Information Sharing, Research Co-ordination and Membership of Research Joint Ventures*

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Abstract

This paper examines which firms from a heterogeneous pool are more likely to join together and form a RJV. It differs from previous contributions as it introduces a set of realistic hypothesis on the characteristics of research co-operation and information sharing. Research paths can be substitute or complementary. This affects the nature of and consequently the gains from co-operation. The model shows that gains from co-operation are likely to be larger in the second case, as the probability of making a discovery is higher. This paper also assumes that firms do not share information voluntarily if they do not co-operate only when the firms' products are substitute. If the firms' products are complementary there may be gains in sharing information also under non co-operation. This eliminates the gains from co-operation arising from information sharing. If this is the case, RJVs are more likely to be formed between firms producing substitute products. If we combine these two results we have the prediction that firms co-operate in research when they produce substitute products and when they follow complementary research paths. The empirical analysis carried out on a sample of European RJVs confirms and supports this prediction. The model also carefully explores the role of asymmetries in costs between the two firms. It shows that it is not possible to derive clear cut predictions. Under some circumstances larger asymmetries increase the gains from co-operation and under other circumstances they reduce them. Also this result is supported by the empirical analysis.

1. Introduction

Over the last fifteen years there has been a considerable amount of interest amongst academics and policymakers in the role of research joint ventures (RJVs) in improving innovative performance[4]. The main focus of interest has been on the performance of RJVs once they have formed, and in contrasting this with the performance of firms in the absence of co-operation. A central reference in much of this literature is the paper by d'Aspremont and Jacquemin (1988), which has subsequently been much developed - in particular by Kamien, Muller and Zang (1992).

More recently interest has shifted to the issue of RJV membership. There are two strands to this literature.

The first assumes a pool of identical firms and seeks to explain how many will join an RJV i.e. the size of the RJV[5].

The second strand of literature assumes that an RJV comprises just two firms, but seeks to explain which two firms from a heterogeneous pool are most likely to join an RJV.

The most recent paper in this strand is by Röller, Tombak and Siebert (1997). They extend the framework developed by Kamien, Muller and Zang (1992) in two ways. First, instead of assuming that products are perfect substitutes, they allow for a variable degree of product substitutability, and indeed allow products to be complements. Second they allow for asymmetries in the initial cost levels of the two firms. They argue that their model therefore captures four incentives for firms to form RJVs, the first two of which were present in the original papers cited above. These incentives are:

(i) cost-sharing through the reduction of needless duplication;
(ii) the internalising of externalities (spillovers);
(iii) exploitation of product complementarities;
(iv) the possibility of exploiting market power to the extent that large firms choose to form RJVs with other large firms.

They conclude that the gains from RJV formation are highest when: (a) R&D spillovers create free rider problems; (b) duplicative R&D creates opportunities for cost-sharing;
(c) firms produce complementary products; (d) firms are of fairly similar size.

They test this model on a sample of US firms in RJVs, and obtain some empirical confirmation of the results.

There are, however, a number of limitations of the theoretical framework employed by Röller, Tombak and Siebert (1997) – and indeed in the theoretical framework by Kamien, Muller and Zang (1992) on which it draws[6]. These limitations follow from the fact that, as in the bulk of the literature on RJVs, the focus is purely on the amount of R&D that

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[4] See for example the book by Poyago -Theotoky (1997) which brings together some recent surveys and contributions.
[5] See for example Ulph(1991), Suzumura and Goto (1994), Poyago-Theotoky (1995), De Bondt and Wu (1997).
[6] See the recent series of papers by by Beath, Poyago-Theotoky and Ulph (1998), Katsoulacos and Ulph (1998a, b & c), and by Ulph (1990) for a fuller discussion of the points that follow.

firms do, and little serious attention is paid to two other crucial parts of the innovation process – information-sharing and research coordination.

First, they ignore an important aspect of RJV behaviour – **research co-ordination**. This comprises two separate decisions.

