, they are not observed in equilibrium because firms already benefit from the other firms' R&D.

1.7.2 RJVs with collusion at the production stage

In this subsection, we replicate the previous analysis now in the presence of collusion at the production stage. Players and strategies are the same as before, but profits change due to the presence of collusion. Thus, the *domestic* and *international games* are represented in normal form in the following way, where subscript C denotes collusion.

Domestic game	Form	No form
Form	(π_C^D, π_C^D)	(π_C^{DN}, π_C^{ND})
No form	(π_C^{ND}, π_C^{DN})	(π_C^0, π_C^0)

International game	Form	No form
Form	(π_C^I, π_C^I)	(π_C^{IN}, π_C^{NI})
No form	(π_C^{NI}, π_C^{IN})	(π_C^0, π_C^0)

♦ *Domestic game*

The unilateral incentive to form a domestic RJV is derived from studying the best-reply of domestic firms given that the firms located in the other country do not form a RJV, i.e., computing $\pi_C^{DN} - \pi_C^0$. This difference is always negative for $0 \leqslant \lambda \leqslant \overline{\lambda} \equiv (1-\beta)/2\beta$.[27]

The best-reply of domestic firms given that the firms located in the other country form a RJV is obtained from the difference $\pi_C^D - \pi_C^{ND}$, which is also negative in our relevant region for any combination of β and λ.

As a consequence, No form is a dominant strategy and the equilibrium of the domestic game is always (No form, No form).

♦ *International game*

The unilateral incentive to form an international RJV is derived from studying the best-reply of two international partners given that the other firms do not form a

[27] The precise details on the computations are available from the authors on request.

RJV, i.e., computing $\pi_C^{IN} - \pi_C^0$. This exercise yields two areas depending on the sign of the difference, as depicted below,

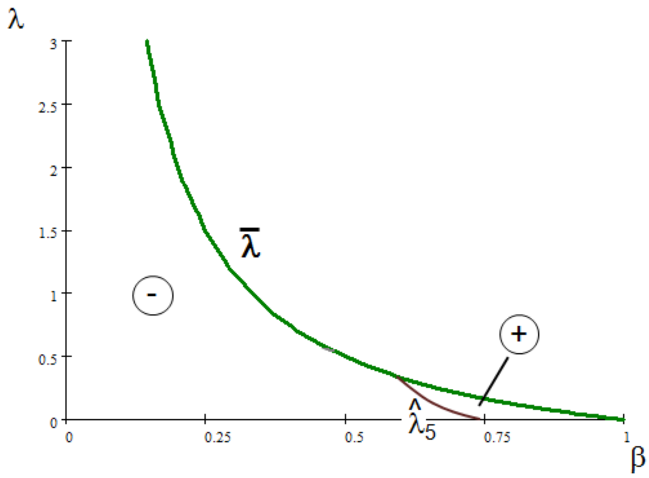

Fig. 1.$A8$: $\pi_C^{IN} - \pi_C^0$

where the function $\widehat{\lambda}_5$ is another threshold value.[28]

The best-reply of two international partners given that the other firms form a RJV is obtained from the difference $\pi_C^I - \pi_C^{NI}$, which is always positive in our relevant region for any combination of β and λ.

[28]The precise value of $\widehat{\lambda}_5$ is complex and is available from the authors on request.

As a consequence, the equilibrium is as shown in the figure below.

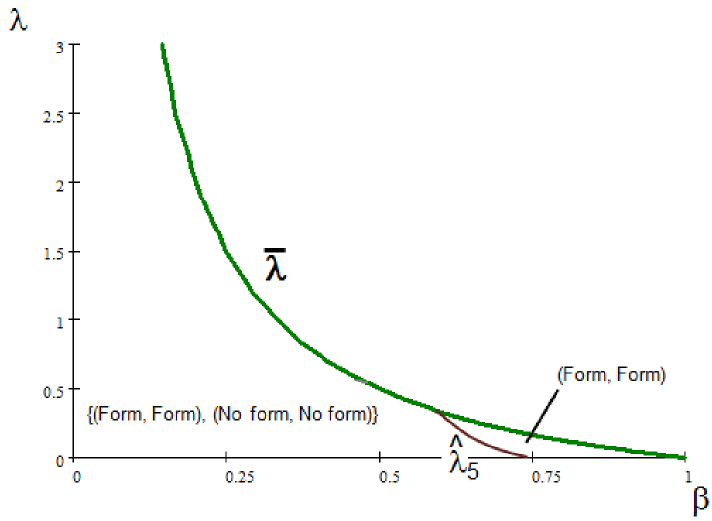

Fig. 1.$A$9: Equilibrium – international game with collusion.

The equilibrium always involves forming an international RJV, but (No form, No form) is also an equilibrium in the western region of Fig. 1.$A$9.

♦ *Conclusion*

The simultaneous consideration of the domestic and the international games is straightforward given that No form is a dominant strategy in the domestic game. Thus, the equilibrium is plotted in Fig. 1.$A$10 below, where λ_3^* (which appears in Fig. 1.2) has been included to better compare firms and consumers' interests.

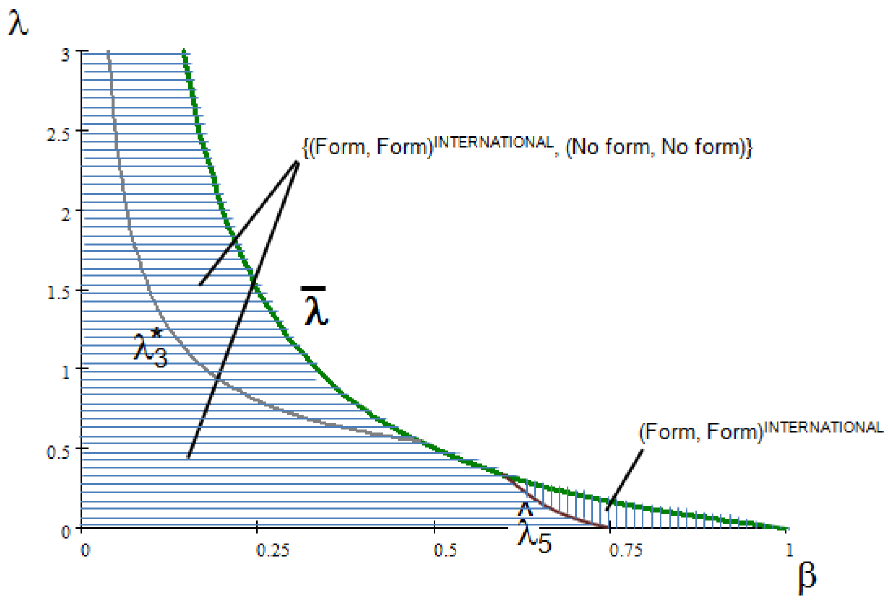

Fig. 1.$A$10: Equilibrium – domestic and international game with collusion.

Thus, in the presence of collusion, firms never engage in domestic RJVs and may always engage in international RJVs, although staying alone may also be an equilibrium for sufficiently low values of β. Comparing Figs. 1.2 and $A$10, we observe that (i) in the northern region (i.e., above λ_3^*), there is no private-public conflict when the equilibrium is of the type (Form, Form)$^{\text{INTERNATIONAL}}$ but there is a conflict when the equilibrium is (No form, No form) because consumer welfare is maximized under international RJVs, (ii) in the central region (below λ_3^* and on the left of $\widehat{\lambda}_5$), there is no private-public conflict when the equilibrium is of the type (No Form, No Form) but there is a conflict when the equilibrium is (Form, Form)$^{\text{INTERNATIONAL}}$ because consumer welfare is maximized in the absence of RJVs, and (iii) in the eastern region (i.e., on the right of $\widehat{\lambda}_5$), there is again a conflict because no RJVs maximize consumer welfare but firms prefer international RJVs. In conclusion, while both consumers and firms dislike domestic RJVs, international RJV formation is always an equilibrium because they are formed as a device to save internationalization costs. ■

Chapter 2

Innovation and Horizontal Mergers in a Vertically Related Industry

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2.1 Introduction

It is widely recognized that innovation is a key issue for competitiveness and economic growth. For example, the EU includes research and innovation as fundamental aspects of 'smart, sustainable and inclusive growth' in the Horizon 2020 strategy (European Commission, 2014), and the American Strategy for Innovation reckons that 'America's future economic growth and international competitiveness depend on our capacity to innovate' (White House, 2014). In this context, firms often argue that mergers and acquisitions (M&As) constitute leverage for innovation. However, it is well known that M&As may have many undesirable repercussions. Particularly, horizontal mergers reduce competition and constitute a major concern for competition authorities (Röller et al., 2000). Therefore, it is especially relevant to understand and assess the consequences of M&As for the innovative potential of firms.

The European Commission in its Guidelines on the Assessment of Horizontal Mergers (2004) includes the evaluation of R&D and innovation effects. Similarly, the US Department of Justice and the Federal Trade Commission consider innovation effects in their Horizontal Merger Guidelines (2010).[1] In practice, however, innovation effects in horizontal mergers are difficult to assess due to their intrinsic uncertainty (Shapiro, 2010). Consequently, the European Commission only takes them into account when claimed by the parties involved in a merger. Until now, innovation-related potential advantages have not been decisive in the prohibition or allowance of horizontal mergers (Veugelers, 2012). In the US, R&D and innovation effects also play a modest role in merger evaluation decisions. However, the US Antitrust Modernization Commission has recommended giving greater weight to R&D efficiencies (Katz and Shelanski, 2007).

The difficulty in evaluating the effects of mergers on innovation might also come from the lack of consensus in the literature results. Since an empirical point of view, Cassiman et al. (2005) find that mergers increase innovation in the case of technologically complementary M&As. While, Cloodt et al. (2006) and Colombo and Rabbiosi (2014) find a negative effect on innovative performance. Cloodt et al. (2006) consider technological and non-technological M&As and their effects on the long run, and Colombo and Rabbiosi (2014) analyse horizontal acquisitions among firms with technological similarity. Nevertheless, nowadays, there is no theoretical analysis of the direct impact of horizontal mergers on R&D in the literature. Instead, the relationship between mergers and R&D has been evaluated indirectly as, on the one hand, the effect of mergers on competition and, on the other hand, the impact of competition on innovation, which are rather well understood (Veugelers, 2012). However, as the models in these literatures use different frameworks, it is not clear to which extend their results can be applied to a different context in which innovation and merger decisions are taken simultaneously. On this ground, this paper

[1]The most recent updated version of the Horizontal Merger Guidelines (2010), Section 6.4., includes an analysis of innovation and product variety as entirely new aspects to be evaluated.

studies the consequences of downstream and upstream mergers for firms' innovation decisions inside an integrated theoretical framework.

We model a vertically related industry with an upstream and a downstream duopoly.[2] Upstream firms supply a homogeneous input to downstream firms, which produce a differentiated final good. In our setting, a downstream firm can reduce its unit cost by undertaking process innovation,[3] stemming from its R&D effort and the spillovers derived from the other firm's R&D. The innovation decision is reflected by a binary variable, which represents whether a downstream firm engages in R&D activities or not. The R&D efforts are costly and reduce the downstream profits. We consider three different market structures: *i*) the Base Case without mergers, *ii*) Upstream Integration, and *iii*) Downstream Integration.

The main findings of the paper are as follows. First, both downstream and upstream mergers affect downstream firms' innovation decisions. Second, concerning total innovation effort it is shown that Upstream Integration has a negative impact on innovation, while Downstream Integration has a positive effect. Third, regarding consumer welfare, it is shown that, for a given innovation strategy across scenarios, it is maximized in the absence of mergers. In addition, we confirm that upstream mergers are detrimental to consumer welfare. By contrast, and most interestingly, downstream mergers can be consumer welfare enhancing when the markets are sufficiently small.

The paper is organized as follows. The literature review is presented in Section 2. In Section 3, we present the three scenarios considered: the Base Case (Subsection 3.1), Upstream Integration (Subsection 3.2), and Downstream Integration (Subsection 3.3). Section 4 studies the implications of horizontal mergers for consumer welfare. Finally, Section 5 presents some policy implications and closes the paper. The positivity, second-order and stability conditions and all the proofs are provided in the Appendix.

[2] According to Banerjee and Lin (2003), much corporate R&D is conducted in a supplier-customer context.

[3] Von Hippel (1988) finds that more than two-thirds of first-to-market innovations are dominated by end-users. Retailers engage in direct interactions with end customers, unlike most manufacturers, which let them capture their changing needs and offer innovative products and services (Sorescu et al., 2011).

2.2 Literature Review

The literature has still not provided a theoretical framework for the analysis of the direct effects of mergers on innovation.[4] Nevertheless, some authors have provided empirical evidence with different results. Cassiman et al. (2005) find a positive effect of M&As on innovation when firms are technologically complementary and do not compete in the same market. Cloodt et al. (2006) analyse technological and non-technological M&As', finding that, in the long run, there is a negative effect on the post-M&As' innovative performance of acquiring firms. Colombo and Rabbiosi (2014) find that horizontal acquisitions among firms with technological similarity, negatively affect post-acquisition innovation performance. Even though, the impact on consumer welfare remains unclear. Thus, the aim of this paper is to provide such a theoretical framework to study the consequences of upstream and downstream horizontal mergers for firms' innovation decisions and consumer welfare. To do so, we connect two strands of the literature. On the one hand, we rely on the literature on vertical relations and innovation and, on the other hand, on the literature that analyses downstream and upstream horizontal mergers in a vertically related industry.

Regarding the literature on vertical relations and innovation, Banerjee and Lin (2003) study innovation in the presence of vertical relations. The authors present a theoretical model in which a monopoly upstream firm supplies an intermediate good to several downstream firms. The downstream firms can reduce their marginal unit cost by undertaking R&D activities. As a result, the upstream monopoly increases the input price, affecting the downstream firms' incentive to innovate. Fixed-price contracts between upstream and downstream firms can be a means of controlling the downstream production costs and stimulating innovation at this level.

Regarding the branch of the literature analysing horizontal mergers in a vertically-related industry and focusing on downstream mergers, von Ungern-Sternberg (1996) finds that they lead to a reduction in the final price when retailers act as price takers. In the same vein, Dobson and Waterson (1997) obtain a similar result when retail services are regarded as very close substitutes. From a different perspective, Lommerud

[4]Cassiman et al. (2005) present an extensive literature review on financial economics, industrial organization, and strategic and technology management, which gives many indirect insights into the relationship between M&As and R&D.

et al. (2005) and Faulí-Oller and Sandonis (2010) analyse the merger consequences for input prices. Lommerud et al. (2005) find that potential merger partners at the downstream level should take into account the presence of market power at the upstream level. Faulí-Oller and Sandonis (2010) show that downstream mergers lead to lower wholesale prices, which translate into lower final prices when there are two sufficiently differentiated suppliers in terms of efficiency. Finally, Symeonidis (2010) finds that downstream mergers may raise the consumer surplus and overall welfare when there is quantity competition, upstream agents are independent, and bargaining is over a uniform input price.[5]

Considering upstream mergers, Milliou and Petrakis (2007) show that upstream firms prefer to merge (not to merge) under wholesale-price contracts (two-part tariff contracts). They conclude that upstream horizontal mergers should not be allowed, although they can generate some efficiency gains.

A couple of papers study mergers both at the upstream and at the downstream level. First, Ziss (1995) shows that upstream mergers are typically anti-competitive under very general demand and cost conditions, whereas downstream mergers are pro-competitive both in the presence and in the absence of intra-brand competition, and for both price and output competition at the downstream level. Second, Horn and Wolinsky (1988) demonstrate that merger incentives are present when the downstream firms compete in the final goods' market.

2.3 The Model

Consider an industry with two upstream and two downstream firms denoted by U_i and D_i, with $i = 1, 2$, respectively. Each upstream firm produces a homogenous input which is transformed by downstream firms into a final good in a one-to-one proportion. An exclusive upstream-downstream relationship is assumed, such that D_i purchases its input only from U_i.

The downstream demand functions are derived from the maximization of the

[5]The opposite result is obtained when there is price competition, the upstream agents are not independent, the bargaining is over a two-part tariff, or the bargaining covers both the input price and the level of output.

welfare function of a representative consumer (as in Bowley, 1924)

$$U = u(M) + aq_i + aq_j - \frac{1}{2}\left[\left(q_i^2 + q_j^2\right) + 2dq_iq_j\right], \quad i, j = 1, 2, \quad i \neq j,$$

subject to the budget constraint

$$Y = M + p_iq_i + p_jq_j,$$

where q_i is the quantity and p_i is the price of good i, M is the quantity of other goods consumed, Y denotes income, parameter $d \in (0, 1)$ measures the degree of product differentiation,[6] and $a > 0$. The resulting downstream demand function is

$$q_i = \frac{a}{1+d} - \frac{1}{1-d^2}p_i + \frac{d}{1-d^2}p_j. \tag{2.3.1}$$

When the products are independent (i.e., $d = 0$), D_i is a monopolist in its market. As the products become closer substitutes (i.e., as d increases), the competition intensity in the downstream market increases.

The profits of D_i are given by

$$\pi_{Di}(x_i, x_j) = (p_i - p_{wi} - c_i)\, q_i - \epsilon x_i, \tag{2.3.2}$$

where p_{wi} is the wholesale price that D_i pays per unit of input to U_i, and $c_i = c - \gamma x_i - \sigma\gamma x_j$ is D_i's cost function. The unit production cost c is reduced by γx_i, where $x_i \in \{0, 1\}$ is a binary variable that denotes the firm's own R&D effort with $\gamma \in [0, 1]$ and $\sigma\gamma x_j$ stands for the spillovers stemming from the competitor's innovation effort x_j with $\sigma \in [0, 1]$ being the spillover intensity parameter.[7] Finally, ϵ is the unit cost of innovation with $\epsilon > 0$. We assume that $c \geq \gamma(1 + \sigma)$, such that $c_i \geq 0$.

[6] The unilateral effects, the role of price/cost margins, and market definition are three related issues that become relevant when a merge proposal is investigated in markets with differentiated products (Shapiro, 2010). The level of product differentiation is relevant when a merger proposal is evaluated. In the 2010 Horizontal Merger Guidelines (US Department of Justice and the Federal Trade Commission, 2010), Sections 6.1 and 6.2 address the pricing and bidding competition among suppliers of differentiated products.

[7] In some related literature, the intensity of spillovers is associated with the protection of the intellectual property. High (low) values of spillovers mean that there is weak (strict) protection of intellectual property.

The profits of U_i are given by

$$\pi_{Ui} = (p_{wi} - c_U)\, q_{U_i}, \tag{2.3.3}$$

where c_U is the upstream unit cost and $q_{U_i} = q_i$ because inputs are transformed into outputs in a one-to-one proportion.

The timing of the game is as follows. In Stage 1, the downstream firms decide whether to innovate or not by choosing strategy $x_i \in \{1, 0\}$, where $x_i = 1$ indicates that D_i innovates, and $x_i = 0$ that D_i does not innovate. In Stage 2, the upstream firms maximise equation (2.3.3) by choosing their wholesale prices p_{wi}. Finally, in Stage 3, the downstream firms choose simultaneously and independently p_i to maximise equation (2.3.2). The game is solved by backward induction.