?? The first is choosing the number of labs that the RJV will operate. This is particularly important where the research paths firms are pursuing are *duplicative* (or *perfect substitutes*)[7], and so firms run the risk of needless duplication. Unlike two independent firms, an RJV has the option of choosing to operate a single lab rather than two separate labs, thereby avoiding this duplication.

?? The second aspect is research design co-ordination. This arises in the opposite case where research paths are *additive* (or *perfectly complements*)[8]. Here, in order to fully exploit these complementarities, firms will typically need to get together and plan out the detailed design of their individual research strategies. This degree of collaboration would normally be ruled out by competition policy, but could be undertaken by an RJV if, as we will assume, RJVs were given exemption from competition policy.

As we can see there are two important features of research co-ordination: it is an activity that has to take place **before** any R&D is undertaken; both aspects of research co-ordination would be impossible in the non-cooperative equilibrium.

Röller, Tombak and Siebert (1997) acknowledge that they do not model the ability of an RJV to exploit complementarities[9] - the second aspect of research co-ordination. However they simply assume that the RJV operates two labs and so do not recognise that they have not allowed for the first aspect of research co-ordination.

This brings us to the second weakness of their model. Röller, Tombak and Siebert (1997) assume that in the non-cooperative equilibrium the progress that each firm makes depends solely on its own R&D, whereas in the RJV each firm's progress depends on the combined R&D of the two firms. They interpret this as reflecting the cost sharing benefit conferred by RJVs through eliminating duplication. Now it is certainly true that this assumption implies that the RJV can achieve a given amount of progress for each of its two firms with a lower total R&D outlay than if the two firms operated independently. However the fact that the total progress made in the RJV depends on the total R&D of each of the two firms means that they are implicitly assuming that research paths are

[7] The notion of duplicative research is formalised in Katsoulacos and Ulph (1998b) (where it is referred to as perfect substitute research) through the idea that if $p_i,\ \ i ? 1,2$ is the progress made by firm *i* as a result of its own research effort, while $?_{ij},\ \ 0 ? ?_{ij} ? 1$ is the fraction of the progress made by firm *j* which is shared with firm *i*, then the total amount of progress made by firm *i* is $t_i ? MAX\{p_i, ?_{ij}.p_j\}$.

[8] The notion of additive research is formalised in Katsoulacos and Ulph (1998b) (where it is referred to as perfect complement research) through the idea that if $p_i,\ \ i ? 1,2$ is the progress made by firm *i* as a result of its own research effort, while $?_{ij},\ \ 0 ? ?_{ij} ? 1$ is the fraction of the progress made by firm *j* which is shared with firm *i*, then the total amount of progress made by firm *i* is $t_i ? p_i ? ?_{ij}.p_j$.

[9] This may not be strictly correct. As pointed out below, they make an assumption about how the RJV operates which is open to a number of interpretations. One possible interpretation is that in the non-cooperative equilibrium firms are unable to engage in research design co-ordination, and so are unable to exploit any complementarities, while the RJV definitely can engage in full research design co-ordination and so can fully exploit complementarities.

perfect complements. This is hard to square with the avoidance of duplication – for this arises when research paths are perfect substitutes and the RJV chooses to operate a single lab.

An alternative interpretation of what is happening in their model is that they are implicitly assuming that in the non-cooperative equilibrium firms would never share any information that they discover, whereas in the RJV firms would always fully share information about the discoveries they had made. As noted, this certainly implies that the RJV can obtain any given total progress at a lower R&D cost than is possible in the non-cooperative equilibrium - but this cost reduction really stems from the full exploitation of research output information sharing rather than from avoiding duplication.

This alternative interpretation is significant because if the major gain from the RJV comes from research output information-sharing, this raises the question as to why this could not be shared in the non-cooperative equilibrium. As noted in Katsoulacos and Ulph (1998a, b & c) there are two ways in which information about research output could be shared in the non-cooperative equilibrium. The first is through licensing. For a variety of well known reasons licensing may not always operate. The second route is through firms simply revealing the information free of charge. As noted in Katsoulacos and Ulph (1998a & b), it is precisely when firms produce complementary products that they would have incentives to share information in this way, even if licensing is not available. This suggests that *ceteris paribus* the gain from forming an RJV might be smaller when firms produce complementary products than when they produce substitute products.

The aim of this paper is to develop a theoretical framework that addresses these two weaknesses of the Roller, Tomak and Siebert (1997), and then to test out this framework on two European data sets for RJVs. The paper addresses very relevant policy issues related to the promotion of R&D. *First*, it examines whether RJVs are formed between firms in substitute or in complementary industries: this is a fundamental factor affecting the efficiency of RJVs, the location of research and possible anti-competitive behaviour. *Second* it looks at the asymmetry between firms in RJVs in terms of relative size and efficiency and at the related implications for the diffusion of research. Indeed, RJVs can favour the concentration or the dispersion of research activities depending on the characteristics of the partners. The more similar the partners, the more we expect investments in R&D to be concentrated.

The plan of the paper is as follows. In the next section we set out a very simple model of RJV formation and behaviour which allows for

(a) both types of research co-ordination explored above;
(b) endogenous information sharing – particularly in the non-cooperative equilibrium.

We show that such a framework can give strikingly different predictions from those of the Roller, Tombak and Siebert (1997). In particular we show:

(i) RJVs are more likely to form where there are significant gains to be had from research co-ordination.
(ii) The two types of research co-ordination are strict alternatives. The gains from avoiding needless duplication arise when research paths are substitutes and are realised when the RJV operates a single lab. However the gains from exploiting

complementarities (through careful research design) arise when research paths are complementary, and require the RJV to keep both labs open.

(iii) Another potential gain from RJV formation comes from increased information sharing. However this gain only arises when there is no information sharing in the non-cooperative equilibrium, and this will only be true when firms produce substitute products. Hence *ceteris paribus* RJVs are more likely to form when firms produce substitute rather than complementary products.

(iv) The effect of initial asymmetries on RJV formation is ambiguous.

We then test this model out on two European data sets on RJVs and show that these theoretical predictions are confirmed.

2. The Theoretical Framework

2.1 The Model and Assumptions

There are 2 firms. The products they produce can be either substitutes or complements. For concreteness we assume that demands for the two products are given by

$$p_i \; ? \; a \; ? \; q_i \; ? \; sq_j, \quad i, j \; ? \; 1{,}2; \quad j \; ? \; i,$$

where $a > 0$ and $s \; ? \; [?1{,}1]$. Positive values of s correspond to substitute goods – negative values to complements.

The technologies that firms use have constant average and marginal costs of production. We allow for the possibility that *prior* to any technological innovation, the firms may have different technologies, and hence may start with *ex ante* cost asymmetries[10]. This initial asymmetry may be the result of asymmetric innovative success in a previous R&D competition. Thus we assume that the *initial* unit costs of the two firms are

$$\bar{c} \, ? \, ? \quad \text{and} \quad \bar{c} \, ? \, ?, \quad \text{where} \quad 0 \, ? \, ? \, ? \, \bar{c} \, ? \, \bar{c} \, ? \, ? \, ? \, a.$$

Notice that, as in Roller, Tombak and Siebert (1997), initial asymmetries are formulated in such a way that, prior to any innovation, the average unit costs, and so the aggregate output of the two firms is independent of the size of the asymmetry.

Firms undertake R&D in order to discover better technologies with lower unit costs. We will assume a stochastic model of innovation. Thus expenditure on R&D determines the probability that a firm will make a discovery. We assume that if a firm makes a discovery on its own it will end up with a new technology with unit costs

$$\underline{c} \; ? \; \bar{c} \; ? \; ? \, .$$

We need to specify the nature of the innovative process. Three important distinctions have been made in the literature.