2.3.1 The Base Case

In the absence of mergers, the Stage-3 profit maximization yields the following reaction function

$$p_i = \frac{1}{2}\left[(1-d)\,a + c_i + dp_j + p_{wi}\right]. \tag{2.3.4}$$

D_i's price depends positively on the wholesale price p_{wi} and on its competitor's price p_j. The equilibrium price and output are

$$p_i = \frac{(2+d)(1-d)\,a + 2(c_i + p_{wi}) + d(c_j + p_{wj})}{4-d^2}, \tag{2.3.5}$$

$$q_i = \frac{(2+d)(1-d)\,a - (2-d^2)(c_i + p_{wi}) + d(c_j + p_{wj})}{(4-d^2)(1-d^2)}. \tag{2.3.6}$$

As products become closer substitutes (i.e., as $d \to 1$), firm j's unit cost and wholesale price affect firm i's price and output positively.

In Stage 2, the upstream firms maximise equation (2.3.3) by choosing their wholesale prices p_{wi}. The upstream firms' reaction functions are

$$p_{wi} = \frac{(2+d)(1-d)\,a + (2-d^2)(c_U - c_i) + d(p_{wj} + c_j)}{2(2-d^2)}. \tag{2.3.7}$$

We observe that the wholesale prices are strategic complements as long as $d > 0$.

The equilibrium wholesale price is

$$p_{wi}^{0}(x_i, x_j) = \frac{1}{4}\left[2(a + c_U - c_i) - \frac{d(2a - 2c_U - c_i - c_j)}{4 - d - 2d^2} - \frac{d(c_i - c_j)}{4 + d - 2d^2}\right], \quad (2.3.8)$$

where superindex 0 makes reference to the Base Case. Regarding the effect of R&D effort on the wholesale prices in equation (2.3.8) we obtain the following result.

Lemma 1 *Firm i's R&D effort produces an increase in its own wholesale price p_{wi}^0, as well as in its competitor's wholesale price p_{wj}^0. The positive effects of D_i's R&D effort on both wholesale prices decreases with product differentiation.*

An increase in D_i's R&D effort reduces its own unit cost c_i, which raises D_i's profits. As a consequence, U_i increases its wholesale price to extract part of these additional profits. Since the wholesale prices are strategic complements, U_j also increases its wholesale price.[8] As the products become closer substitutes, the downstream prices fall and the scope for further price reductions is more limited. Thus, the effect of the downstream R&D effort on the wholesale prices decreases.

Looking at equation (2.3.4), we can now identify two differentiated effects of R&D efforts on consumer prices. On the one hand, there is a direct negative effect: R&D effort reduces the unit costs, which is transferred to a price reduction. On the other hand, there is an indirect positive effect: R&D effort increases the wholesale prices (as shown in Lemma 1), which in turn yield an increase in the consumer prices.

Substituting equation (2.3.8) into equations (2.3.5) and (2.3.6), we obtain the Stage-2 Nash equilibrium downstream price and output

$$\begin{aligned} p_i^0(x_i, x_j) &= \frac{2(1-d)(3-d^2)a + (2-d^2)c_U}{(2-d)(4-d-2d^2)} + \\ &\quad \frac{(2-d^2)\left[(8-3d^2)c_i + 2d(3-d^2)c_j\right]}{(4-d^2)(4+d-2d^2)(4-d-2d^2)}, \qquad (2.3.9)\\ q_i^0(x_i, x_j) &= \frac{(2-d^2)(a-c_U)}{(2-d)(1+d)(4-d-2d^2)} - \\ &\quad \frac{(2-d^2)\left[(8-9d^2+2d^4)c_i - d(2-d^2)c_j\right]}{(4-d^2)(1-d^2)(4+d-2d^2)(4-d-2d^2)}, \qquad (2.3.10) \end{aligned}$$

[8] The fact that U_j increases its wholesale price due to D_i's R&D effort is known as a rising rival cost effect, as noted by Banerjee and Lin (2003).

and plugging these values into equation (2.3.2), we obtain the SPNE downstream and upstream profits

$$\pi^0_{Di}(x_i, x_j) = \left(1-d^2\right) q^0_i (x_i, x_j)^2 - \epsilon x_i, \quad (2.3.11)$$

$$\pi^0_{Ui}(x_i, x_j) = q^0_i (x_i, x_j)^2 \frac{\left(4-d^2\right)\left(1-d^2\right)}{\left(2-d^2\right)}. \quad (2.3.12)$$

From the above expressions, we can observe that the upstream and downstream profits decrease as the products become closer substitutes. For the ensuing analysis, let us denote $W \equiv (a - c - c_U)$ and make the following assumption, which ensures positivity of the prices and outputs (see Appendix 2.6 for further details). For the sake of simplicity and to simplify the notation, we will refer to W as the market size, although it also comprises the downstream and upstream unit costs.

Assumption 1 Let $W > \underline{W} \equiv \frac{\gamma(d-\sigma)}{(1-d)}$ delimit the relevant region in our analysis.

The condition in Assumption 1 comes from the positivity conditions, which are thoroughly explained in Appendix 2.6. In Stage 1, the downstream firms choose their R&D strategy to maximise their profits. We compare the equilibrium downstream profits $\pi^0_i(x_i, x_j)$ under the three innovation strategies considered, i.e., when both downstream firms innovate, when neither of them innovates, and when only one of them innovates.

Considering the possible innovation strategies that can be chosen by the downstream firms, we may have four equilibrium regions, which are delimited by functions $\sigma_1(d)$ and $\sigma_2(d)$ in Fig.2.1, which are implicitly defined by $\pi^0_i(1, 0) - \pi^0_i(0, 0) = 0$, and $\pi^0_i(1, 1) - \pi^0_i(0, 1) = 0$, respectively. The function $\sigma_1(d)$ is obtained from D_i's unilateral incentive to innovate, and $\sigma_2(d)$ is obtained from D_i's incentive to innovate when D_j also innovates. In Region 1, both firms engage in innovation strategies. This equilibrium occurs for sufficiently low values of product differentiation (d) and spillover intensity (σ). Multiple equilibria arise in Region 2 and Region 3. On the one hand, in Region 2, the downstream firms follow symmetric innovation strategies and either both of them innovate or neither of them innovates. On the other hand, in Region 3, we have two asymmetric equilibria in which only one firm innovates.

Finally, in Region 4, no firm innovates.

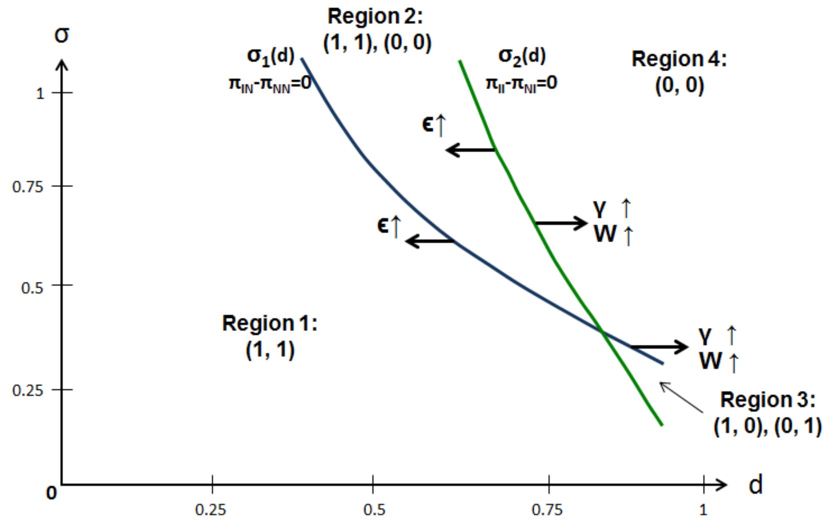

Fig. 2.1. Innovation equilibria in the base case.

Lemma 2 below specifies the conditions under which the different innovation equilibria exist.

Lemma 2 *In the Base Case, the equilibria in innovation strategies are characterized as follows:*
i) for $\sigma(d) < \min\{\sigma_1(d), \sigma_2(d)\}$*, both firms engage in innovation (Region* 1*),*
ii) for $\sigma_1(d) < \sigma(d) < \sigma_2(d)$*, there are symmetric multiple equilibria of the type* $\{(1,1), (0,0)\}$ *(Region 2),*
iii) for $\sigma_2(d) < \sigma(d) < \sigma_1(d)$*, there are asymmetric multiple equilibria of the type* $\{(1,0), (0,1)\}$ *(Region 3),*
iv) for $\sigma(d) > \max\{\sigma_1(d), \sigma_2(d)\}$*, neither firm innovates (Region 4).*
We have $d\sigma_i/dW > 0$*,* $d\sigma_i/d\gamma > 0$*, and* $d\sigma_i/d\epsilon < 0$*, with* $i = 1, 2$ *for* $W > W^*$*.*

Lemma 2 suggests that firms optimally decide to innovate (not to innovate) when the spillovers are low (high) and the products are sufficiently independent (close substitutes).[9] On the one hand, the effect of d on innovation is favourable as pointed out in Lemma 1. On the other hand, the effect of σ is negative since firm i can benefit from firm j's R&D effort. For high values of d and σ, we observe that the net effect is negative, giving rise to an equilibrium without innovation.

Examining the effect of the parameters on $\sigma_1(d)$ and $\sigma_2(d)$, a comparative static exercise can be conducted, in which the effects obtained are as expected. When the cost of innovation (ϵ) increases, the region where both downstream firms innovate (do not innovate) shrinks (expands). Differently, the market size (W) and the marginal benefit of R&D (γ) have a positive effect on innovation.[10] In the next section, we consider an upstream horizontal merger while the downstream duopoly remains and we study its effects on the equilibrium innovation strategies.

2.3.2 Upstream Integration

Having explained the Base Case, our attention now shifts to the Upstream Integration scenario, in which upstream firms form a monopoly U, which produces a homogenous input to downstream firms. Consequently, the upstream demand is given by

$$q_U = \sum_{i=1,2} q_i \tag{2.3.13}$$

and, therefore, the upstream profit function becomes

$$\pi_U = \sum_{i=1,2} (p_{wi} - c_U)\, q_i. \tag{2.3.14}$$

Stage 3 is as in the Base Case. In Stage 2, the integrated upstream firm chooses its profit-maximizing wholesale prices p_{wi}, which are given by

$$p_{wi}^T(x_i, x_j) = \frac{1}{2}(a + c_U - c_i), \tag{2.3.15}$$

where superindex T makes reference to a merger at the *top* (upstream merger). In-

[9] There are two regions with multiple equilibria. Thus, there is a parsimonious transition between the two regions with a unique equilibrium.

[10] The described effect of parameters is satisfied for $W > W^*$. See Appendix 2.7, Proof of Lemma 2 for further details of the definition of W^*.

terestingly, unlike the Base Case, the wholesale price depends neither on product differentiation nor on the competitor's unit cost (c_j). The reason is that, now, the upstream monopoly has the market power to determine both wholesale prices and, thus, the level of product differentiation is irrelevant. Substituting equation (2.3.15) into equations (2.3.5) and (2.3.6), we obtain the Stage-2 Nash equilibrium downstream prices and outputs:

$$p_i^T(x_i, x_j) = \frac{(2+d)[a(3-2d)+c_U]+2c_i+dc_j}{2(2-d)(2+d)}, \tag{2.3.16}$$

$$q_i^T(x_i, x_j) = \frac{(2+d)(1-d)(a-c_U)-(2-d^2)c_i+dc_j}{2(2-d)(2+d)(1-d)(1+d)}. \tag{2.3.17}$$

Notice that, as the products become increasingly independent (i.e., as $d \to 0$), the downstream firms become unrelated; therefore, the price and the output converge to the ones under the Base Case, in which there are exclusive relationships between the upstream and the downstream firms. The Stage-2 downstream and upstream profits, respectively, can be expressed as a function of the output:

$$\pi_{Di}^T(x_i, x_j) = \left(1-d^2\right) q_i^T(x_i, x_j)^2 - x_i\epsilon, \tag{2.3.18}$$

$$\pi_U^T(x_i, x_j) = \sum_{i=1,2}\left[\left(p_{wi}^T(x_i, x_j) - c_U\right) q_i^T(x_i, x_j)\right]. \tag{2.3.19}$$

From equation (2.3.18) we can observe that the expression is similar to that obtained in the Base Case (i.e., profits decrease with d) and the two scenarios converge as $d \to 0$.

The Stage-1 equilibrium analysis in innovation strategies under Upstream Integration gives rise to four equilibrium regions (as before), which are shown in Fig. 2.2. Functions $\sigma_3(d)$ and $\sigma_4(d)$ correspond to functions $\sigma_1(d)$ and $\sigma_2(d)$ in Fig. 2.1. The difference with respect to the Base Case is that the functions have moved leftward.

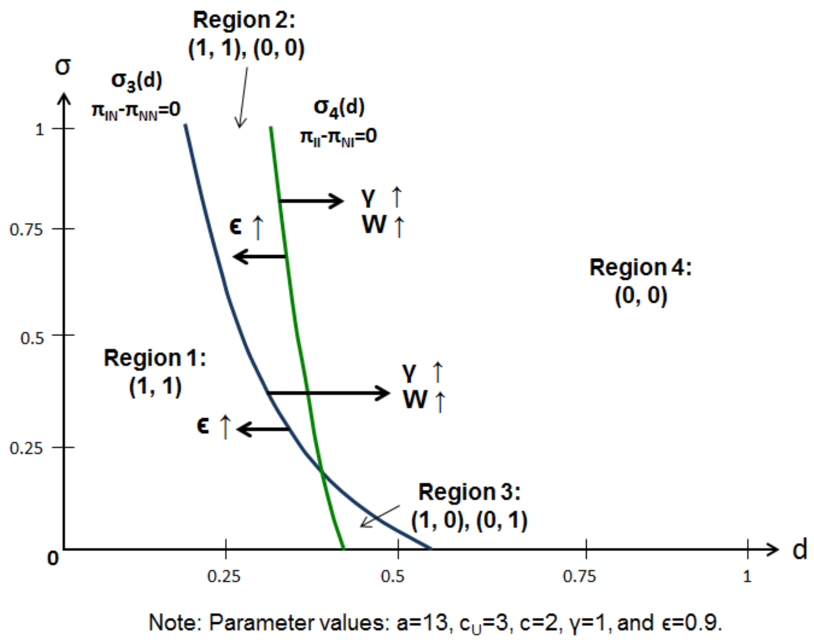

Fig. 2.2. Innovation equilibria under upstream integration.

We now obtain Lemma 3, which specifies the conditions for the different innovation equilibria to arise.

Lemma 3 *Under Upstream Integration the equilibria in innovation strategies are characterized as follows:*
i) for $\sigma(d) < \min\{\sigma_3(d), \sigma_4(d)\}$*, both firms engage in innovation* $(Region\ 1)$*,*
ii) for $\sigma_3(d) < \sigma(d) < \sigma_4(d)$*, there are multiple equilibria of the type* $(1,1)$ *and* $(0,0)$ $(Region\ 2)$*,*
iii) for $\sigma_4(d) < \sigma(d) < \sigma_3(d)$*, there are asymmetric equilibria of the type* $(1,0)$ *and* $(0,1)$ $(Region\ 3)$*,*
iv) for $\sigma(d) > \max\{\sigma_3(d), \sigma_4(d)\}$*, neither firm innovates* $(Region\ 4)$*.*
We have $d\sigma_i/dW > 0$*,* $d\sigma_i/d\gamma > 0$*, and* $d\sigma_i/d\epsilon < 0$*, with* $i = 3, 4$ *for* $W > W^{\blacktriangle}$*.*

From the comparison of Fig. 2.1 and Fig. 2.2, we observe that the region where both downstream firms engage in innovation is reduced, while the region where no downstream firm innovates increases. The following proposition that arises from the results in Lemma 2 and Lemma 3 states this formally.

Proposition 3 *Upstream integration has a negative effect on innovation.*

Proposition 1 indicates that downstream firms have fewer incentives to innovate in the presence of an upstream monopoly. This is explained by the fact that the wholesale prices in scenario T are greater than those in scenario 0, i.e., $p^T_{wi}(x_i, x_j) > p^0_{wi}(x_i, x_j)$, and the negative effect of innovation on the wholesale prices is now greater.[11] The comparative-static effects of parameters W, γ, and ϵ are as in the Base Case.[12] This result justifies the systematic concerns of competition authorities regarding horizontal mergers between upstream firms.[13] In the next scenario, we analyse the implications for the equilibrium innovation strategies of a downstream merger (while the upstream duopoly remains).

2.3.3 Downstream Integration

Under Downstream Integration, the merged entity becomes a multiproduct monopoly that transforms inputs into two differentiated products.[14] Thus, the downstream profit function is now defined as

$$\pi_D = \sum_{i=1,2} \left[(p_i - p_{wi} - c_i)\, q_i - \epsilon x_i \right], \tag{2.3.20}$$

since there is a unique decision-maker.

In Stage 3, the downstream firm D maximises its profits by choosing prices p_1 and p_2. The Stage-3 Nash equilibrium prices and output are given by

$$p_i = \frac{1}{2}(a + c_i + p_{wi}), \tag{2.3.21}$$

$$q_i = \frac{(1-d)\,a - c_i + p_{wi} - d\,(c_j + p_{wj})}{2\,(1-d)\,(1+d)}. \tag{2.3.22}$$

[11] It can be checked that $\frac{\partial p^0_{wi}}{\partial c_i}\frac{\partial c_i}{\partial x_i} < \frac{\partial p^T_{wi}}{\partial c_i}\frac{\partial c_i}{\partial x_i}$, where $\frac{\partial p^0_{wi}}{\partial c_i}\frac{\partial c_i}{\partial x_i} = \frac{\gamma}{4}\left(2 + \frac{d}{4+d-2d^2} - \frac{d}{4-d-2d^2}\right)$ and $\frac{\partial p^T_{wi}}{\partial c_i}\frac{\partial c_i}{\partial x_i} = \frac{\gamma}{2}$.

[12] See Appendix 2.7, Proof of Lemma 3 for further details of the definition of $W^{\blacktriangle}$.

[13] The US Department of Justice Merger Guidelines (1982) were written with relatively homogeneous, industrial products in mind. This reflects the long-standing antitrust concerns about the performance of concentrated markets for basic industrial commodities (Shapiro, 2010).

[14] An alternative assumption would be to consider that the integrated firm just produces an homogeneous output. However, this would require the adjustment of the production process in at least one of the plants, which might involve additional costs (e.g., because of specific investments in each of the plants).

When the products are independent, having a multimarket monopoly is tantamount to having two independent monopolies. Therefore, the price in equation (2.3.21) is the same as that in the Base Case (equation (2.3.5)) for $d = 0$.

In Stage 2, the upstream firms maximise their profits in equation (2.3.3) by choosing p_{wi}. The Stage-2 wholesale prices are given by

$$p_{wi}^{B}(x_i, x_j) = \frac{(2+d)\left[(1-d)a + c_U\right] - c_i\left(2-d^2\right) + dc_j}{(2+d)(2-d)}, \tag{2.3.23}$$

where superindex B makes reference to a merger at the *bottom* (downstream merger).