The first is between *tournament* and *non-tournament* models of innovation. In a *non-tournament* model there are many different ways of obtaining the same technology (as specified by the level of costs). A firm that discovers one way of obtaining a given technology, and patents that discovery, cannot prevent another firm from discovering the same technology by some different route, and also patenting its discovery. Thus in a *non-tournament* model patents protect firms from costless imitation by non-innovators, but cannot protect firms from independent discovery by rival innovators. By contrast, in a *tournament* model there is a unique way of obtaining any given technology, and only one firm can hold a patent on it. R&D competition therefore takes the form of a race to be first to make the unique discovery. In this paper we will follow the bulk of the literature on RJVs and assume that the innovation process is a *non-tournament* one.

[10] Since R&D is stochastic it is possible for *ex post* cost asymmetries to arise if one firm succeeds in innovating and information is not fully shared.

The second key distinction that has been made in characterising innovative processes is that between *leapfrogging* and *catching-up*[11]. This distinction relates to the dynamics of the innovative process.

With *leapfrogging*, all firms end up discovering exactly the same new technology, whatever technology they currently employ. Thus suppose that at a particular time firm 1 employs the latest technology - say technology k - while firm 2 is using some earlier technology – say technology $j < k$. Then under *leapfrogging* the technology each firm will discover as a result of its R&D effort is technology $k+1$. One way to think of this innovative process as arising is as follows. Suppose that patents provide complete protection to whoever has discovered the latest technology, so the only firms that can **use** this technology in production are those that have discovered it themselves or those that been granted a license to use it. However, while patents protect the *technology* all the scientific knowledge underlying this latest technology is common, so all firms can use this knowledge as the starting point of their own R&D effort. Consequently all firms can potentially discover exactly the same new technology, whatever technology they currently employ. Thus under *leapfrogging* if *both* firms make a discovery then initial cost asymmetries are eliminated.

By contrast, in *catch-up*[12] models all firms obtain exactly the same amount of cost-reduction if they succeed in innovating. Thus suppose again that at a particular time firm 1 employs the latest technology – say technology k - while firm 2 is using some earlier technology – say technology $j < k$. Then, under *catch-up*, if firm 1 makes a discovery, it will discover technology $k+1$, while if firm 2 makes a discovery it will only discover technology $j+1$. This situation will arise if innovation requires that firms have to make exactly the same sequence of discoveries by themselves, and cannot benefit from R&D done by others. Thus under *catch-up* if *both* firms make a discovery initial cost asymmetries are maintained.

In what follows we will focus mainly on what happens under leapfrogging and then briefly note what happens under catch-up.

The third distinction is between those cases where firms are effectively following *duplicative* (or substitute research paths) and those where the research paths are *additive* (or complementary). This distinction matters when both firms succeed in making a discovery. When firms are pursuing *duplicative* research then, if both discover, neither can gain anything by sharing information about what it has discovered with the other. By contrast, when firms are pursuing *additive* research paths then, when they both discover, they can potentially benefit from sharing information since, by combining their discoveries they can each achieve a better technology than they can obtain by relying solely on their own discovery. The extent of this improvement will depend on not just how much information they share, but on how far they have been able to co-ordinate their research designs so as to fully exploit this complementarity. We assume that if research paths are complementary, if this complementarity is fully exploited and information is fully shared, then firms end up with a technology with unit costs

[11] For an analysis of how these different types of innovative process affect the pace of innovation, see Encaoua and Ulph (2000).

[12] Catch-up is sometimes referred to as step-by- step innovation, or gradual adjustjment.

$$\underline{\underline{c}} ? \underline{c}.$$

To understand the implications of these distinctions for the behaviour of firms in both the cooperative (RJV) and non-cooperative equilibrium – and hence the private gains to firms from joining an RJV, we are going to consider a 5-stage game.

In Stage 1 firms decide whether or not to join an RJV. In Stage 2 they make their research co-ordination decisions. In the case where research paths are *substitute* this amounts to choosing the number of labs to operate. In the case where research paths are *additive* this amounts to choosing the research design and hence the degree of complementarity that can be exploited. In Stage 3 they choose the amount of R&D that each lab will do. In Stage 4 they choose whether or not to share any information arising from any discoveries that they have made. Finally, in Stage 5 they choose output.