It emerges that the Stage-2 prices and output are equal to those under Upstream Integration (see equations (2.3.16) and (2.3.17)). The upstream and downstream profits are now

$$\pi_{D}^{B}(x_i, x_j) = \sum_{i,j=1,2}\left[\frac{(2+d)(a-c_U) - 2c_i - dc_j}{2(2-d)(2+d)} q_i^B - \epsilon x_i\right], \quad i,j = 1,2, \quad i \neq j, \tag{2.3.24}$$

$$\pi_{Ui}^{B}(x_i, x_j) = 2\left(1-d^2\right)\left[q_i^B(x_i, x_j)\right]^2. \tag{2.3.25}$$

In Stage 1, the downstream monopolist firm chooses its R&D strategy regarding its two products. We compare the equilibrium profits $\pi_D^B(x_i, x_j)$ under the three innovation strategies considered, i.e., to innovate in both products simultaneously, $(1,1)$, to innovate just in one product, either $(1,0)$ or $(0,1)$, or not to innovate in either product $(0,0)$. Considering the possible innovation strategies that can be chosen by the downstream firm, we may have different equilibria delimited by functions $\sigma_5(d)$, $\sigma_6(d)$, and $\sigma_7(d)$, displayed in Fig. 2.3, which are implicitly defined by $\pi_D^B(1,1) - \pi_D^B(0,0) = 0$, $\pi_D^B(1,1) - \pi_D^B(1,0) = 0$, and $\pi_D^B(1,0) - \pi_D^B(0,0) = 0$, respectively. In Region 1, for sufficiently high values of d and σ, the downstream firm innovates in both products. In Region 2, for sufficiently low values of product differentiation and spillover intensity, there is no innovation in either of the two products. Finally, in Region 3, when the products are close substitutes and there is a low level of spillover intensity, the downstream monopoly innovates in just one product.

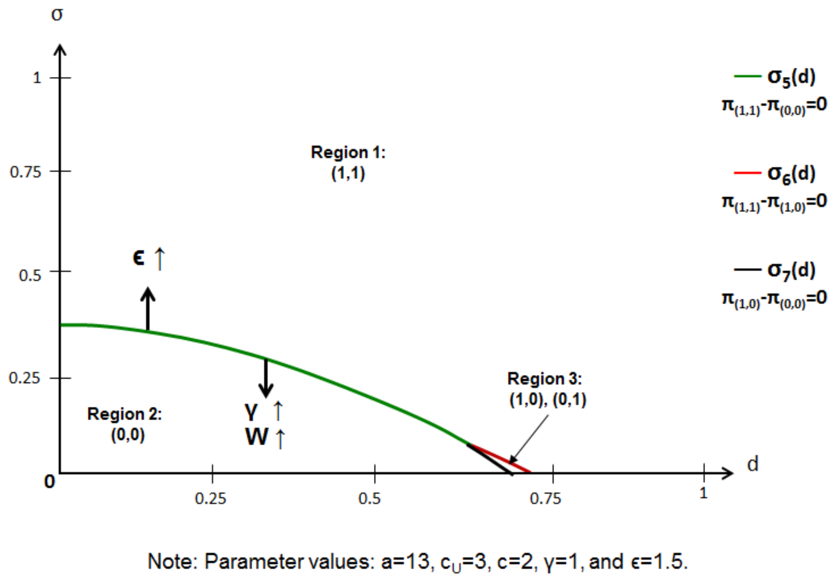

Fig. 2.3. Innovation equilibria under downstream integration.

Lemma 4 below specifies the conditions under which the different innovation equilibria exist.

Lemma 4 *Under Downstream Integration the equilibria in innovation strategies are characterized as follows:*
i) for $\sigma(d) > \max\{\sigma_5(d), \sigma_6(d)\}$, *the downstream monopolist innovates in both products* (*Region* 1),
ii) for $\sigma(d) < \min\{\sigma_5(d), \sigma_7(d)\}$, *the downstream monopolist does not innovate in either product* (*Region* 2),
iii) for $\sigma_7(d) < \sigma(d) < \sigma_6(d)$, *the downstream monopolist innovates in one product* (*Region* 3).
We have $d\sigma_i/dW < 0$, $d\sigma_i/d\gamma < 0$, *and* $d\sigma_i/d\epsilon > 0$, *with* $i = 5, 6, 7$.

Comparing the results in Lemma 4 with those of the Base Case, we see that while the effect of an increase in d on innovation under Downstream Integration remains positive, now the effect of an increase in σ on innovation is positive. The reason is that innovation occurs as a result of the internalization of the spillovers when a downstream merger takes place. The downstream firm engages in innovation in both products when the knowledge acquired during the innovation process in one product is highly applicable to the other one. Thus, the presence of a high level of adaptability or applicability between innovation projects becomes innovation-enhancing. The spillovers' internalization reinforces the unit cost reduction associated with innovation. As a consequence, for high values of d and σ, the equilibrium in innovation strategies is now $(1,1)$, whereas it was $(0,0)$ in the Base Case. The proposition that follows arises from the comparison of the results in Lemmas 2 and 4.

Proposition 4 *Downstream integration has a positive effect on innovation.*

Proposition 2 indicates that the downstream firm has more incentives to innovate in the presence of a downstream monopoly. This is explained by the fact that the wholesale prices in scenario B are smaller than those in scenario 0, i.e., $p_{wi}^{B}(x_i, x_j) < p_{wi}^{0}(x_i, x_j)$, and the unpleasant effect of innovation on the wholesale prices is now smoother.[15] The comparative static effects of parameters W, γ, and ϵ have the same interpretation as in the Base Case, i.e., an increase in W or γ, enlarges the region where innovation occurs and an increase in ϵ shrinks it.

At this point, we have analysed the effects on innovation produced by horizontal mergers at either the upstream or the downstream level. In the next section, we assess the effects of horizontal mergers on consumer welfare and the policy implications regarding innovation.

2.4 The Effect of Horizontal Mergers on Welfare

We compare the consumer surplus under all the scenarios considered, since 'a first objective upon which merger analysis may be based is the protection of consumer interests' (Röller et al., 2000). Competition and antitrust authorities use this criterion to assess the welfare effects of horizontal mergers. With linear demand functions,

[15]It can be checked that $\frac{\partial p_{wi}^{B}}{\partial c_i}\frac{\partial c_i}{\partial x_i} < \frac{\partial p_{wi}^{0}}{\partial c_i}\frac{\partial c_i}{\partial x_i}$, where $\frac{\partial p_{wi}^{0}}{\partial c_i}\frac{\partial c_i}{\partial x_i} = \frac{\gamma}{4}\left(2 + \frac{d}{4+d-2d^2} - \frac{d}{4-d-2d^2}\right)$ and $\frac{\partial p_{wi}^{B}}{\partial c_i}\frac{\partial c_i}{\partial x_i} = \frac{\gamma\left(2-d^2\right)}{\left(4-d^2\right)}$.

this is tantamount to comparing quantities. As pointed out by 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*' (SLC) test 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. (2014) and Flores-Fillol et al. (2014), have also used this criterion.

Before comparing consumer welfare across scenarios, our model confirms that innovation is beneficial for consumers for a given scenario (0, T, and B).

Lemma 5 *Considering all the possible innovation strategies that can be chosen by downstream firms in each scenario,* $q^{\kappa}(1,1) > q^{\kappa}(1,0) = q^{\kappa}(0,1) > q^{\kappa}(0,0)$*, for* $\kappa \in \{0, T, B\}$.

Based on a pairwise comparison of equilibrium total output ($q = q_i + q_j$) under Upstream and Downstream Integration (see equation (2.3.17)) with respect to the Base Case (see equation (2.3.10)), the following proposition arises.

Proposition 5 *For a given innovation strategy across scenarios,*
i) $q^0(1,1) > q^T(1,1) = q^B(1,1)$,
ii) $q^0(0,0) > q^T(0,0) = q^B(0,0)$, *and*
iii) $q^0(1,0) > q^T(1,0) = q^B(1,0)$.
Therefore, consumer welfare is maximised in scenario 0*, and it is the same under scenarios* T *and* B.

In the light of the previous proposition, we find that consumer welfare is maximised in the absence of mergers when merger formation does not affect the innovation strategy chosen by downstream firms. Thus, upstream and downstream competition enhances consumer welfare in a two-tier market structure with two differentiated outputs. However, as we have seen in Section 2, merger formation affects the equilibrium in innovation strategies. For example, under Upstream Integration, innovation requires products to be highly differentiated and a low level of spillovers. By contrast, under Downstream Integration, innovation requires products to be close substitutes and a high level of spillovers (see Figs. 2.2 and 2.3). Therefore, to perform a comprehensive welfare analysis, the comparison of total output must take account of changes in innovation strategies under different merger scenarios.

First, let us compare scenario 0 and scenario T (see jointly Figs. 2.1 and 2.2). Thus, if we start from a particular point (d, σ) in scenario 0 such tat the innovation equilibrium strategy is $(1,1)$, it is relevant to compare the total output at this point, i.e., $q^0(1,1)$, with respect to the total output corresponding to the other innovation strategies that can occur at this point under scenario T: either $q^T(0,0)$ or $q^T\{(1,0),(0,1)\}$.[16] Now, if we consider another particular point in scenario 0, at which the innovation strategy is $\{(1,0),(0,1)\}$, it is relevant to compare the total output at this point with the total output corresponding to the innovation strategy that occurs at this point under scenario T, which is $q^T(0,0)$. We obtain the following result.

Proposition 6 *When firms adopt different innovation strategies in equilibrium under scenarios* 0 *and* T, *we have*
i) $q^0(1,1) > q^T(0,0)$,
ii) $q^0(1,1) > q^T\{(1,0),(0,1)\}$,
iii) $q^0\{(1,0),(0,1)\} > q^T(0,0)$,
and, therefore, upstream horizontal mergers are detrimental to innovation and consumer welfare.

Proposition 4 confirms that upstream integration undermines innovation and consumer welfare, because the upstream monopoly under scenario T sets the greatest wholesale prices of all the scenarios considered. As a result of the horizontal integration between upstream firms, the region where both firms innovate is reduced. More precisely, a share of Region 1 in scenario 0 (Fig. 2.1), where both downstream firms innovate, falls into Regions 3 and 4 in scenario T (Fig. 2.2), i.e., regions where either just one downstream firm innovates or neither of them engages in innovation activities.

[16] Note that the comparison between $q^0(1,1)$ and $q^T(1,1)$ has already been made in Proposition 3.

Now we consider Figs. 2.1 and 2.3 corresponding to scenarios 0 and B. We observe that the following comparisons become relevant: $q^0\{(1,0),(0,1)\}$ versus $q^B(1,1)$, $q^0(0,0)$ versus $q^B(1,1)$, and $q^0(0,0)$ versus $q^B\{(1,0),(0,1)\}$. Let us define $W_1^\dagger \equiv \frac{\gamma(2+d)(1-d)(1+\sigma)}{d}$ and $W_2^\dagger \equiv \frac{\gamma\left(4-d-2d^2\right)(1+\sigma)}{d}$, where $W_2^\dagger > W_1^\dagger$. Then, the following proposition arises.

Proposition 7 *When* $W \in \left(\underline{W}, W_1^\dagger\right)$ *and firms adopt different innovation strategies in equilibrium under scenarios* 0 *and* B*, we have*
i) $q^B(1,1) > q^0\{(1,0),(0,1)\}$,
ii) $q^B(1,1) > q^0(0,0)$,
iii) $q^B\{(1,0),(0,1)\} > q^0(0,0)$,
and, therefore, downstream horizontal mergers are innovation and consumer welfare enhancing.
For $W > \max\left\{W_2^\dagger, \underline{W}\right\}$*, the opposite results are obtained. For the remaining cases downstream horizontal mergers can be consumer welfare enhancing depending on d and* σ*.*

Comparing scenario 0 with scenario B, we observe that consumer welfare depends on the size of W. When the markets are relatively small (i.e., for $W \in \left(\underline{W}, W_1^\dagger\right)$) and a downstream merger implies a change in the equilibrium R&D effort, consumer welfare is larger under downstream integration than under the Base Case. Innovation enhances consumer welfare (see Lemma 5). In most cases, horizontal mergers favour innovation but are detrimental to consumer welfare, i.e., there is a trade-off between promoting innovation (which is supposed to increase consumer welfare in the long run) and increasing consumer welfare in the short run. However, Proposition 5 above shows that there is no such trade-off when the markets are sufficiently small and therefore, in this case, downstream horizontal mergers are always consumer welfare enhancing.[17]

[17] For $W \in \left(W_1^\dagger, W_2^\dagger\right)$, the total output can be greater under either scenario 0 or scenario B depending on the particular innovation strategy followed by each of the firms.

2.5 Policy Implications and Concluding Remarks

This paper explores the effect of horizontal mergers in a vertically-related industry with two upstream and two downstream firms, which can undertake innovation activities. We first conclude that upstream integration (downstream integration) has a negative (positive) effect on innovation. Regarding consumer welfare, we show that downstream mergers can be beneficial.

The policy implications of this paper are as follows. In the one hand, horizontal mergers between upstream firms should always be forbidden because they are detrimental to innovation and consumer welfare. On the other hand, downstream horizontal mergers are innovation-enhancing, even though, they may have a negative effect on consumer welfare in large markets (derived from innovation is expected an increase in consumer welfare in the long run). Interestingly, it is shown that, when markets are sufficiently small, downstream horizontal mergers can even be beneficial for consumers in the short run. As a consequence, competition authorities should distinguish between upstream and downstream horizontal mergers and, in the case of downstream mergers, assess their short-run and long-run effects.

The results in this paper can be generalized in different directions. First, enlarging the number of firms should not change our results substantially since we consider a duopoly setting with price competition and product differentiation, in which the prices converge towards the marginal costs (i.e., perfect competition) as the degree of product differentiation decreases. Second, a multiple-sourcing relationship between upstream and downstream firms would increase the competition at the upstream level and, therefore, increase the negative effect of upstream mergers (this extension would connect our model with the literature on bundling). However, the presence of product differentiation among the upstream firms would downplay this negative effect.

2.6 Appendix. Positivity, 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.

2.6.1 Positivity conditions

Claim 3 *All the prices and quantities under the Base Case, Upstream Integration, and Downstream Integration are positive for* $W > \underline{W} \equiv \frac{\gamma(d-\sigma)}{1-d}$.

The threshold value $\underline{W}$ is obtained as $\underline{W} = \max\{W_1, ..., W_8\}$, where the different W_i for r $i = 1, ..., 8$ come from the following positivity conditions.

♦ *Base Case*

In Stage 2, a necessary condition for equation (2.3.8) to be positive is

$$W > W_1 \equiv \gamma \frac{2d - d^3 + \sigma\left(9d^2 - 8 - 2d^4\right) - c_U\left(4 - d - 2d^2\right)\left(4 + d - 2d^2\right)}{\left(1-d\right)\left(2+d\right)\left(4+d-2d^2\right)}.$$

In Stage 3, the price and output in equations (2.3.9) and (2.3.10) are positive when

$$\begin{aligned} W &> W_2 \equiv \frac{\gamma\left(2-d^2\right)\left(1+\sigma\right) - \left(c+c_U\right)\left(2-d\right)\left(4-d-2d^2\right)}{2\left(1-d\right)\left(3-d^2\right)}, \\ W &> W_3 \equiv \gamma\frac{2d - d^3 - 8\sigma + 9d^2\sigma - 2d^4\sigma}{\left(1-d\right)\left(2+d\right)\left(4+d-2d^2\right)}. \end{aligned}$$

♦ *Upstream Integration*

In Stage 3, the price and output in equations (2.3.16) and (2.3.17) are positive when

$$\begin{aligned} W &> W_4 \equiv \frac{\gamma\left(2+d+2\sigma+d\sigma\right)-2\left(c+c_U\right)\left(2-d\right)\left(2+d\right)}{\left(2+d\right)\left(3-2d\right)}, \\ W &> W_5 \equiv \gamma\frac{d-2\sigma+d^2\sigma}{\left(1-d\right)\left(2+d\right)}. \end{aligned}$$

♦ *Downstream Integration*

In Stage 2, the wholesale price in equation (2.3.23) is positive when

$$W > W_6 \equiv \frac{\gamma\left(d-2\sigma+d^2\sigma\right)-c_U\left(2-d\right)\left(2+d\right)}{\left(1-d\right)\left(2+d\right)}. \blacksquare$$

2.6.2 Second-order conditions

♦ *Base Case*

From equation (2.3.2), in Stage 3, we obtain

$$\frac{\partial^2\pi_{Di}}{\partial p_i^2} = -\frac{2}{1-d^2} < 0.$$

From equation (2.3.3), in Stage 2, we obtain

$$\frac{\partial^2\pi_{U_i}}{\partial p_{wi}^2} = -\frac{2\left(2-d^2\right)}{\left(4-d^2\right)\left(1-d^2\right)} < 0.$$

♦ *Upstream Integration*

From equation (2.3.2), in Stage 3, we obtain

$$\frac{\partial^2\pi_{Di}^T}{\partial p_i^2} = -\frac{2}{1-d^2} < 0.$$

From equation (2.3.19), in Stage 2, we obtain

$$\frac{\partial^2\pi_U^T}{\partial p_{wi}^2} = -\frac{2\left(2-d^2\right)}{\left(4-d^2\right)\left(1-d^2\right)} < 0,$$

and

$$\begin{aligned}\frac{\partial^2 \pi_U^T}{\partial p_{wi}^2}\frac{\partial^2 \pi_U^T}{\partial p_{wj}^2} - \left(\frac{\partial^2 \pi_U^T}{\partial p_{wi}\partial p_{wj}}\right)^2 &= \frac{4\left(2-d^2\right)^2}{\left(4-d^2\right)^2\left(1-d^2\right)^2} - \frac{4d^2}{\left(4-d^2\right)^2\left(1-d^2\right)^2} \\ &= \frac{4}{\left(4-d^2\right)\left(1-d^2\right)} > 0.\end{aligned}$$

♦ *Downstream Integration*

From equation (2.3.20), in Stage 3, we obtain

$$\frac{\partial^2 \pi_D^B}{\partial p_i^2} = -\frac{2}{1-d^2} < 0,$$

and

$$\frac{\partial^2 \pi_D^B}{\partial p_i^2}\frac{\partial^2 \pi_D^B}{\partial p_j^2} - \left(\frac{\partial^2 \pi_D^B}{\partial p_i \partial p_j}\right)^2 = \frac{4}{\left(1-d^2\right)^2} - \frac{4d^2}{\left(1-d^2\right)^2} = \frac{4}{1-d^2} > 0.$$

From equation (2.3.3), in Stage 2, we obtain

$$\frac{\partial^2 \pi_{Ui}^B}{\partial p_{wi}^2} = -\frac{1}{1-d^2} < 0. \blacksquare$$

2.6.3 Stability conditions

The Nash equilibria in Stages 2 and 3 need to comply with the stability conditions (see chapter 2 in Vives (2001) for further details).

♦ *Base Case*

The Stage-3 Nash equilibrium prices $p_i^0(x_i, x_j)$ and $p_j^0(x_i, x_j)$ are stable for

$$\left|\frac{\partial^2 \pi_i^0}{\partial p_i^2}\frac{\partial^2 \pi_j^0}{\partial p_j^2}\right| > \left|\frac{\partial^2 \pi_i^0}{\partial p_i \partial p_j}\frac{\partial^2 \pi_j^0}{\partial p_i \partial p_j}\right| \implies \frac{4}{\left(1-d^2\right)^2} > \frac{d^2}{\left(1-d^2\right)^2},$$

which is always observed.

The Stage-2 Nash equilibrium wholesale prices $p_{wi}^0(x_i, x_j)$ and $p_{wj}^0(x_i, x_j)$ are stable for

$$\begin{aligned}\left|\frac{\partial^2\pi^0_{Ui}}{\partial p^2_{wi}}\frac{\partial^2\pi^0_{Uj}}{\partial p^2_{wj}}\right| &> \left|\frac{\partial^2\pi^0_{Ui}}{\partial p_{wi}\partial p_{wj}}\frac{\partial^2\pi^0_{Uj}}{\partial p_{wi}\partial p_{wj}}\right| \implies \\ \frac{4\left(2-d^2\right)^2}{\left(4-d^2\right)^2\left(1-d^2\right)^2} &> \frac{d^2}{\left(4-d^2\right)^2\left(1-d^2\right)^2},\end{aligned}$$

which is always observed.

♦ *Upstream Integration*

In Stage 3, the stability condition is the same as in the Base Case.

♦ *Downstream Integration*

The Stage-2 Nash equilibrium wholesale prices $p^B_{wi}(x_i, x_j)$ and $p^B_{wj}(x_i, x_j)$ are stable for

$$\left|\frac{\partial^2\pi^B_{Ui}}{\partial p^2_{wi}}\frac{\partial^2\pi^B_{Uj}}{\partial p^2_{wj}}\right| > \left|\frac{\partial^2\pi^B_{Ui}}{\partial p_{wi}\partial p_{wj}}\frac{\partial^2\pi^B_{Uj}}{\partial p_{wi}\partial p_{wj}}\right| \implies \frac{1}{\left(1-d^2\right)^2} > \frac{d^2}{4\left(1-d^2\right)^2},$$

which is always observed. ■

2.7 Appendix. Proofs of Lemmas and Propositions

2.7.1 Proof of Lemma 1

First, notice that $\frac{\partial p^0_{wi}}{\partial x_i} > 0$ is tantamount to $\frac{\partial p^0_{wi}}{\partial c_i}\frac{\partial c_i}{\partial x_i} > 0$, which is always observed since
$\frac{\partial p^0_{wi}}{\partial c_i} = -\frac{1}{4}\left(2 - \frac{d}{4-d-2d^2} + \frac{d}{4+d-2d^2}\right) < 0$ and $\frac{\partial c_i}{\partial x_i} = -\gamma < 0$.
Second, $\frac{\partial p^0_{wj}}{\partial x_i} > 0$ is tantamount to $\frac{\partial p^0_{wj}}{\partial c_j}\frac{\partial c_j}{\partial x_i} > 0$, which is always observed since
$\frac{\partial p^0_{wj}}{\partial c_j} = -\frac{1}{4}\left(2 - \frac{d}{4-d-2d^2} + \frac{d}{4+d-2d^2}\right) < 0$ and $\frac{\partial c_j}{\partial x_i} = -\sigma\gamma < 0$.
Finally, $\frac{\partial^2 p^0_{wi}}{\partial x_i \partial d} = -\frac{\gamma}{4}\left[\frac{d(1+4d)}{4-d-2d^2} + \frac{d(1-4d)}{4+d-2d^2} + \frac{1}{4-d-2d^2} + \frac{1}{4+d-2d^2}\right] < 0$ and
$\frac{\partial^2 p^0_{wj}}{\partial x_i \partial d} = -\frac{\sigma\gamma}{4}\left[\frac{d(1+4d)}{4-d-2d^2} + \frac{d(1-4d)}{4+d-2d^2} + \frac{1}{4-d-2d^2} + \frac{1}{4+d-2d^2}\right] < 0$. ■

2.7.2 Proof of Lemma 2

Define $\sigma_1(d)$ implicitly by $F \equiv \pi^0_{Di}(1,0) - \pi^0_{Di}(0,0) = 0$, where $\pi^0_{Di}(1,0)$ and $\pi^0_{Di}(0,0)$ are obtained from equation (2.3.11). It follows that $\pi^0_{Di}(1,0) > \pi^0_{Di}(0,0)$ for $\sigma(d) < \sigma_1(d)$ and $\pi^0_{Di}(1,0) < \pi^0_{Di}(0,0)$ for $\sigma(d) > \sigma_1(d)$, where $\sigma_1(d)$ is given by

$$\sigma_1(d) = \frac{\gamma d\left(2-d^2\right)^3\left[W(1-d)(2+d)\left(4+d-2d^2\right)+\gamma\left(8-9d^2+2d^4\right)\right]-\sqrt{A}}{\gamma^2 d^2\left(2-d^2\right)^4}, \tag{2.7.1}$$

with $A = \gamma^2 d^2 (1-d)(2+d)^2\left(2-d^2\right)^4\left(4+d-2d^2\right)^2$

$$\left[W^2(1-d)\left(2-d^2\right)^2+\epsilon(2-d)^2(1+d)\left(4-d-2d^2\right)^2\right].$$

Similarly, define $\sigma_2(d)$ implicitly by $G \equiv \pi^0_{Di}(1,1) - \pi^0_{Di}(0,1) = 0$, where $\pi^0_{Di}(1,1)$ and $\pi^0_{Di}(0,1)$ are obtained from equation (2.3.11). It follows that $\pi^0_{Di}(1,1) > \pi^0_{Di}(0,1)$ for $\sigma(d) < \sigma_2(d)$ and $\pi^0_{Di}(1,1) < \pi^0_{Di}(0,1)$ for $\sigma(d) > \sigma_2(d)$, where $\sigma_2(d)$ is given by

$$\begin{aligned}\sigma_2(d) &= \frac{\gamma d(W+\gamma)\left(2-d^2\right)\left(8-9d^2+2d^4\right)}{\gamma^2 d\left(2-d^2\right)\left(16-2d-18d^2+d^3+4d^4\right)} \\ &\quad -\frac{\sqrt[2]{B}(2+d)^2\left(1-d^2\right)\left(4+d-2d^2\right)^2\left(4-d-2d^2\right)^2}{\gamma^2 d\left(2-d^2\right)\left(16-2d-18d^2+d^3+4d^4\right)} \\ &\quad -\frac{\left[Wd^2\left(2-d^2\right)^2-\gamma\left(64-140d^2+109d^4-35d^6+4d^8\right)\right]}{\gamma d\left(2-d^2\right)\left(16-2d-18d^2+d^3+4d^4\right)},\end{aligned} \tag{2.7.2}$$

with $B = \left\{\gamma^2\left(2-d^2\right)^3 \frac{Wd(1-d)\left(2-d^2\right)^2\left[Wd\left(2-d^2\right)+2\gamma(2-d)(1+d)\left(4-d-2d^2\right)\right]}{(2-d)^4(1-d)(1+d)^2(2+d)^2\left(4-d-2d^2\right)^4\left(4+d-2d^2\right)^2}+\right.$
$\left.\gamma^2\left(2-d^2\right)^3 \frac{\left(4-d-2d^2\right)^2(2-d)^2(1+d)\left[\gamma^2\left(1-d^2\right)\left(2-d^2\right)-d\epsilon\left(16-2d-18d^2+d^3+4d^4\right)\right]}{(2-d)^4(1-d)(1+d)^2(2+d)^2\left(4-d-2d^2\right)^4\left(4+d-2d^2\right)^2}\right\}.$

From the properties of $\sigma_1(d)$ and $\sigma_2(d)$, the different regions of equilibria arise straightforwardly. Regarding the partial derivatives from F we obtain:[18]

$$\frac{d\sigma_1}{dW} = -\frac{\partial F/\partial W}{\partial F/\partial \sigma} > 0,\ \frac{d\sigma_1}{d\gamma} = -\frac{\partial F/\partial \gamma}{\partial F/\partial \sigma} > 0,\ \frac{d\sigma_1}{d\epsilon} = -\frac{\partial F/\partial \epsilon}{\partial F/\partial \sigma} < 0,$$

[18] In the following we make use of the fact that $q^0_i(1,1) > q^0_i(1,0) = q^0_i(0,1) > q^0_i(0,0)$ which is proven in Lemma 5.

since

$$\begin{aligned}
\frac{\partial F}{\partial W} &= \frac{2\left(2-d^2\right)\left(1-d^2\right)}{\left(2-d\right)\left(1+d\right)\left(4-d-2d^2\right)}\left[q_i^0\left(1,0\right)-q_i^0\left(0,0\right)\right]>0, \\
\frac{\partial F}{\partial \gamma} &= 2\frac{\left(2-d^2\right)\left(8-9d^2+2d^4-2d\sigma+d^3\sigma\right)}{\left(4-d^2\right)\left(4-d-2d^2\right)\left(4+d-2d^2\right)}q_i^0\left(1,0\right)>0, \\
\frac{\partial F}{\partial \epsilon} &= -1<0, \\
\frac{\partial F}{\partial \sigma} &= -\frac{2d\left(2-d^2\right)^2}{\left(4-d^2\right)\left(4-d-2d^2\right)\left(4+d-2d^2\right)}q_i^0\left(1,0\right)<0.
\end{aligned}$$

Regarding the partial derivatives from G, we obtain

$$\frac{d\sigma_2}{dW}=-\frac{\partial G/\partial W}{\partial G/\partial \sigma}>0,\ \frac{d\sigma_2}{d\gamma}=-\frac{\partial G/\partial \gamma}{\partial G/\partial \sigma}>0,\ \frac{d\sigma_2}{d\epsilon}=-\frac{\partial G/\partial \epsilon}{\partial G/\partial \sigma}<0,$$

since

$$\begin{aligned}
\frac{\partial G}{\partial W} &= \frac{2\left(2-d^2\right)\left(1-d^2\right)}{\left(2-d\right)\left(1+d\right)\left(4-d-2d^2\right)}\left[q_i^0\left(1,1\right)-q_i^0\left(0,1\right)\right]>0, \\
\frac{\partial G}{\partial \gamma} &= \frac{2\left(2-d^2\right)\left(1-d^2\right)}{\left(2-d\right)\left(1+d\right)\left(4-d-2d^2\right)}\left[q_i^0\left(1,1\right)-q_i^0\left(0,1\right)\right]>0, \\
\frac{\partial G}{\partial \epsilon} &= -1<0, \\
\frac{\partial G}{\partial \sigma} &= \frac{2\gamma\left(2-d^2\right)\left(1-d^2\right)}{\left(2+d-d^2\right)\left(4-d-2d^2\right)}\left[q_i^0\left(1,1\right)-q_i^0\left(0,1\right)\frac{8-9d^2+2d^4}{\left(2-d-d^2\right)\left(4+d-2d^2\right)}\right]<0, \\
\text{for } W &> W^*,
\end{aligned}$$

where $W^*=\frac{\gamma\left[64-16d-140d^2+26d^3+109d^4-13d^5-35d^6+2d^7+4d^8-\sigma d\left(2-d^2\right)\left(16-2d-18d^2+d^3+4d^4\right)\right]}{d(1-d)(2+d)(2-d^2)(4+d-2d^2)}$. ■

2.7.3 Proof of Lemma 3

Define $\sigma_3(d)$ implicitly by $H\equiv\pi_{Di}^T\left(1,0\right)-\pi_{Di}^T\left(0,0\right)=0$, where $\pi_{Di}^T\left(1,0\right)$ and $\pi_{Di}^T\left(0,0\right)$ are obtained from equation (2.3.18). It follows that $\pi_{Di}^T\left(1,0\right)>\pi_{Di}^T\left(0,0\right)$ for $\sigma(d)<\sigma_3(d)$, and $\pi_{Di}^T\left(1,0\right)<\pi_{Di}^T\left(0,0\right)$ for $\sigma\left(d\right)>\sigma_3\left(d\right)$, where $\sigma_3\left(d\right)$ is given by

$$\sigma_3(d) = \frac{W(1-d)(2+d)+\gamma(2-d^2)}{\gamma d} - \frac{\sqrt{\gamma^2 d^2(1-d)(2+d)^2\left[W^2(1-d)+4\epsilon(2-d)^2(1+d)\right]}}{\gamma^2 d^2}. \quad (2.7.3)$$

Similarly, define $\sigma_4(d)$ implicitly by $I \equiv \pi_{Di}^T(1,1) - \pi_{Di}^T(0,1) = 0$, where $\pi_{Di}^T(1,1)$ and $\pi_{Di}^T(0,1)$ are obtained from equation (2.3.18). It follows that $\pi_{Di}^T(1,1) > \pi_{Di}^T(0,1)$ for $\sigma(d) < \sigma_4(d)$, and $\pi_{Di}^T(1,1) < \pi_{Di}^T(0,1)$ for $\sigma(d) > \sigma_4(d)$, where $\sigma_4(d)$ is given by

$$\sigma_4(d) = -\frac{\gamma\left[Wd(1-d)(2+d)-\gamma(4-2d-3d^2+d^3+d^4)\right]}{\gamma^2 d(4-d-2d^2)} - \frac{\sqrt{M}}{\gamma^2 d(4-d-2d^2)}, \quad (2.7.4)$$

with $M \equiv \{\gamma^2(-1+d)(2+d)^2$
$\left[(-1+d)(Wd+\gamma(2+d-d^2))^2 + 4d\epsilon(2-d)^2(1+d)(4-d-2d^2)\right]\}$.

From the properties of $\sigma_3(d)$ and $\sigma_4(d)$, the different regions of equilibria arise straightforwardly. Regarding the partial derivatives from H we obtain:[19]

$$\frac{d\sigma_3}{dW} = -\frac{\partial H/\partial W}{\partial H/\partial \sigma} > 0, \quad \frac{d\sigma_3}{d\gamma} = -\frac{\partial H/\partial \gamma}{\partial H/\partial \sigma} > 0, \quad \frac{d\sigma_3}{d\epsilon} = -\frac{\partial H/\partial \epsilon}{\partial H/\partial \sigma} < 0,$$

since

$$\begin{aligned}
\frac{\partial H}{\partial W} &= \frac{1-d}{2-d}\left[q_i^T(1,0) - q_i^T(0,0)\right] > 0,\\
\frac{\partial H}{\partial \gamma} &= \frac{2-d^2-\sigma d}{4-d^2}\left[q_i^T(1,0)\right] > 0,\\
\frac{\partial H}{\partial \epsilon} &= -1 < 0,\\
\frac{\partial H}{\partial \sigma} &= -\frac{\gamma d}{4-d^2}\left[q_i^T(1,0)\right] < 0.
\end{aligned}$$

[19] In the following we make use of the fact that $q_i^T(1,1) > q_i^T(1,0) = q_i^T(0,1) > q_i^T(0,0)$, which is proved in Lemma 5.

Regarding the partial derivatives from I, we obtain

$$\frac{d\sigma_4}{dW} = -\frac{\partial I/\partial W}{\partial I/\partial \sigma} > 0, \quad \frac{d\sigma_4}{d\gamma} = -\frac{\partial I/\partial \gamma}{\partial I/\partial \sigma} > 0, \quad \frac{d\sigma_4}{d\epsilon} = -\frac{\partial I/\partial \epsilon}{\partial I/\partial \sigma} < 0,$$

since

$$\begin{aligned}
\frac{\partial I}{\partial W} &= \frac{1-d}{2-d}\left[q_i^T(1,1) - q_i^T(0,1)\right] > 0, \\
\frac{\partial I}{\partial \gamma} &= \frac{1-d}{2-d}\left[(1+\sigma)\, q_i^T(1,1) - \frac{2\sigma - \sigma d^2 - d}{(1-d)(2+d)} q_i^T(0,1)\right] > 0, \text{ for } W > W^{\blacklozenge}, \\
\frac{\partial I}{\partial \epsilon} &= -1 < 0, \\
\frac{\partial I}{\partial \sigma} &= \frac{\gamma(1-d)}{2-d}\left[q_i^T(1,1) - \frac{2-d^2}{(1-d)(2+d)} q_i^T(0,1)\right] < 0, \text{ for } W > W^{\blacktriangle},
\end{aligned}$$

where $W^{\blacklozenge} = \frac{\gamma\left(-2+2d+d^2-4\sigma+d\sigma+2d^2\sigma\right)}{(1-d)(2+d)}$ and $W^{\blacktriangle} = \frac{\gamma\left(4-2d-3d^2+d^3+d^4-4d\sigma+d^2\sigma+2d^3\sigma\right)}{d(1-d)(2+d)}$.where it is easy to check that $W^{\blacktriangle} > W^{\blacklozenge}$. ■

2.7.4 Proof of Proposition 1

Straightforward. ■

2.7.5 Proof of Lemma 4

Define $\sigma_5(d)$ implicitly by $J \equiv \pi_{Di}^B(1,1) - \pi_{Di}^0(0,0) = 0$, where $\pi_{Di}^B(1,1)$ and $\pi_{Di}^B(0,0)$ are obtained from equation (2.3.24). It follows that $\pi_{Di}^B(1,1) > \pi_{Di}^B(0,0)$ for $\sigma(d) > \sigma_5(d)$ and $\pi_{Di}^B(1,1) < \pi_{Di}^B(0,0)$ for $\sigma(d) < \sigma_5(d)$, where $\sigma_5(d)$ is given by

$$\sigma_5(d) = -\frac{1}{\gamma(4-3d^2-2d^3)}\left\{\gamma\left[W(1-d)(2+d)^2 + \gamma\left(8-6d^2-d^3\right)\right] - \sqrt{S}\right\} \tag{2.7.5}$$

with $S \equiv \gamma^2\left[W(1-d)(2+d)^2 + \gamma(8-6d^2-d^3)\right]^2 +$
$(4-3d^2-2d^3)\left[-\gamma\left(2W(1-d)(2+d)^2 + \gamma(4-3d^2-2d^3)\right) + 4\epsilon(4-d^2)^2(1-d^2)\right]$.

Similarly, define $\sigma_6(d)$ implicitly by $K \equiv \pi_{Di}^B(1,1) - \pi_{Di}^B(1,0) = 0$, where $\pi_{Di}^B(1,1)$ and $\pi_{Di}^B(1,0)$ are obtained from equation (2.3.24). It follows that $\pi_{Di}^B(1,1) >$

$\pi_{Di}^{B}(1,0)$ for $\sigma(d) > \sigma_6(d)$ and $\pi_{Di}^{B}(1,1) < \pi_{Di}^{B}(1,0)$ for $\sigma(d) < \sigma_6(d)$, where $\sigma_6(d)$ is given by

$$\sigma_6(d) = \frac{-\gamma(W+\gamma) + \sqrt{\gamma^2\left[W^2 + 4\epsilon(2-d)^2(1+d)\right]}}{\gamma^2}. \tag{2.7.6}$$

Finally, define $\sigma_7(d)$ implicitly by $L \equiv \pi_D^B(1,0) - \pi_D^B(0,0) = 0$, where $\pi_D^B(1,0)$ and $\pi_D^B(0,0)$ are obtained from equation (2.3.24). It follows that $\pi_D^B(1,0) > \pi_D^B(0,0)$ for $\sigma(d) > \sigma_7(d)$ and $\pi_D^B(1,0) < \pi_D^B(0,0)$ for $\sigma(d) < \sigma_7(d)$, where $\sigma_7(d)$ is given by

$$\sigma_7(d) = -\frac{1}{\gamma^2(4-3d^2)}\gamma\left(E - \gamma d^3\right) - \sqrt{\gamma^2(4-3d^2-d^3)[N]}, \tag{2.7.7}$$

with $E \equiv W(1-d)(2+d)^2$ and
$N = \left[W^2(1-d)(2+d)^2 + (4-3d^2+d^3)\left[-2\gamma W - \gamma^2 + 4\epsilon(4-3d^2)\right]\right]$.