We assume that the output decisions at Stage 5 are made non-cooperatively, and, as pointed out above, the non-cooperative equilibrium concept that we use is that of Cournot.

We will contrast the outcomes when the decisions made at the previous 3 stages are made non-cooperatively, with those that are made in a cooperative RJV equilibrium. This enables us to determine the private gains that firms obtain if the choose to form an RJV at Stage 1.

Now providing a general analysis of both the cooperative and non-cooperative outcomes for such a 5-stage model is extremely complicated. To make progress, and to highlight the special role that the information-sharing and research co-ordination benefits of RJVs can bring, we are going to make the following simplifying assumptions. We will subsequently relax almost all of them.

A.1) There are no spillovers – defined as unrewarded, unintentional leakages of information. This assumption is also made by Roeller, Tombak and Siebert (1997). Incorporating spillovers into the model is fairly straightforward when firms are identical but it would greatly lengthen and complicate the analysis when there are initial cost asymmetries.

A.2) If a lab operates then it has a fixed probability of discovery $\bar{p}$, $0 ? \bar{p} ? 1$ for which it has to incur an R&D cost $x > 0$. This means that there is no effective decision to be made at Stage 3. We will call this the *exogenous R&D* case. This assumption is effectively equivalent to assuming that there is an R&D cost function $?(p)$ with the property that, for some very small $?$, $?'(p) ? 0$, $0 ? p ? \bar{p} ? ?$, $?'(p) ? ?$ as $p ? \bar{p}$. Later on we will consider what happens when we replace this the more usual assumption of a general quadratic R&D cost function in which we have *endogenous R&D*.

A.3) In the non-cooperative equilibrium:

(i) Licensing is impossible. This means that if only one firm discovers then, following Katsoulacos and Ulph (1998a & b), no information is voluntarily shared if $s > 0$; but information is fully shared if $s < 0$.

(ii) Research co-ordination is impossible. Hence, if both firms discover each firm ends up with costs $\underline{c} ? \bar{c} ? ?$, whether research paths are *duplicative* or *additive*.

A4) In the cooperative (RJV) equilibrium the following is true.

(i) It is a requirement of joining the RJV that full information sharing takes place[13].

(ii) If the RJV chooses to operate 2 labs it can achieve full R&D coordination in the case where research paths are complementary.

(iii) However, the RJV can also choose to concentrate all R&D in a single lab.

With these assumptions, in the next sub-section we will set out the analysis of RJV formation for our central case. In the following subsection we will consider how the conclusions are altered when we drop the various assumptions.

2.2 *The Central Case: Leapfrogging, Exogenous R&D, No Initial Cost Asymmetries.*

We set out the analysis for the full 5-Stage game.

<u>Stage 5: Output</u>

As mentioned above we assume that output is always set in a non-cooperative Cournot equilibrium. Consequently, it follows from standard theory that if one firm has (constant) marginal costs $\gamma < a$ while the other has (constant) marginal costs $\delta < a$ then, if both firms are active in equilibrium, the first firm's equilibrium operating profits will be

$$\pi(\gamma, \delta) = \left[\frac{(2+s)a - 2\gamma - s\delta}{4 - s^2}\right]^2 .$$

Notice that if goods are substitutes, $s < 0$, then this firm's profits are reduced by any improvement in the other firm's technology (reduction in δ) while if goods are complements ($s > 0$) then the firm benefits from any improvements in the other firm's technology.

<u>Stage 4: Information Sharing</u>

To see what happens here we need to consider various possible outcomes of the R&D process at the Stage 3.

There are only three possible outcomes.

(i) Neither firm succeeds in making a discovery.

Here there is no information be shared. Both firms will have initial technology with unit costs $\bar{c}$, so each makes profits $\pi_{00} = \pi(\bar{c}, \bar{c})$. Joint profits will be $\Pi_{00} = 2\pi_{00}$.