From the properties of $\sigma_5(d)$, $\sigma_6(d)$, and $\sigma_7(d)$, the different regions of equilibria arise straightforwardly. Regarding the partial derivatives from J we obtain:

$$\frac{d\sigma_5}{dW} = -\frac{\partial J/\partial W}{\partial J/\partial \sigma} < 0, \quad \frac{d\sigma_5}{d\gamma} = -\frac{\partial J/\partial \gamma}{\partial J/\partial \sigma} < 0, \quad \frac{d\sigma_5}{d\epsilon} = -\frac{\partial J/\partial \epsilon}{\partial J/\partial \sigma} > 0,$$

since

$$\begin{aligned}
\frac{\partial J}{\partial W} &= \frac{\gamma(1+\sigma)}{(2-d)^2(1+d)} > 0,\\
\frac{\partial J}{\partial \gamma} &= \frac{[W+\gamma(1+\sigma)](1+\sigma)}{(2-d)^2(1+d)} > 0,\\
\frac{\partial J}{\partial \epsilon} &= -2 < 0,\\
\frac{\partial J}{\partial \sigma} &= \frac{\gamma[W+\gamma(1+\sigma)]}{(2-d)^2(1+d)} > 0.
\end{aligned}$$

Regarding the partial derivatives from K, we obtain

$$\frac{d\sigma_6}{dW} = -\frac{\partial K/\partial W}{\partial K/\partial \sigma} < 0, \quad \frac{d\sigma_6}{d\gamma} = -\frac{\partial K/\partial \gamma}{\partial K/\partial \sigma} < 0, \quad \frac{d\sigma_6}{d\epsilon} = -\frac{\partial K/\partial \epsilon}{\partial K/\partial \sigma} > 0,$$

since

$$\begin{aligned}
\frac{\partial K}{\partial W} &= \frac{\gamma(1+\sigma)}{2(2-d)^2(1+d)} > 0, \\
\frac{\partial K}{\partial \gamma} &= \frac{W(1-d)(2+d^2)(1+\sigma)}{2(4-d^2)^2(1-d^2)} + \frac{\gamma T}{2(4-d^2)^2(1-d^2)} > 0, \text{ for } W > W^{\clubsuit}, \\
\text{with } T &\equiv 4-3d^2-2d^3-16\sigma-12d^2\sigma-2d^3\sigma+4\sigma^2-3d^2\sigma^2-2d^3\sigma^2. \\
\frac{\partial K}{\partial \epsilon} &= -1 < 0, \\
\frac{\partial K}{\partial \sigma} &= \frac{\gamma\left[W(1-d)(2+d)^2+\gamma(8-6d^2-d^3+4\sigma-3d^2\sigma-2d^3\sigma)\right]}{2(4-d^2)^2(1-d^2)} > 0,
\end{aligned}$$

where $W^{\clubsuit} = -\frac{\gamma\left(4-3d^2-2d^3-16\sigma-12d^2\sigma-2d^3\sigma+4\sigma^2-3d^2\sigma^2-2d^3\sigma^2\right)}{(1-d)(2+d)^2(1+\sigma)}$.

Finally, regarding the partial derivatives from L, we obtain

$$\frac{d\sigma_7}{dW} = -\frac{\partial L/\partial W}{\partial L/\partial \sigma} < 0, \quad \frac{d\sigma_7}{d\gamma} = -\frac{\partial L/\partial \gamma}{\partial L/\partial \sigma} < 0, \quad \frac{d\sigma_7}{d\epsilon} = -\frac{\partial L/\partial \epsilon}{\partial L/\partial \sigma} > 0,$$

since

$$\begin{aligned}
\frac{\partial L}{\partial W} &= \frac{\gamma(1+\sigma)}{2(2-d)^2(1+d)} > 0, \\
\frac{\partial L}{\partial \gamma} &= \frac{W(1-d)(2+d)^2(1+\sigma)+\gamma(4-3d^2-2d^3\sigma+4\sigma^2-3d^2\sigma^2)}{2(4-d^2)^2(1-d^2)} > 0, \\
\frac{\partial L}{\partial \epsilon} &= -1 < 0, \\
\frac{\partial L}{\partial \sigma} &= \frac{\gamma\left[W(1-d)(2+d)^2+\gamma(4\sigma-3d^2\sigma-d^3)\right]}{2(4-d^2)^2(1-d^2)} > 0, \text{ for } W > W^{\heartsuit},
\end{aligned}$$

where $W^{\heartsuit} = \frac{\gamma\left(d^3-4\sigma+3d^2\sigma\right)}{(1-d)(2+d)^2}$ and it is easy to check that $\underline{W} > W^{\heartsuit} > W^{\clubsuit}$. ■

2.7.6 Proof of Proposition 2

Straightforward. ■

2.7.7 Proof of Lemma 5

In the Base Case ($\kappa = 0$),

$$\underbrace{\frac{(2-d^2)\left[W+\gamma(1+\sigma)\right]}{(2-d)(1+d)(4-d-2d^2)}}_{q^0(1,1)} > \underbrace{\frac{(2-d^2)\left[2W+\gamma(1+\sigma)\right]}{(2-d)(1+d)(4-d-2d^2)}}_{q^0(1,0)} > \underbrace{\frac{(2-d^2)\,2W}{(2-d)(1+d)(4-d-2d^2)}}_{q^0(0,0)}.$$

Under Upstream Integration ($\kappa = T$) and Downstream Integration ($\kappa = B$),

$$\underbrace{\frac{W+\gamma(1+\sigma)}{(2-d)(1+d)}}_{q^T(1,1)=q^B(1,1)} > \underbrace{\frac{W+\frac{\gamma}{2}(1+\sigma)}{(2-d)(1+d)}}_{q^T(1,0)=q^B(1,0)} > \underbrace{\frac{W}{(2-d)(1+d)}}_{q^T(0,0)=q^B(0,0)}. \blacksquare$$

2.7.8 Proof of Proposition 3

To prove statement (i), when both downstream firms innovate, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{W+\gamma(1+\sigma)}{2(2-d)(1+d)}}_{q^0(1,1)} > \underbrace{\frac{W+\gamma(1+\sigma)}{2(2-d)(1+d)}}_{q^T(1,1)=q^B(1,1)}.$$

To prove statement (ii), when neither of the two downstream firms innovates, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{W}{(2-d)(1+d)}}_{q^0(0,0)} > \underbrace{\frac{W}{(2-d)(1+d)}}_{q^T(0,0)=q^B(0,0)}.$$

To prove statement (iii), when just one downstream firm innovates, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{2W+\gamma(1+\sigma)}{2(2-d)(1+d)}}_{q^0(1,0)} > \underbrace{\frac{2W+\gamma(1+\sigma)}{2(2-d)(1+d)}}_{q^T(1,0)=q^B(1,0)}. \blacksquare$$

2.7.9 Proof of Proposition 4

To prove statement (i), when both downstream firms innovate under the base case and neither firm innovates under upstream integration, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{W+\gamma(1+\sigma)}{(2-d)(1+d)}}_{q^0(1,1)} > \underbrace{\frac{W}{(2-d)(1+d)}}_{q^T(0,0)}.$$

To prove statement (ii), when both downstream firms innovate under the base case and one firm innovates under upstream integration, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{W+\gamma(1+\sigma)}{(2-d)(1+d)}}_{q^0(1,1)} > \underbrace{\frac{W+\frac{\gamma}{2}(1+\sigma)}{(2-d)(1+d)}}_{q^T(1,0)}.$$

To prove statement (iii), when one firm innovates under the base case and neither firm innovates under upstream integration, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{W+\frac{\gamma}{2}(1+\sigma)}{(2-d)(1+d)}}_{q^0(1,0)} > \underbrace{\frac{W}{(2-d)(1+d)}}_{q^T(0,0)}. \blacksquare$$

2.7.10 Proof of Proposition 5

To prove statement (i), when one firm innovates under the base case and both firms innovate under downstream integration, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{W+\frac{\gamma}{2}(1+\sigma)}{(2-d)(1+d)}}_{q^0(1,0)} < \underbrace{\frac{W+\gamma(1+\sigma)}{(2-d)(1+d)}}_{q^B(1,1)}$$

for $W < W_1^{\dagger} \equiv \frac{\gamma(2+d)(1-d)(1+\sigma)}{d}$.

To prove statement (ii), when neither firm innovates under the base case and both firms innovate under downstream integration, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{W}{(2-d)(1+d)}}_{q^0(0,0)} < \underbrace{\frac{W+\gamma(1+\sigma)}{(2-d)(1+d)}}_{q^B(1,1)}$$

for $W < W_2^\dagger \equiv \frac{\gamma\left(4-d-2d^2\right)(1+\sigma)}{d}$.

To prove statement (iii), when neither firm innovates under the base case and one firm innovates under downstream integration, we have

$$\underbrace{\frac{4-2d^2}{4-2d^2-d}\frac{W}{(2-d)(1+d)}}_{q^0(0,0)} < \underbrace{\frac{W+\frac{\gamma}{2}(1+\sigma)}{(2-d)(1+d)}}_{q^B(1,0)}$$

for $W < W_3^\dagger \equiv \frac{\gamma\left(4-d-2d^2\right)(1+\sigma)}{2d}$.

It can be checked that $W_1^\dagger < W_2^\dagger < W_3^\dagger$ and that the interval $\left(\underline{W}, W_1^\dagger\right)$ is non-empty for $\sigma < \frac{d^2+d-2(1-d)-d^3}{2(1-d)+d^3}$, which can occur in all the scenarios that have been studied. For $W > \max\left\{W_2^\dagger, \underline{W}\right\}$ the opposite results are obtained. ■

Chapter 3

The Determinants of Partner Choice for Cooperative Innovation: The Effect of Competition

Comments and suggestions given during the *3rd Ph.D. Workshop on Industrial and Public Economics (WIPE)*, at Universitat Rovira i Virgili of Tarragona (Spain), helped to improve this chapter.

3.1 Introduction

Firms consider cooperation to be a key innovation strategy for widening their technological base in a competitive environment where innovation is growing in complexity, risk, and cost. Research partnerships facilitate the access to complementary resources, the deployment of new skills and capabilities, and the sharing of the costs and risks related to innovation (Staropoli, 1998; Grant and Bade-Fuller, 2004; Lavie, 2006). This allows for economies of scale and fosters the development of competitive advantages, all of which leads to an improvement of firms' strategic position (Teece, 1986; Lavie, 2006).

The industrial organization literature has shown that R&D cooperation is determined by competition in the product market, spillovers, and R&D investments. Collaborative agreements make it possible for firms to protect knowledge spillovers

(López, 2008), improving firms' competitive position. Therefore, market structure can be affected by research partnerships (Hagedoorn et al., 2000).

The promotion of cooperative R&D has been a central policy tool to enhance the firms' competitiveness, mainly in the high-tech sectors. However, R&D collaborations may also harm competition in the product market since they can be used as a subterfuge to sustain tacit collusion agreements, especially in the case of collaboration among rival firms (Duso et al., 2014; Flores-Fillol et al., 2014).

Despite its importance to explain the firms' decision to cooperate in R&D, the empirical literature has not considered competition intensity as a determinant of R&D cooperation. This is probably due to the lack of information regarding firms' competitive environment. This study is the first to address this question by using new data to assess the effect of competition intensity on the decision to cooperate in R&D with different types of partners.

While the relationship between R&D cooperation and competition has not been addressed, the relationship between competition and innovation has captured the interest of many authors. Aghion et al. (2005) find evidence of an inverted-U relationship between competition and innovation. We connect the literature on R&D cooperation and the findings provided by Aghion et al. (2005) to elucidate, empirically, how competition affects firms' decision to cooperate in R&D with a certain type of partner.[1] We make use of two different measures to capture competition intensity: the number of competitors in the core market and the price elasticity reported by firms.

Following the existing literature, we control for firms' characteristics, innovation obstacles, and appropriability conditions to explain the determinants of firms' partner choice. Our analysis uses the Mannheim innovation panel (MIP), which provides information from firms located in Germany. The survey focuses on firms' innovative activities and provides useful information on cooperative agreements. We select the 2011 survey wave because it provides valuable information on firms' market structure. Our study focuses on a subsample of innovative manufacturing firms. Six different

[1]In some studies competition has been approximated by general or indirect measures, such as exports as a proxy for firms' participation in more competitive markets, and the Herfindahl index used by Becker and Dietz (2004) to estimate the impact of competition on the firm's propensity to cooperate.

types of collaborative partners are considered as dependent variables: 1) *customers*, 2) *supplier*s, 3) *competitors*, 4) *universities*, 5) *firms of the same group*, and 6) *consultants*.[2] The considered explanatory variables are: competition intensity (number of competitors in the core market and price elasticity), firm's characteristics, importance of appropriability measures, obstacles to innovation, and dummy variables for industries. A set of logit specifications is used to estimate the probability of the firm to conduct cooperative agreements in general, and with a certain type of partner in particular.

The main findings can be summarised as follows. Competition intensity does not affect German firm's propensity to cooperate in general. Nevertheless, it is an important determinant in firms' decision to cooperate in R&D with a certain type of partner in particular. More precisely, the effect of competition is negative in the case of cooperation with universities, customers, and firms of the same group; and it is positive in the case of cooperation with suppliers and competitors. The negative effect of competition intensity on partnerships with customers and universities is explained by the search of radical innovations and the high risks of disclosure. In contrast, the positive effect of competition intensity on partnerships with suppliers and competitors is explained by the search of incremental innovations and a symmetric risk of information disclosure. These findings lead to the conclusion that market competition and appropriability measures are the main determinants of the German firms' decisions to cooperate with particular types of partner.

The rest of the paper is organised as follows. Section 2 reviews the literature. Section 3 presents some stylised facts, the data, describes the variables and the empirical model. The results and their discussion are presented in Section 4 and Section 5, respectively. Finally, a brief concluding section closes the paper.

3.2 Literature Review

It is well known that innovation is a crucial factor for competitiveness in an environment with an accelerated pace of technological progress, which leads firms to

[2] 3) also includes firms from the same industry. 4) also includes public research centres. 6) also includes commercial laboratories, and private R&D institutions.

broaden their innovative capabilities (Miotti and Sachwald, 2003). According with Cassiman and Veugelers (2002), successful innovation depends on the development and integration of new knowledge in the innovation process. In this context, innovative cooperation allows firms to develop new knowledge and to incorporate external knowledge into the innovation process (Colombo, 1998). Many authors point out that firms engage in cooperative agreements with the purpose of combining their own specific assets and core competencies with other firms that have complementary assets and competencies which cannot be acquired independently (Sakakibara, 2001; López, 2008). Other authors argue that collaboration is a means of shaping competition by improving a firm's competitive position (Hagedoorn et al., 2000). Such collaborative behaviour protects and reinforces firms' existing competitive advantages and creates new ones.

There is a vast volume of literature that analyses why firms enter into collaborative innovation and what the results of such collaborative agreements are. Firms' cooperative behaviour can largely be explained from two main literature approaches.[3] First, the theoretical approach, in which most of the analyses have been addressed from an industrial organisation perspective, particularly using game-theory tools to study the relative efficiencies of competition and cooperation in R&D in raising final output and enhancing social welfare (Hagedoorn et al., 2000).[4] Second, the empirical approach from a resource-based perspective (Lowe and Taylor, 1998; Fritsch and Lukas, 2001; Tether, 2002; Miotti and Sachwald, 2003), which explains that innovation partnerships can facilitate firms' access to external complementary resources. These complementarities could yield competitive advantages that would ultimately improve the strategic position of firms in competitive markets (Teece, 1986; Lavie, 2006).

In the theoretical literature, cooperation among firms is used, mainly, as a means of internalizing technological externalities (Colombo, 1998; Hanaki et al., 2007).

[3]Many authors explain R&D cooperation considering the transaction cost approach, which analyses the conditions under collaborative agreements are the most efficient form of organization. This approach rests on the idea of cost minimization, but does not capture many of the strategic advantages of cooperation such as knowledge sharing, or advantages of cooperation depending on the partner choice (Williamson, 2002; Arranz and Fdez. de Arroyabe, 2008).

[4]Into this theoretical approach, a separate mention is given to the economics networks, which analyses collaborative incentives to reduce production costs in an environment of market competition, although this approach does not address particularly R&D collaboration.

Most of the authors make use of game-theory models to examine the effects of R&D cooperation on R&D investment, on equilibrium prices and output, and on social welfare, considering oligopoly competition. The seminal works of Brander and Spencer (1983), Spence (1984), Katz (1986), and d'Aspremont and Jacquemin (1988) show that cooperation in R&D can be welfare-enhancing due the increment on R&D investments when the spillovers are large enough and when there is competition in the product market. D'Aspremont and Jacquemin (1988) present a duopoly model, which is extended by Suzumura (1992) to oligopoly competition in quantities, and by Kamien et al. (1992), who analyse R&D cartelisation and joint research ventures. This branch of the literature provides a framework for the analysis of the effect of cooperation that depends on the nature of market competition and the market structure in which firms are embedded.

In the literature of economic networks, R&D cooperation has been studied with interesting results in a seminal paper by Goyal and Joshi (2003). The authors analyse networks of collaboration in an oligopoly context, and show how the firms' incentives to collaborate are influenced by the nature of market competition and the costs of forming links. They conclude that firms collaborate to generate competitive advantages and demonstrate that, when the costs of forming links are small, the empty network is the unique stable result under price competition. This suggests that, in a general setting with fierce price competition, collaborative links are not established. Billand and Bravard (2004) extend Goyal and Joshi's (2003) model, finding that collaboration arises as an equilibrium result under Bertrand competition.[5]

The empirical literature from a resource-based perspective of cooperation considers that strategic cooperation arises when firms in vulnerable strategic positions need the resources that cooperation brings (Arranz and Fdez. de Arroyabe, 2008). Cooperation improves the strategic position of firms in competitive markets by providing resources from other firms that enable them to share costs and risks (Staropoli, 1998; Grant and Bade-Fuller, 2004; Lavie, 2006). This perspective emphasises the strategic factors, the characteristics of the firms, and the idea of needs and opportunities. The literature derived from this approach focuses, on the one hand, on the identification

[5] Although Goyal and Joshi (2003) do not focus particularly on R&D collaboration, they point out that their results can explain the cooperative incentives that motivate the behavior of a set of firms who are competing to apply for a patent for a cost-reducing technological process, where the patent race is won by a group of collaborative firms.

of cooperation determinants, which can be grouped into (*i*) a firm's characteristics, (*ii*) appropriability conditions, and (*iii*) obstacles to innovation; and, on the other hand, it also focuses on the analysis of the impact of R&D collaboration on the innovation output, which is strongly related to the chosen cooperative partner. The main findings on the determinants of cooperation and on the effects that the cooperation with certain partners have on innovation are explained below.

3.2.1 Determinants of cooperation

Firms' characteristics

Firm characteristics that have an effect on the cooperation decision are firm size, R&D intensity, participation in a group of firms, export intensity, proportion of employees with a university degree, and technological level.

Firm size. Most of the authors find that size has a positive and significant effect on the propensity to cooperate in R&D. Size is measured as the number of employees or sales (Link and Bauer, 1987; Kleinknecht and Reijnen, 1992; Vonortas, 1997: Fritsch and Lukas, 2001; Cassiman and Veugelers, 2002; Becker and Dietz, 2004; Veugelers and Cassiman, 2005; Cassiman et al., 2007; Arranz and Fdez. de Arroyabe, 2008; López, 2008; de Faria et al., 2010). However, Kleinknecht and Reijnen (1992) find that size and R&D intensity only matters for private firms which cooperate with public research institutions, but not in their relationships with other private firms. Belderbos et al. (2006) find no significance of firm size on the probability of cooperation, although the authors include other independent variables that are positively and significantly related to size, such as investment intensity and being part of a foreign group.

R&D intensity. Size and R&D intensity are found to be associated, as generally larger firms also have a higher investment in R&D, which is often considered as the basic input of innovation. Cohen and Levinthal (1989) point out that external knowledge is more effective for firms' innovation processes when the firms undertake their own R&D. It has been shown that the higher the R&D intensity, the greater the propensity for R&D cooperation (Becker and Dietz, 2004; Negassi, 2004; Sampson, 2007). According with Link and Bauer (1987), R&D capital determines firms' absorptive capacity, their ability to identify new technological opportunities, and their capacity to establish collaborative agreements. However, König et al. (1994) and Vonortas (1997) do not find a significant relationship between R&D intensity and cooperation. Finally, Fritsch and Lukas (2001) find that R&D intensity has a positive effect on the probability to cooperate with suppliers and research institutes, but that it negatively influences the propensity to cooperate with customers and competitors.

Group. Being part of a group can influence a firm's likelihood to cooperate (Dachs et al., 2008), given that the integration of the firm into a group may indicate access to a substantial pool of resources (Lowe and Taylor, 1998; Miotti and Sachwald, 2003). According to de Faria et al. (2010), firms that belong to a formal group are more likely to search for knowledge outside their boundaries and to engage in cooperation activities.

Export intensity. Export intensity (share of exports in turnover) is generally included in the analyses to capture the intensity of the competition that a firm faces (Abramovsky et al., 2009; de Faria et al., 2010). Frequently, it is also considered as a proxy of firms' competitiveness since firms that participate in more competitive environments usually are more export intensive (Cassiman and Veugelers, 2002). According to Dachs et al. (2008), firms that sell large parts of their production abroad are also more likely to cooperate in R&D. Export intensity and being part of a group are characteristics that can be associated with size, and many authors assume that they also measure firm's competitiveness.

Personnel education. The degree of personnel education is commonly associated with a firm's capacity to capture externalities (de Faria et al., 2010). It has been found that firms with a greater proportion of personnel with a university degree are more likely to engage in R&D cooperation agreements, and give more importance to the management of knowledge spillovers.

Technological level. According with many authors, a firm's technological level is a determinant of collaborative behaviour. In this regard, firms that seek R&D cooperation tend to be concentrated in the high-tech and medium-high-tech sectors, since these firms conduct more expensive, risky, or complex innovation projects (Miotti and Sachwald, 2003; Becker and Dietz, 2004; Arranz and Fdez. de Arroyabe, 2008). Some authors indicate that cooperative relationships are more common between firms that belong to high-tech industries (Kotabe and Swan, 1995; Yasuda, 2005; Vuola and Hameri, 2006).

Appropriability conditions

Appropriability is intrinsically associated with cooperation, since it affects the firm's ability to protect the returns from cooperative innovation (Cassiman and Veugelers, 2002). Appropriability conditions have been deeply analysed, particularly in the theoretical literature. D'Aspremont and Jacquemin (1988) and Kamien et al. (1992) show that when spillovers are high enough, cooperative firms increase their R&D investment and are more profitable in comparison to firms acting non-cooperatively. However, high levels of spillovers also lead to a free-rider effect and discourage cooperation. Sakakibara (2001) finds evidence that cooperative projects among Japanese industries are formed in industries with strong appropriability conditions. Cassiman and Veugelers (2002) show that better appropriability conditions increase the likelihood of cooperation with customers and suppliers. Veugelers and Cassiman (2005) find that appropriability conditions do not affect firms' decisions to cooperate with universities, and López (2008) shows that a high level of legal protection is a disincentive to R&D cooperation among Spanish firms.

Appropriability conditions are considered in most empirical analyses. Generally, these conditions are classified as legal or strategic. Examples of legal appropriability measures of intellectual property protection include patents, utility patents, industrial designs, trademarks, and copyrights. Examples of strategic measures to protect cooperation output include commonly used secrecy, lead time advantage, and complex design. Cassiman and Veugelers (2002) find that higher appropriability through strategic protection has a positive effect on the probability of cooperation.

Obstacles to innovation

Firms tend to use R&D cooperation as a means of complementing innovation inputs and to overcome obstacles to innovation. The obstacles that are considered in the literature can be grouped into high costs of innovation, high risks of innovation, lack of technological information, and lack of market information. Cassiman and Veugelers

(2002) and Veugelers and Cassiman (2005) consider as obstacles to innovation: the lack of suitable available financing, high costs of innovation, payback periods being too long, innovation costs being hard to control, and the high risks of innovation. Sakakibara (2001), Cassiman and Veugelers (2002), Miotti and Sachwald (2003), Arranz and Fdez. de Arroyabe (2008), and Okamuro (2007) include in their analyses at least one of the following variables to explain the effect of the obstacles to innovation on the propensity to cooperate: high cost of innovation, high risk of innovation, lack of technological information, and lack of market information. According to Miotti and Sachwald (2003), firms' cooperative behaviour may be positively related to the number of obstacles to innovation, although their results show that these obstacles do not influence the propensity to cooperate. Similarly, Veugelers and Cassiman (2005) show that risk of innovation is not an important obstacle that needs to be considered by firms when they decide to cooperate with universities. In contrast, Tether (2002) finds a positive and significant effect of sharing costs and risks on the propensity to cooperate. Miotti and Sachwald (2003) and Belderbos et al. (2004) qualify these results, finding that cooperation with rivals, which is quite rare, seems to mostly be used to share R&D costs, particularly in high-tech sectors. López (2008) finds that cost-risk sharing is the most important determinant for cooperation with suppliers and customers and cooperation with research institutions.

3.2.2 Impact of R&D collaboration and the importance of cooperative partner

The impact that the choice of cooperative partner has on innovation has not been studied to the same extent that the determinants of cooperation have. The choice of cooperative partner is generally associated with the impact of R&D collaboration on the firm's innovation output. Most of the works have included in their analysis the determinants of cooperation with customers, suppliers, and universities and/or public research centres. Competitors are considered less because there is no available information on this category or the surveys observations are not large enough. Fritsch and Lukas (2001) and Cassiman and Veugelers (2002) find, respectively, that vertical cooperation is focused on incremental innovation and development activities. Miotti and Sachwald (2003) show that vertical cooperation has a positive effect on product innovation, but that is not frequent in high-tech industries, rather, firms that conduct expensive, risky, or complex research projects tend to be concentrated in high-tech sectors. Belderbos et al. (2004) find that competitors' cooperation focus on incremental innovations, while cooperation with customers and universities are important knowledge sources for firms pursuing radical innovations. Veugelers and Cassiman (2005) find that firms in high-technology sectors are more likely to be involved in cooperative agreements with universities and research centres, and demonstrate that cooperation with universities is complementary to other innovation activities.[6]. Vertical cooperation is more common in medium-low technology industries where competition discourages innovation (Aghion et al., 2005). Moreover, Becker and Dietz (2004) find that market power enables firms to shift R&D expenditures to suppliers through cooperation agreements. Moreover, de Faria et al. (2010) show that cooperation with customers is focused on product innovation, while suppliers' cooperation is focused on process innovation. From the above-mentioned perspective, some studies have deepened on the determinants of this choice. Miotti and Sachwald (2003) conclude that the choice of R&D cooperative partners is determined by the complementarity of resources for innovation for accessing knowledge and building innovative networks. Arranz and Fdez. de Arroyabe (2008) analyse the choice of partners in R&D cooperation among Spanish firms, finding that vertical cooperation is used as a means of overcoming market and technological risks, while cooperation with public partners is used to obtain financing. De Faria et al. (2010) study the importance of cooperative partners, showing that the firms which give greater value to cooperation with suppliers and firms from the same group are firms that belong to high-tech industries, with high levels of innovation intensity and absorptive capacity.

Competition has not been considered as a determinant of R&D cooperation or of the choice of collaborative partner. Only Becker and Dietz (2004) have considered in their analysis the effect of competitive conditions including a variable that measures the degree of market concentration, finding no significant effect on the propensity to cooperate, and negative and low significance in the number of partners chosen. Sakakibara (2001) analyses three decades of Japanese government-sponsored R&D

[6]The link between scientific knowledge and innovating firms is especially important in fast developing technologies sectors, such as biotechnology, IT, and new materials (Mowery, 1998; Zucker et al., 1998; Cockburn and Henderson, 2001).

consortia, finding that firms in oligopolistic industries are motivated to cooperate on R&D projects with industries that have higher growth. Elsewhere, the effect of oligopolistic competition on a firm's incentive to cooperate has been studied theoretically by d'Aspremont and Jacquemin (1988), Katz (1986), De Bondt and Veugelers (1991), Kamien et al. (1992), and Suzumura (1992), among others, who all stress the role of spillovers on the cooperation decision. In this regard, Hanaki et al. (2007) point out that R&D collaboration is a strategy for controlling knowledge spillovers, and find it reasonable that innovative firms may want to form R&D collaboration strategically to control knowledge externalities. Sakakibara (2001) points out that firms in more concentrated industries have fewer appropriability problems and less need to share innovation costs. From a strategic perspective, competition becomes a relevant condition as a determinant of cooperative innovation behaviour, especially considering the evidence that demonstrates the relationship between competition and innovation. In this regard, Aghion et al. (2005) find an inverted-U relationship between competition and innovation. Competition discourages laggard firms from innovating but encourages innovation among neck-and-neck firms which operate at a similar technological level. Innovation incentives depend upon the difference between post-innovation and pre-innovation rents of incumbent firms. More competition may encourage innovation and growth, because it may reduce a firm's pre-innovation rents by more than it reduces its post-innovation rents. Competition may increase the incremental profits from innovating, and thereby foster R&D investments aimed at escaping competition among neck-and-neck firms. In the neck-and-neck sectors, pre-innovation rents should be especially reduced by product market competition. In sectors where innovations are made by laggard firms with already low initial profits, product market competition will mainly affect post-innovation rents, and therefore the Schumpeterian effect of competition should dominate. Aghion et al. (2005) point out that neck-and-neck industries show a higher level of innovation activity for any level of product market competition, which only occurs in industries considered high-tech.[7]

[7]Industries such as aerospace, pharmaceuticals, machinery, IT-telecommunications, and scientific instruments face neck-and-neck competition, where there is an innovations race to sustain a comparative and competitive advantage in the market.

3.3 Empirical Study

3.3.1 Stylised Facts

Most of the literature has focused on cooperation as a way to complement capabilities and resources to overcome innovation obstacles. The present empirical analysis contributes to the literature by including market structure as a determinant of cooperation. The market structure is approximated by two different variables: the number of competitors in the relevant market, and a measure of price elasticity. In addition, different types of cooperative partners are considered: 1) customers, 2) suppliers, 3) competitors, 4) universities, 5) firms of the same group, and 6) consultants.

From the previous literature, the following stylised facts allow the effect of market structure on cooperation with a certain partner type to be deduced. First, R&D cooperation, which allows firms to develop new knowledge and to incorporate external knowledge into the innovation process, is a crucial aspect for successful innovation. Second, as there is an inverted-U relationship between competition intensity and innovation, and as R&D cooperation is a fundamental input for innovation, the relationship between competition intensity and R&D cooperation should also be (typically) inverted-U shaped. Third, appropriability conditions are an important factor for R&D cooperation. Fourth, R&D cooperation with customers and universities has a positive effect on radical product innovation, which is more common in high-tech industries. Fifth, R&D cooperation with suppliers and competitors has a positive effect on incremental process innovation (mainly focused on input cost reduction and quality improvement).

Following these stylised facts, the empirical analysis studies the effect of competition intensity on R&D cooperation. In particular, we identity the determinants of R&D cooperation with a certain partner type. In the following section, we describe the data and the variables, and the considered empirical model.

3.3.2 Data and Variables

The MIP is a micro dataset based on annual data that captures the innovation behaviour of German firms. The innovation survey covers firms with at least five employees and from various industries, and which are representative for Germany, allowing projections about the population of German firms. This survey is conducted by the Centre for European Economic Research (ZEW) on behalf of the Federal Ministry of Education and Research, in cooperation with the Institute of Applied Social Science and the Institute for Systems and Innovation Research. The MIP is the German contribution to the European Commission's Community Innovation Surveys (CIS).

For this analysis, the 2011 wave of the MIP is used, which provides valuable information on firms' competition environment. Particularly, the survey includes information regarding the number of competitors in the firm's relevant market, and a proxy for price elasticity. Each firm responds directly about the number of competitors that participate in their core market. Regarding price elasticity, firms indicate to what extent the characteristic "*price increases lead to immediate loss of clients*" describes their competitive situation. The respondents can indicate whether the described characteristic *applies fully*, *applies somewhat*, *applies very little*, *or does not apply*. With this information a categorical variable is built with three categories: (1) *does not apply at all or very little*, which indicates low price elasticity, (2) *applies somewhat*, which indicates intermediate price elasticity, and (3) *applies fully*, which indicates high price elasticity. The price elasticity variable allows the intensity of price competition to be approximated. As the two questions regarding number of competitors and price elasticity are not part of the regular questionnaire, it is not possible to construct a panel dataset. The 2011 wave also contains general information on firms, e.g. the number of employees, the number of employees with a university degree, and exports as a percentage of turnover, among others. More importantly for the purpose of this study, the survey contains data on innovation and R&D activities, for example on whether firms have undertaken continuous R&D activities in the last three years, R&D expenditures as a percentage of turnover, use of legal and strategic measures to protect intellectual property, obstacles to innovation such as high costs and risk of innovation, lack of technological information, and lack of market information.

This study concentrates on manufacturing firms, given that collaboration in R&D is more frequent in these industries. The sample includes $3,606$ firms. 55.5% $(2,000)$ of these firms report innovation in products or processes in the last three years

(2008 – 2010).[8] However, only 19.1% (688 firms) report cooperative agreements on innovation activities in this time. Table 1 displays the descriptive statistics (mean) of the innovative manufacturing firms of the sample. The descriptive statistics show the differences between the firms' characteristics depending on their collaborative partners. The statistics demonstrate that firms which cooperate with partners of the same group are the those with the largest number of employees, those that show the greatest proportion of exporters, and those that give the most importance to legal measures of intellectual property protection. Firms that collaborate with customers show the highest R&D intensity, while firms that cooperate with competitors have the greatest proportion of employees with a university degree, and are the firms that give the most importance to the three obstacles of innovation considered, i.e., high cost and high financial risk, lack of technological information, and lack of market information. These firms also report the greater importance of strategic measures for their innovation output. Regarding the competition variables, it is shown that the sample mean of the number of competitors is higher than the average number of competitors of cooperative firms, i.e. cooperative firms face a lower number of competitors.[9] Focusing on cooperative firms, the ones that cooperate with competitors report that they face the highest number of competitors in their core market. Observing the variable that measures price elasticity, it is shown that firms which cooperate with rivals have the highest price elasticity reported by cooperative firms.[10]

Analysing the proportion of firms that cooperate with certain types of partner by industry, we observe that: cooperation with firms of the same group is preferred in the food-tobacco, chemical, and glass-ceramic industries; cooperation with customers is the most common among firms from the metal industry; firms from wood, plastic, and furniture industries cooperate the most with suppliers; cooperation with competitors is the most frequent among firms from the mining, transportation, and telecommunications industries; cooperation with universities is preferred by electric-equipment manufacturers; and cooperation with consultants is the most common among firms from the textile and machinery industries.

[8] We focus attention on innovative firms, as it is only firms that respond affirmatively to innovation questions that are able to respond to cooperative questions of the survey.

[9] Undertaking a t-test we find evidence that the difference between the sample mean of the number of competitors and the mean of cooperative firms is significant at 5%.

[10] The null hypothesis of equal means is rejected under the t-test.

Table 1
Descriptive statistics for innovative and cooperative firms (mean).

					Cooperative Partner					
Variable	Sample	Innovative	Non-cooperative	Co-operative	Customers	Suppliers	Competitors	Universities	Group	Consultants
Firm's characteristics										
Size	3.6023	3.9649	3.6864	4.5816	4.6510	4.7630	4.9833	4.7987	5.4223	5.0026
Exports	0.5897	0.7182	0.6741	0.8564	0.8920	0.8431	0.7979	0.8912	0.9086	0.8737
Univ	0.3271	0.3998	0.3399	0.5294	0.5410	0.5187	0.6263	0.5893	0.5644	0.5512
Rdicat	1.6197	2.1176	1.7550	2.8395	2.9386	2.8739	2.8375	2.8903	2.9209	2.8216
Competition										
Competitors	2.7292	2.7019	2.7146	2.6404	2.5861	2.6436	2.6700	2.5978	2.5238	2.7087
Pricecat	1.7085	1.6766	1.6696	1.6547	1.6014	1.6953	1.7692	1.6381	1.6343	1.6493
Appropriability										
Legal	0.1541	0.2325	0.1727	0.3518	0.3572	0.3907	0.3847	0.3899	0.4643	0.3956
Strategic	0.2852	0.4243	0.3521	0.5811	0.6224	0.6008	0.6519	0.6208	0.6185	0.6008
Obstacles to innovation										
Cost_risk	0.4974	0.5942	0.5780	0.6367	0.6683	0.7282	0.7391	0.6312	0.6776	0.6623
Lack-teck	0.1235	0.1478	0.1431	0.1551	0.1733	0.2030	0.2055	0.1693	0.1419	0.1667
Lack_mkt	0.1463	0.1767	0.1545	0.2114	0.2453	0.2282	0.2949	0.2371	0.2360	0.1892
Industries										
Mining	0.0696	0.0435	0.0472	0.0334	0.0277	0.0279	0.0648	0.0412	0.0493	0.0415
Foodt	0.0899	0.0805	0.0954	0.0363	0.0173	0.0314	0.0093	0.0351	0.0359	0.0184
Textil	0.0585	0.0540	0.0530	0.0480	0.0484	0.0557	0.0370	0.0495	0.0493	0.0645
Woodp	0.0549	0.0490	0.0588	0.0232	0.0173	0.0348	0.0093	0.0144	0.0179	0.0276
Chemical	0.0527	0.0720	0.0597	0.1076	0.1384	0.1115	0.1111	0.1155	0.1390	0.1106
Plastic	0.0538	0.0540	0.0539	0.0610	0.0588	0.0662	0.0278	0.0515	0.0628	0.0507
Glassc	0.0374	0.0355	0.0337	0.0407	0.0415	0.0418	0.0370	0.0392	0.0628	0.0369
Metal	0.1078	0.0975	0.1050	0.1003	0.1176	0.0906	0.0741	0.1052	0.0942	0.1106
Electric	0.0990	0.1375	0.1127	0.1962	0.1903	0.1533	0.1759	0.1979	0.1749	0.1567
Machinery	0.0765	0.1095	0.0963	0.1497	0.1661	0.1533	0.0926	0.1670	0.1435	0.1843
Furniture	0.0987	0.0980	0.1012	0.0770	0.0623	0.1045	0.0741	0.0701	0.0807	0.0737
Transport	0.1328	0.0800	0.0877	0.0378	0.0277	0.0488	0.1111	0.0268	0.0269	0.0691
Telecom	0.0682	0.0890	0.0954	0.0887	0.0865	0.0801	0.1759	0.0866	0.0628	0.0553
Obs.	*3606*	*2000*	*1038*	*688*	*289*	*287*	*108*	*485*	*223*	*217*

See Table A1 for the description of the variables.