(ii) Only one firm succeeds in making a discovery.

Whichever firm this is, it obtains a technology with costs $\underline{c} < \bar{c}$.

[13] Later on we will assume that in fact firms will always want to share information in the RJV, so this requirement is innocuous.

In an RJV this firm will fully shares information with the other firm that has not made a discovery, so both firms will have costs $\underline{c}$ and profits $?_{11} ? ?\left(\underline{c},\underline{c}\right)$. Joint profits are $?_{11} ? 2?_{11}$.

In the non-cooperative equilibrium no information is shared. The firm making the discovery has costs $\underline{c}$ while the other has costs $\bar{c}$. The firm making the discovery will have profits $?_{10} ? ?\left(\underline{c},\bar{c}\right)$ while the firm that failed to discover makes profits $?_{01} ? ?\left(\bar{c},\underline{c}\right)$. Joint profits are $?_{10} ? ?_{10} ? ?_{01}$.

(iii) Both firms make a discovery

Here we have to recognise two separate cases.

(a) The discoveries are duplicates (perfect substitutes).

In this case each firm will again end up with costs $\underline{c}$ - however much information is shared. So individual and joint profits in both the RJV and the non-cooperative equilibrium are $?_{11}$ and $?_{11}$ respectively.

(b) The discoveries are additive (perfect complements).

We have assumed that through research design co-ordination and full information-sharing, the RJV can fully exploit this complementarity. Thus the two firms will each have a technology with costs $\underline{\underline{c}} ? \underline{c}$. Each firm in the RJV will have profits $?_{22} ? ?\left(\underline{\underline{c}},\underline{\underline{c}}\right)$ while their combined profits will be $?_{22} ? 2?_{22}$.

We have assumed that in the non-cooperative equilibrium firms are unable to co-ordinate their research designs and unable to share information. So each firm will end up with costs $\underline{c}$ while individual and joint profits are $?_{11}$ and $?_{11}$ respectively.

Stage 3 R&D

Given our assumptions in this section each lab that operates will spend x on R&D and have a probability of discovery $\bar{p}$, $0 ? \bar{p} ? 1$.

Stage 2 Research Design

In the non-cooperative equilibrium there are no decisions to make. Each firm operates a lab and ends up pursuing an independently chosen path. The expected joint profits of the two firms from being in the non-cooperative equilibrium are therefore:

$$V^n ? \bar{p}^2 ?_{11} ? 2\bar{p}.\left(1 ? \bar{p}\right).?_{10} ? \left(1 ? \bar{p}\right)^2 .?_{00} ? 2x \qquad (1)$$

if goods are substitutes, and

$$V^n = \left[1 - (1 - \bar{p})^2\right]\pi_{11} + (1 - \bar{p})^2 \cdot \pi_{00} - 2x \qquad (2)$$

if they are complements.

In the RJV firms can choose whether to operate 1 lab or 2 labs. If it operates 1 lab it will be unable to exploit any complementarities in the case where research paths are additive, but can avoid duplication where research paths are duplicative.

The expected profits with one lab are therefore

$$V_1^c = \bar{p} \cdot \pi_{11} + (1 - \bar{p})\pi_{00} - x \qquad (3)$$

while the expected profits with 2 labs are:

$$V_2^c = \left[1 - (1 - \bar{p})^2\right]\pi_{11} + (1 - \bar{p})^2 \cdot \pi_{00} - 2x \qquad (4)$$

if research paths are duplicate, and

$$V_2^c = \bar{p}^2 \pi_{22} + 2\bar{p} \cdot (1 - \bar{p}) \cdot \pi_{11} + (1 - \bar{p})^2 \cdot \pi_{00} - 2x \qquad (5)$$

if research paths are additive.