As mentioned above, six different types of partners are considered: 1) customers, 2) suppliers, 3) competitors, 4) universities, 5) firms of the same group, and 6) consultants. Table 2 describes the number and percentage of firms by partners. There are in total 745 cooperative firms. 33.7% (251 firms) cooperate only with one partner, universities being the most frequent (16.8%), followed by suppliers (6%), consultants (4%), customers (3.6%), other firms of the same group (2.3%), and competitors

(0.9%). 29.3% of the cooperative firms are engaged in cooperation with two different types of partners, universities being one of these two partners in 69% of cases. Less common is cooperation with three or more different type of partners. In decreasing order, 18.8% cooperate with three different types of partners, 10.7% cooperate with four different types of partners, 6% cooperate with five different type of partners, and 1.5% cooperates with all the types of partners considered.

The considered dependent variables are a general measure of R&D cooperation (*coop*) and a specific measure of cooperation with each partner (*coop_cust*, *coop_supp*, *coop_comp*, *coop_unires*, *coop_gr*, *coop_cons*).[11] [12] To explain the choice of cooperative partner, independent variables grouped into five categories are considered: firm characteristics, market characteristics, appropriability measures, obstacles to innovation, and industries. According to the literature, the following firm characteristic variables are included: *size*, *exports*, personnel with a university degree above the sample mean (*univ*), and R&D intensity (*#rdicat*). Two variables are included to measure appropriability: the use and importance of (*i*) *legal* and (*ii*) *strategic* measures as a means of protecting intellectual property.[13] In the legal category are considered: applications for patents, the registration of trademarks, and the use of copyrights. In the strategic measures are included: secrecy, complex design, and lead time advantage over competitors. Three dichotomic variables are includes as obstacles to innovation: high innovation costs and risks (*cost_risk*),[14] lack of technological information (*lack_tech*), and lack of market information (*lack_mkt*). These obstacles can lead to the extension, the end or the discontinuity of innovation

[11] See Table *A*1 in the Appendix, for a description of the variables.

[12] Fritsch and Lukas (2001) include in their analysis the relationship with customers, suppliers, other firms, and public research institutions. Cassiman and Veugelers (2002) consider cooperation with suppliers and customers, and cooperation with research institutions. Miotti and Sachwald (2003) include cooperation within interrelated groups of firms, clients, suppliers, competitors, and universities. Belderbos et al. (2004) and Belderbos et al. (2006) consider cooperation with competitors, suppliers, customers, and universities. López (2008) analyse cooperation with competitors, with suppliers and customers, and with research institutions. Arranz and Fdez. de Arroyabe (2008) group partners into three categories: vertical, horizontal, and public institutions. Into these categories are suppliers and clients, competitors, consultancy enterprises, and enterprises within firm's group, and government research institutes and universities, respectively. De Faria et al. (2010) study cooperation with other firms within the firm group, suppliers, clients or customers, competitors, consultants, commercial labs or R&D firms, universities, and government research institutions.

[13] Sakakibara (2001), Cassiman and Veugelers (2002), Veugelers and Cassiman (2005), and López (2008) include in their studies appropriability conditions to explain the propensity to cooperate.

[14] We build a unique variable that measures both aspects -high innovation costs and high financial risks- given the high correlation between both if we consider them separately.

projects, and even the decision not to start any innovation project at all.[15] A full description of variables is shown in Table $A1$ in the Appendix.

The correlation matrix is presented in Table $A3$ (see Appendix). Generally, correlation coefficients are either low or moderate and never exceed 0.6. Therefore, there is a low risk of facing collinearity issues or redundancies with this set of variables.

The main novelty of this study is the inclusion of market characteristics as determinants for cooperation with certain types of partners. As was mentioned above, two dimensions of competition are considered: the number of competitors in the firm's core market (*competitors*), and a proxy for price elasticity (*pricecat*). The variable that measures price elasticity captures the intensity of price competition, and can be determined by the degree of product differentiation. Three categories of price elasticity are considered: low, intermediate (*2.pricecat*), and high (*3.pricecat*), which correspond to independent products, partial substitutes, and close substitutes, respectively.

[15] Sakakibara, (2001), Cassiman and Veugelers (2002), Miotti and Sachwald (2003), Veugelers and Cassiman (2005), Okamuro (2007), and Arranz and Fdez de Arroyabe (2008) include in their works variables regarding obstacles to innovation to explain the propensity to cooperate in R&D.

Table 2
Number and percentage of cooperative firms by partners.

Manufacturing firms	**3606**
Cooperative firms	745 (20.66%)[a]
Firms that cooperate only with one partner	251 (33.69%)[b]
Firms that cooperate only with firms of the same enterprise group	17 (2.28%)[b]
Firms that cooperate only with customers	27 (3.62%)[b]
Firms that cooperate only with suppliers	45 (6.04%)[b]
Firms that cooperate only with competitors	7 (0.94%)[b]
Firms that cooperate only with universities	125 (16.78%)[b]
Firms that cooperate only with consultants	30 (4.03%)[b]
Firms that cooperate with two partners	218 (29.26%)[b]
Firms that cooperate with two partners, being one of them a university	150 (20.13%)[b]
Firms that cooperate with two partners, and one of them is not a university	68 (9.13%)[b]
Firms that cooperate with three partners	140 (18.79%)[b]
Firms that cooperate with four partners	80 (10.74%)[b]
Firms that cooperate with five partners	45 (6.04%)[b]
Firms that cooperate with all the partners	11 (1.48%)[b]

a: percentage with respect to manufacturing firms.
b: percentage with respect to cooperative firms (745 firms).

3.3.3 Empirical Model

This section describes the empirical strategy. Taking into account that the dependent variables are dichotomic (1 when a firm undertakes R&D cooperation or when it chooses a certain type of partner), a logit regression model is used.[16] The key question is whether the competition environment affects the decision to cooperate, and what its specific effect on the partner choice for cooperative R&D is. The regression coefficients estimate the impact of the independent variables on the probability that the firm will conduct cooperative agreements in general, and with a certain type of partner in particular. I restrict attention to innovative firms to estimate the likelihood of cooperation. To estimate the probability of choosing a particular partner, I restrict attention to innovative and cooperative firms.

[16]Many authors analyse the choice of cooperative partner using a logit model to estimate de probability of cooperation with a particular partner. See Fritsch and Lukas (2001), Miotti and Sachwald (2003), and Arranz and Fdez. de Arroyabe (2008).

The logit model estimates $p = Pr(y = 1|x)$, that is, either the probability of cooperation in general, or the probability of choosing a particular partner to cooperate with, given a set of explanatory variables $\mathbf{x}$. Therefore, the following equations are estimated:

$$\begin{aligned} y \;=\; & \alpha + \beta_1 competitors + \beta_2 pricecat + \beta_3 size + \beta_4 exports + \beta_5 univ + \beta_6 rdicat + \\ & + \beta_7 legal + \beta_8 strategic + \beta_9 cst\_risk + \beta_{10} lack\_tech + \beta_{11} lack\_mkt + \\ & + \gamma_i industry\_dummies, \quad (i = 1, ..., 13) \end{aligned}$$

where y represents the different dependent variables that are estimated: *coop*, *coop_gr*, *coop_cust*, *coop_supp*, *coop_comp*, *coop_unires*, and *coop_cons*, $\beta_1, ..., \beta_{11}$ are the coefficients to be estimated, and γ_i are a set of coefficients for industry dummies. The thirteen industries considered in the sample are included. The estimations cluster the standard errors on the industries to obtain a better adjustment.

The same set of independent variables is used to successively estimate first the likelihood of cooperation, and second the likelihood of cooperating with a certain type of partner. The difference between the two estimations is that in the first only the sub-sample of innovative firms is considered, while in the second the sub-sample of innovative and cooperative firms is considered. This set of logit specifications allows a clear interpretation of the results, which are presented in the next section.

3.4 Results

This section is organised as follows. First, the determinants for R&D cooperation are analysed. Second, the estimation results for partner choice for R&D cooperation are discussed by grouping the explanatory variables in the following way: firms' characteristics, competition intensity, appropriability measures, obstacles to innovation, and industry-specific effects.

3.4.1 Determinants for R&D cooperation

Table 3 provides the estimates (coefficients and robust standard errors) of the cooperation variable. The robust standard errors have been clustered by industry. As expected and in accordance with the literature, *size* and R&D intensity (*rdicat*) positively and significantly affect the propensity to engage in cooperative agreements. Firms that have a proportion of employees with a degree above the sample mean (*univ*) are more likely to collaborate in innovation. As R&D intensity (*rdicat*) and employees' qualifications (*univ*) approximate the firm's absorptive capacity, the results confirm that German firms with higher absorptive capacity are more likely to cooperate in innovation activities. Being an export firm (*exports*) does not appear to influence the likelihood to cooperate, in contrast to the majority of the results in the literature.

Regarding competition intensity, it is found that it does not have an influence on the firms' decision to cooperate. Neither the number of competitors (*competitors*) nor price elasticity (*pricecat*) are significant for firms' propensity to cooperate. These results coincide with Becker and Dietz (2004), who find that competition intensity (measured by the Herfindahl index for industrial sectors) is not significant for the decision to cooperate.

The results confirm the importance that German firms give to appropriation measures when they evaluate whether to collaborate in innovative projects. The coefficients of *legal* and *strategic* appropriation are positive and significant, with legal measures being more significant than the strategic ones. Obstacles to innovation do not significantly affect the likelihood of engaging in cooperation. The coefficient estimates of *cost_risk* and *lack_tech* are positive, while that of *lack_mkt* is negative, although none of the three cases are significant.

Belonging to a particular industry appears to be relevant the explanation of why firms collaborate on innovation. In comparison with firms from the chemical (*chemical*) sector, mining firms are more likely to cooperate. Firms from the food-tobacco (*foodt*), wood-paper (*woodp*), metal (*metal*), electric equipment (*electric*), machinery (*machinery*), furniture-toys (*furniture*), and telecommunications (*telecom*) industries cooperate less on innovation than their counterparts from the chemical sector. Firms from the textile (*textil*), plastic (*plastic*), glass-ceramic (*glassc*), or transportation (*transport*) industries do not show significant differences with respect to firms in the chemical industry regarding the likelihood to engage in collaborative R&D agreements.[17]

Table 3
Logit regressions on cooperation decision

Variable	COOP		Variable	COOP	
size	0.234***	(0.068)	*Industry*		
exports	0.266	(0.291)			
univ	0.374*	(0.222)	mining	0.263*	(0.142)
2.rdicat	1.650***	(0.226)	foodt	-0.492***	(0.106)
3.rdicat	1.844***	(0.268)	textil	0.249	(0.155)
4.rdicat	2.419***	(0.295)	woodp	-0.957***	(0.129)
2.competitors	0.315	(0.788)	plastic	-0.020	(0.101)
3.competitors	0.550	(0.710)	glassc	-0.080	(0.082)
4.competitors	0.454	(0.752)	metal	-0.240**	(0.118)
2.pricecat	0.118	(0.108)	electric	-0.282***	(0.043)
3.pricecat	-0.001	(0.178)	machinery	-0.379***	(0.080)
legal	0.501**	(0.235)	furniture	-0.511***	(0.084)
strategic	0.518*	(0.271)	transport	0.139	(0.102)
cost_risk	0.134	(0.163)	telecom	-0.644***	(0.165)
lack_tech	0.071	(0.198)			
lack_mkt	-0.154	(0.140)	Constant	-3.822***	(0.704)
Observations	936				

Notes:
(1) The variables categories 1.competitors, i.e., no competitors, and 1.pricecat, i.e., low price elasticity, are the references.
(2) The industry of reference is chemicals.
*** Significant at 1%, ** Significant at 5%, *Significant at 10%.

3.4.2 Partner choice for R&D cooperation

In this section, the determinants of cooperation with certain types of partners are shown. Table 4 presents the estimation results showing that the propensity to cooperate with each partner is driven by different factors.

[17] We do not group industries by technology level, as the original allocation of sector is mixed regarding the technological level of the firms, e.g. the industry called 'furniture' includes furniture, toy, medical technology, and maintenance firms, making it difficult to classify them in only one category of technological level.

A firm's characteristics

A firm's size is found to have positive and highly significant effect on the likelihood to cooperate with competitors, firms of the same group, and consultants. By contrast, size is not a determinant either for vertical cooperation or for cooperation with universities. These results may be explained by the fact that 80% of the German firms included in the sample have less than 140 employees, that is, most of the firms are small and medium size. Otherwise, firms that cooperate with competitors, consultants, and firms of the same group are larger than firms that cooperate with customers, suppliers or universities, according to the descriptive statistics shown in Table 1. The *exports* variable does not have a significant effect on the choice of cooperative partner, coinciding with the results obtained in Table 3. The proportion of employees with a university degree positively and significantly affects the propensity to cooperate with universities and consultants, confirming the literature results, which shows that firms with more qualified human resources have a greater propensity to cooperate with scientific institutions. In contrast, personnel qualification shows a negative and low significant effect on the likelihood to cooperate with customers. Finally, the results show that the R&D intensity has a positive and significant effect on the propensity to cooperate with customers and suppliers. In contrast with the findings in the literature, German firms with high investment in R&D show a tendency to cooperate vertically. Despite the fact that R&D intensity explains firms' decision to cooperate, it does not show a significant effect on the probability to cooperate with competitors, universities, firms of the same group or consultants.

Competition intensity

The results show that competition intensity is a relevant determinant for firms' cooperation with customers, suppliers, competitors, universities, and firms of the same group, while it has no significant impact on firms' cooperation with consultants. Competition intensity, measured by the number of competitors in the firm's core market, has a negative and significant effect on the likelihood to cooperate with customers and firms of the same group. Nevertheless, the causality of these results does not seem to be the same.

Cooperation with customers is generally associated with product innovation and/or radical innovation, which involves greater risks.[18] Two circumstances could explain this result. First, higher competition intensity may discourage radical product innovations, given the intrinsic risk and uncertainty associated with this type of innovation. Second, higher competition intensity may discourage collaboration with customers given the risks of appropriation or disclosure of a firm's valuable knowledge. Indeed, the positive effect of the *strategic* variable indicates that risk of appropriation is an important issue for cooperation with customers.

Regarding cooperation with firms of the same group, the results also show that the number of competitors negatively and significantly affects the propensity to cooperate. Firms that belong to a group have access to a substantial pool of resources for innovation (Lowe and Taylor, 1998). However, as the competition intensity increases, these firms may seek outside cooperation to complement their innovative skills. This could explain why an increase in competition negatively affects a firm's propensity to cooperate with partners of the same group.

The number of competitors does not show a significant effect on the likelihood of cooperating with suppliers, competitors, universities, or consultants.

Price elasticity (measured by *2.pricecat* and *3.pricecat*) affects the propensity to cooperate with suppliers, competitors, and universities differently. The likelihood to cooperate with suppliers is positively affected by a high price elasticity. High price elasticity (*3.pricecat*) indicates that firms compete with other firms producing close-substitute products. These firms are more likely to look for cost reductions or quality improvements to enhance their competitiveness. Cooperation with suppliers is commonly associated either with incremental or with process innovation (Fritsch and Lukas, 2001; de Faria et al., 2010).

Moreover, an intermediate level of competition (*2.pricecat*, which indicates a moderate degree of product differentiation) is found to have a positive and significant effect on the propensity to cooperate with competitors,[19] while this effect vanishes for a higher level of competition (*3.pricecat*). Therefore, competition intensity and

[18] Fritsch and Lukas (2001); Miotti and Sachwald (2003); Belderbos et al. (2004); and De Faria et al. (2010) show that cooperation with customers is mainly oriented towards product innovation and/or radical innovation.

[19] Cooperation with rivals allows firms to look for complementary R&D resources (Cassiman and Veugelers, 2002), although this kind of collaboration is more hazardous than vertical cooperation (Atallah, 2002).

cooperation with competitors are related to an inverted U-shape manner (Aghion et al., 2005). The reason for this is that the inherent risk associated with collaboration with competitors diminishes as the degree of substitutability across firms decreases.

In contrast, price elasticity (*2.pricecat* and *3.pricecat*) discourages cooperation with universities. This means that firms in more competitive environments are less likely to cooperate with universities. Similarly to the case of collaboration with customers, high competition intensity may discourage collaboration given the risk of disclosure of a firm's valuable knowledge. Again, the positive effect of the *legal* variable indicates that legal protection of intellectual property is a relevant factor for collaboration with universities. Furthermore, cooperation with universities is characterised by a low degree of short-run applicability, which is important in highly competitive markets.

Appropriability measures

The appropriability measures positively affect the propensity to cooperate in general, and the propensity to cooperate with a certain type of partner in particular.[20] Legal protection (*legal*) positively affects the likelihood of cooperating with suppliers and universities, while strategic measures (such as secrecy, design complexity, and lead time advantage) foster cooperation with customers, competitors, firms of the same group, and consultants.

The results suggest that the higher the risk of technological information disclosure is (which is the case for cooperation with suppliers, universities, and consultants), the more important legal protection becomes. On the other hand, the use of strategic appropriability measures has a positive effect on the propensity to cooperate with customers and competitors. The reason for this is that these kinds of collaborative agreements involve sharing valuable information from a commercial point of view, which explains the importance of secrecy, design complexity, and lead time advantage over competitors as a means of protecting cooperative output.

[20] Firms better prepared to protect their knowledge are more likely to cooperate in innovation (Cassiman and Veugelers, 2002; Abramovsky et al., 2009).

Obstacles to innovation

Concerning the obstacles to innovation, the results show that firms that face high innovation costs and risks (*cost_ risk*) are more likely to cooperate with customers and suppliers.[21] Lack of market information (*lack_ mkt*) positively affects the propensity to cooperate with customers. This result is easily explained, as one of the main sources of a firm's market information is clients and customers. These results confirm findings from the previous literature, which suggests that many innovative projects arise as a result of the continued interaction between members of the same supply chain. Collaboration becomes a means of overcoming mutual obstacles to innovation and an instrument for improving the overall competitiveness of the supply chain (Ireland and Webb, 2007). In contrast, the lack of technological information (*lack_ tech*) is found not to have a significant effect on the probability to cooperate with certain types of partners, because sharing technological information involves a higher risk of disclosure.

[21] This result coincides with the findings of López (2008), who finds that cost-risk sharing is an important determinant for vertical cooperation.

Table 4

Logit regressions on the partner choice

	(1)	(2)	(3)	(4)	(5)	(6)
Variable	coop_cust	coop_supp	coop_comp	coop_unires	coop_gr	coop_cons
size	-0.037	0.164	0.317***	0.217	0.526***	0.261***
	(0.083)	(0.119)	(0.065)	(0.176)	(0.105)	(0.080)
exports	-0.427	-0.221	-0.269	0.337	0.497	-0.099
	(0.434)	(0.443)	(0.544)	(0.457)	(0.481)	(0.507)
univ	-0.425*	-0.236	0.413	0.631***	0.385	0.489**
	(0.258)	(0.399)	(0.354)	(0.203)	(0.278)	(0.235)
2.rdicat	0.976	0.640	0.539	-0.353	0.134	0.294
	(0.727)	(0.466)	(0.751)	(0.593)	(0.530)	(0.467)
3.rdicat	1.325*	0.873**	-0.197	-0.082	0.306	0.463
	(0.739)	(0.407)	(0.877)	(0.544)	(0.544)	(0.726)
4.rdicat	1.330	0.938**	0.712	-0.233	0.253	0.444
	(0.812)	(0.409)	(0.705)	(0.500)	(0.541)	(0.780)
2.competitors	-1.595*	0.875	-0.735	-0.478	-1.310***	-0.425
	(0.912)	(1.323)	(0.857)	(1.313)	(0.357)	(0.982)
3.competitors	-2.105**	1.017	-0.380	-0.812	-1.263***	0.318
	(0.962)	(1.167)	(1.093)	(1.321)	(0.342)	(1.056)
4.competitors	-2.038**	0.435	-0.518	-0.349	-1.222***	0.208
	(0.985)	(1.360)	(1.071)	(1.201)	(0.462)	(0.791)
2.pricecat	0.271	0.533	0.932**	-0.330**	-0.124	-0.074
	(0.253)	(0.353)	(0.414)	(0.166)	(0.300)	(0.264)
3.pricecat	-0.105	0.869*	0.404	-0.947**	0.336	0.087
	(0.762)	(0.516)	(0.512)	(0.473)	(0.570)	(0.640)
legal	0.053	1.195**	0.319	1.024*	1.842***	0.901**
	(0.306)	(0.525)	(0.711)	(0.603)	(0.441)	(0.359)
strategic	1.480***	0.131	1.220***	0.702	-0.071	0.120
	(0.488)	(0.345)	(0.323)	(0.590)	(0.402)	(0.483)
cost_risk	0.521**	1.003***	0.221	0.109	0.271	0.141
	(0.224)	(0.196)	(0.345)	(0.253)	(0.311)	(0.181)
lack_tech	0.084	0.721	-0.603	0.127	-0.105	0.279
	(0.338)	(0.503)	(0.395)	(0.448)	(0.413)	(0.301)
lack_mkt	0.498**	-0.577	0.118	0.222	0.357	-0.235
	(0.219)	(0.382)	(0.391)	(0.213)	(0.352)	(0.372)
Constant	0.122	-3.839***	-4.801***	-0.430	-3.479***	-3.088***
	(1.019)	(1.358)	(1.177)	(1.501)	(0.724)	(1.179)
Observations	323	319	281	366	315	316

Notes:

(1) The categorical variables have as references: 1.rdicat, i.e., no investment in R&D; 1.competitors, i.e., no competitors; and 1.pricecat, i.e., low price elasticity.

(2) *** Significant at 1%, ** Significant at 5%, *Significant at 10%.

Industry

Table 4 presents the estimates for the industry dummies. Taking firms from the chemical sector as a reference, the results show that firms from the electric industry (*electric*) cooperate more with customers. Firms from the textile (*textil*), wood-paper (*woodp*), plastic (*plastic*), glass-ceramic (*glassc*), machinery (*machinery*) and transportation (*transport*) sectors are more likely to cooperate with suppliers. Cooperation with competitors is relevant for firms from the mining (*mining*), textile, glass-ceramic, electric, machinery and transportation industries. Firms from the mining, textile, electric and machinery are more likely to cooperate with universities. Cooperation with firms of the same group is important for firms from the mining, textile, plastic, glass-ceramic, and transportation industries. Finally, the propensity to cooperate with consultants is relevant for firms from the mining, textile, wood-paper, glass-ceramic, metal (*metal*), electric, machinery and furniture (*furniture*) industries.

The results do not show a consistent pattern which can explain the propensity to cooperate with a particular type of partner depending on the technological level of the industry. Thus, the results from the industry variables do not provide evidence on the propensity to cooperate with a certain type of partner. In conclusion, the firms' partner choice is mainly driven by competition intensity and appropriability measures.

Table 4 (continued)
Logit regressions

Variable	(1) coop_cust	(2) coop_supp	(3) coop_comp	(4) coop_unires	(5) coop_gr	(6) coop_cons
Industry sectors						
mining	0.838	0.132	1.790**	1.957***	0.695*	0.945**
	(0.550)	(0.301)	(0.697)	(0.534)	(0.362)	(0.429)
foodt	-1.324***	-0.408**	-	0.141	0.217	-0.039
	(0.347)	(0.207)		(0.451)	(0.216)	(0.374)
textil	-0.642**	1.020***	1.320***	1.036***	0.368***	1.270***
	(0.265)	(0.217)	(0.356)	(0.208)	(0.117)	(0.141)
woodp	-0.246	1.918***	-	-1.780***	0.085	1.168***
	(0.267)	(0.194)		(0.207)	(0.184)	(0.298)
plastic	0.085	0.634***	-0.059	0.297	0.681***	0.130
	(0.205)	(0.208)	(0.303)	(0.199)	(0.113)	(0.135)
glassc	-0.641***	0.310**	1.076***	0.394	0.542***	0.782***
	(0.220)	(0.135)	(0.175)	(0.253)	(0.200)	(0.109)
metal	0.360	0.307	0.423	0.302	-0.475**	0.683***
	(0.233)	(0.223)	(0.271)	(0.268)	(0.216)	(0.229)
electric	0.217***	0.194	0.948***	0.247***	0.001	0.299*
	(0.079)	(0.121)	(0.087)	(0.066)	(0.068)	(0.154)
machinery	-0.449***	0.242**	0.364**	0.532***	-0.764***	0.457***
	(0.115)	(0.111)	(0.142)	(0.139)	(0.171)	(0.102)
furniture	-0.662***	0.006	-0.142	0.168	-0.571***	0.319**
	(0.209)	(0.242)	(0.214)	(0.140)	(0.108)	(0.136)
transport	-0.953***	1.173***	2.507***	-1.102**	1.007***	0.517
	(0.345)	(0.440)	(0.564)	(0.542)	(0.375)	(0.464)
telecom	-	-	-	-	-	-
Observations	323	319	281	366	315	316

Notes:
(1) The industry of reference is chemicals.
(2) *** Significant at 1%, ** Significant at 5%, *Significant at 10%.

3.5 Discussion

In previous works, competition has either been ignored as a determinant of the partner choice for cooperative innovation, or it has been approximated by general or indirect measures.[22] To the best of our knowledge this is the first study that includes competition intensity as a determinant of cooperative partner choice. More precisely, two competition intensity variables are included: the number of competitors in the

[22] Many authors consider exports as a proxy for firms' participation in more competitive markets. Becker and Dietz (2004) use the Herfindahl index to estimate the impact of competition on the firm's propensity to cooperate.

core market (*competitors*), and the price elasticity (*pricecat*) reported by the firms. Our results show that competition intensity is a determinant for different types of collaborative innovation (e.g., with customers, suppliers, competitors, universities, or firms of the same group). Overall, the effect of competition is negative for cooperation with universities, customers and firms of the same group, and positive for cooperation with suppliers and competitors (and ambiguous for cooperation with consultants).

In order to explain these results, the different types of collaborative partnerships are classified in Figure 3.1 according to two dimensions: the intensity of innovation and the risk of disclosure. While collaboration with universities and customers aims at obtaining radical innovations, collaboration with suppliers and competitors typically produces incremental innovation (Fritsch and Lukas, 2001; Belderbos et al., 2004; Cassiman and Veugelers, 2002; de Faria et al., 2010). Regarding the risk of disclosure, it is lower in collaborations with closely-related partners (suppliers) and in collaboration with competitors, as the incentives to disclose information are symmetric, and the adoption of legal protection mechanisms is a pre-requisite for the existence of these partnerships (Arranz and Fdez. de Arroyabe, 2008). Differently, the risk of disclosure is higher in partnerships with universities and customers. Appropriation does not preoccupy firms when cooperating with universities (Veugelers and Cassiman, 2005), and the outflow of sensitive information can considered as a part of the regular flow of information between firms.

Therefore, when both the intensity of innovation and the risk of disclosure are high (north-east region in Fig. 3.1) the effect of competition on the propensity to cooperate is negative. On the other hand, this effect is positive when both the intensity of innovation and the risk of disclosure are low (south-west region in Fig. 3.1).

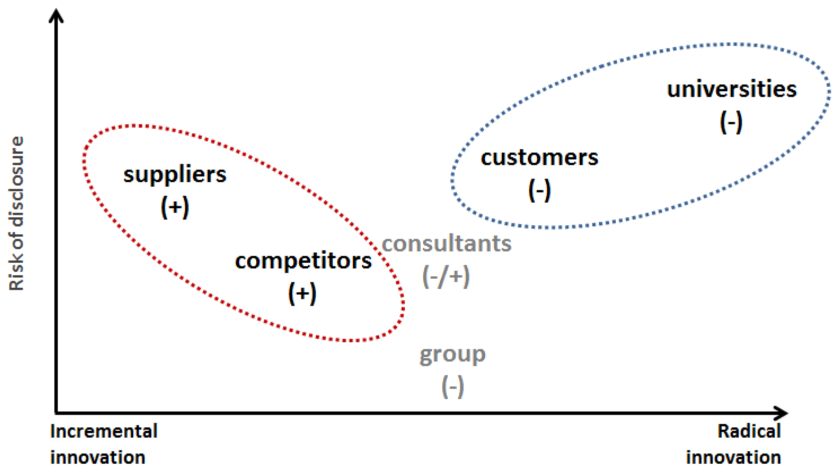

Fig. 3.1. Partnerships classification.

3.6 Concluding Remarks

This study is the first to analyse the effect of competition intensity as a determinant of cooperative partner choice. Competition intensity is measured by the number of competitors in the core market and the price elasticity reported by firms.

Using information from German firms for 2011, the results show that competition intensity is a determinant for different types of collaborative innovation (e.g., with customers, suppliers, competitors, universities, or firms of the same group). Overall, the effect of competition is negative for cooperation with universities, customers, and firms of the same group, and positive for cooperation with suppliers and competitors (and ambiguous for cooperation with consultants). Competition negatively affects partnerships with customers and universities, which look for radical innovation and involve high risks of disclosure. In contrast, competition positively influences partnerships with suppliers and competitors, which pursue incremental innovation and which involve a more egalitarian risk of information disclosure. These findings suggest that our results could be extended by considering the intrinsic risk of disclosure in collaborative agreements (which is exogenous in our analysis) and the innovation intensity of such agreements (incremental or radical innovation).

Several limitations of the present analysis call for further research on this topic. This study adopts a static perspective due to data availability. The use of panel data would allow firm-specific unobserved heterogeneity to be accounted for. Furthermore, a deeper analysis within industries would allow industry-specific appropriability and competition conditions to be included.

3.7 Appendix

Table A1
Description of variables

Variable	Definition
	Dependent variables
coop	Dummy variable =1 if the firm cooperates on innovation activities during the last three years (2008-2010).
coop_gr	=1 if the firm cooperates with firms within the same enterprise group.
coop_cust	=1 if the firm cooperates with customers or clients.
coop_supp	=1 if the firm cooperates with suppliers of equipment, materials, components, of software.
coop_comp	=1 if the firm cooperates with competitors or other enterprises of the same sector.
coop_unires	=1 if firm cooperates with universities, other higher education institutions, or governmental research institutes.
coop_cons	=1 if firm cooperates with consultants, commercial labs or private R&D institutes
	Independent variables
Firm characteristics	
size	Log of the average number of employees in the last three years.
exports	=1 if the firm reports positive exports in the last three years.
univ	=1 if the firm reports a percentage of employees with university degree above the average of the sample.
rdicat#	Categorical variable of the total R&D expenditure as a share of turnover. 1: no investment in R&D, 2: 0%<x=1%, 3: 1%<x=3%, 4: x>3%.
Market characteristics	
competitors#	Categorical variable of the number of the main competitors: 1: none, 2: 1 to 5, 3: 6 to 15, 4: more than 15.
pricecat#	Categorical variable of the level of applicability of the condition "price increase lead to immediate loss of clients": 1: applies not at all or very little, 2: applies somewhat, 3: applies fully.
Appropriability	
legal	Legal measures that the firm used to protect its IP during the last three years, and its importance: patents, trademarks, and copyright. x=0 if the firm has not used any of the measures, and 0<x=1 depending on the average importance of used measures.
strategic	Strategic measures that the firm used to protect its IP during the last three years, and its importance: secrecy, complex design, and lead time advantage. x=0 if the firm has not used any of the measures, and 0<x=1 depending on the average importance of used measures.
Obstacles to innovation	
cost_risk	Dummy variable =1 if the firm recognizes that high innovation cost and/or high financial risk provokes the ended/discontinued, not started, or extended duration of innovation projects.
lack_tech	Dummy variable =1 if the firm recognizes that lack of technological information provokes the ended/discontinued, not started, or extended duration of innovation projects.
lack_mkt	Dummy variable =1 if the firm recognizes that lack of market information provokes the ended/discontinued, not started, or extended duration of innovation projects
Industries	
See Table A2 for Industries description and the equivalence with the NACE Rev.2.	

Table A2

Description of industries and equivalence with NACE Rev.2 classification.

MIP Sector	Description	NACE Rev. 2
1	Mining	5-9, 19, 35
2	Food/Tobacco	10-12
3	Textiles	13-15
4	Wood/Paper	16-17
5	Chemicals	20-21
6	Plastics	22
7	Glass/Ceramics	23
8	Metals	24-25
9	Electrical equipment	26-27
10	Machinery	28
12	Furniture/Toys/Medical technology/Maintenance	31-33
15	Transport equipment/postal services	49-53, 79
17	IT/Telecommunications	61-63

Table A3
Correlation matrix

	coop	size	exports	univ	rdicat	competitors	pricecat	legal	strategic	cost_risk	lack_tech	lack_mkt
coop	1.00											
size	0.30*	1.00										
exports	0.24*	0.31*	1.00									
univ	0.19*	-0.02	0.11*	1.00								
rdicat	0.51*	0.28*	0.38*	0.30*	1.00							
competit	-0.06*	-0.06*	-0.01	-0.05*	-0.07*	1.00						
pricecat	-0.03	-0.03	-0.07*	-0.05*	-0.05	0.20*	1.00					
legal	0.34*	0.38*	0.34*	0.22*	0.47*	-0.09*	-0.04	1.00				
strategic	0.38*	0.31*	0.35*	0.25*	0.55*	-0.03	-0.08*	0.57*	1.00			
cost_risk	0.12*	0.07*	0.12*	0.12*	0.20*	0.04	0.06*	0.15*	0.19*	1.00		
lack_tech	0.07*	0.05	0.07*	0.00	0.13*	0.03	0.05*	0.07*	0.08*	0.25*	1.00	
lack_mkt	0.08*	0.07*	0.09*	-0.00	0.14*	0.01	0.06*	0.12*	0.10*	0.29*	0.55*	1.00
mining	-0.05	0.04	-0.21*	0.02	-0.11*	0.03	0.05*	-0.07*	-0.13*	-0.05*	-0.04	-0.04
foodt	-0.09*	-0.03	-0.18*	-0.15*	-0.12*	0.06*	0.06*	-0.05*	-0.09*	-0.04	0.00	0.01
textil	-0.02	-0.09*	0.11	-0.06*	-0.04	0.02	0.04	-0.00	-0.04	-0.02	0.04	0.03
woodp	-0.09*	-0.02	0.04	-0.11*	-0.09*	0.02	0.03	-0.05*	-0.07*	-0.01	0.00	0.01
chemical	0.10*	0.05*	0.14	0.14*	0.20*	-0.01	-0.03	0.16	0.15*	0.06*	0.03	0.03
plastic	0.01	0.00	0.12	-0.08*	-0.00	0.03	-0.02	-0.01	0.03	0.1	-0.01	-0.02
glassc	0.02	0.01	0.00	-0.04	0.02	-0.04	0.01	0.02	0.01	-0.00	0.02	-0.00
metal	-0.02	0.06*	0.09*	-0.11*	-0.02	0.03	0.00	-0.04	0.00	-0.01	-0.03	-0.01
electric	0.13*	0.06*	0.20*	0.18*	0.33*	-0.02	-0.04	0.15*	0.19*	0.06*	0.06*	0.04
mach.	0.10*	0.16*	0.17*	0.07*	0.21*	-0.06*	-0.04	0.16*	0.16*	0.07*	0.01	0.03
furniture	-0.04	-0.07*	-0.03	-0.05*	-0.04	-0.01	-0.06*	-0.04	-0.04	0.02	-0.01	0.00
transport	-0.12*	-0.06*	-0.30*	-0.12*	-0.20*	-0.05*	0.06*	-0.18*	-0.21*	-0.07*	-0.05	-0.05*
telecom	0.01	-0.09*	-0.08*	0.32*	-0.12*	-0.00	-0.06**	0.01	0.08*	0.01	-0.02	-0.04

*Level of significance at 0.01
See Table A1 for the description of the variables

Table A3 (continued)
Correlation matrix

	mining	foodt	textil	woodp	chemical	plastic	glassc	metal	electric	machinery	furniture	transport	telecom
mining	1.00												
foodt	-0.09*	1.00											
textil	-0.07*	-0.08*	1.00										
woodp	-0.07*	-0.08*	-0.06*	1.00									
chemical	-0.06*	-0.07*	-0.06*	-0.06*	1.00								
plastic	-0.07*	-0.07*	-0.06*	-0.06*	-0.06*	1.00							
glassc	-0.05*	-0.06*	-0.05*	-0.05*	-0.05*	-0.05*	1.00						
metal	-0.10*	-0.11*	-0.09*	-0.08*	-0.08*	-0.08*	-0.07*	1.00					
electric	-0.09*	-0.10*	-0.08*	-0.08*	-0.08*	-0.08*	-0.07*	-0.12*	1.00				
mach.	-0.08*	-0.09*	-0.07*	-0.07*	-0.07*	-0.07*	-0.06*	-0.10*	-0.10*	1.00			
furniture	-0.09*	-0.10*	-0.08*	-0.08*	-0.08*	-0.08*	-0.07*	-0.12*	-0.11*	-0.10*	1.00		
transport	-0.11*	-0.12*	-0.10*	-0.09*	-0.09*	-0.09*	-0.08*	-0.14*	-0.13*	-0.11*	-0.13*	1.00	
telecom	-0.07*	-0.09*	-0.07*	-0.07*	-0.06*	-0.06*	-0.05*	-0.09*	-0.09*	-0.08*	-0.09*	-0.11*	1.0

*Level of significance at 0.01
See Table A1 for the description of the variables

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