The expected profits of an RJV are therefore

$$V^c = MAX\left\{V_1^c, V_2^c\right\}. \qquad (6)$$

To understand when the RJV will choose to operate 2 labs consider first the case where research paths are duplicate. Then it follows from (3) and (4) that

$$\left(V_2^c - V_1^c\right) = \left[\bar{p} \cdot (1 - \bar{p}) \cdot (\pi_{11} - \pi_{00}) - x\right]. \qquad (7)$$

The intuition is clear. The gain to the RJV from operating 2 labs is that it gives it an extra chance of making a discovery if one of the labs fails to discover. This gain is given by the term $\bar{p} \cdot (1 - \bar{p}) \cdot (V_{11} - V_{00})$. However the additional R&D cost is *x*. So what (7) tells us that the RJV will operate 2 labs iff the gain from doing so outweighs the cost.

When research paths are additive then (7) becomes:

$$\left(V_2^c - V_1^c\right) = \left[\bar{p}^2 \cdot (V_{22} - V_{11}) + \bar{p} \cdot (1 - \bar{p}) \cdot (\pi_{11} - \pi_{00}) - x\right]. \qquad (8)$$

Again the intuition is clear. When research paths are additive then an additional gain from operating two labs is that it gives the chance of having both labs discover and exploit the complementarity. Notice that if R&D costs x are sufficiently large an RJV may choose to forego the gains from complementarity in order to reap the gains from avoiding duplication.

Stage 1. RJV Formation.

To consider the gain to the two firms from forming an RJV it is worth considering a number of cases.

(i) Substitute Products, Duplicative Research Products.

It follow from (1), (3) and (4) that that gain to forming an RJV is

$$G^{sd} ? ?2\overline{p}.?1 ? \overline{p}?.??_{11} ? ?_{10}?? ? MAX ??x ? \overline{p}.?1 ? \overline{p}?.??_{11} ? ?_{00}??, 0? \qquad (9)$$

The first term on the RHS of (9) is the **information-sharing** gain. The sign of this term depends on the sign of $?_{11} ? ?_{10}$. There are three cases.

(a) If $?_{11} ? ?_{10}$ is positive, then the inability of firms to share information through licensing in the non-cooperative equilibrium confers a real gain on the RJV. While we have assumed that the RJV is required to share information, if this term is positive then the RJV would indeed always share information even if it had a choice in the matter, so the assumption is innocuous in this case.

(b) If $?_{11} ? ?_{10}$ is negative then the obligation on firms to share information if they choose to join an RJV imposes a cost on forming an RJV. Notice that in this case, our assumption that the firms are unable to license in the non-cooperative equilibrium becomes innocuous, because, if they could licence, they would choose not to.

(c) Finally note that if firms were able to licence in the non-cooperative equilibrium and able to choose whether or not to share information in the RJV then this term would be zero.

Now since information sharing is thought to be one of the major advantages of RJV formation, in all that follows we will assume that

$$?_{11} ? ?_{10} \qquad (10)$$

so that information-sharing is desirable.

The second term on the RHS of (9) is the **research co-ordination** gain. In this case the gain from research co-ordination comes from the possible gains from avoiding duplication. Our discussion above has highlighted when this gain will arise.

(ii) *Complementary Products, Duplicative Research Paths*

Using (2), (3) and (4) we now find that

$$G^{cd} ? MAX ? ?x ? \overline{p}.?1 ? \overline{p}?.?? _{11} ? ? _{00} ??,0? . \quad (11)$$

The intuition is clear – when products are complementary then firms will share information without any licence, so the only gain from RJV formation is that from **research co-ordination.**

(iii) *Substitute Products, Additive Research Paths*

From (1) (3) and (5) it follows that

$$G^{sa} ? ?2\overline{p}.?1 ? \overline{p}?.?? _{11} ? ? _{10} ?? ? MAX ? ?x ? \overline{p}.?1 ? \overline{p}?.?? _{11} ? ? _{00} ??, \overline{p}^{2}.?? _{22} ? ? _{11} ? \quad (12)$$

If we compare this with (9) we see that the **research co-ordination** gain is now the maximum it can get from avoiding duplication by operating a single lab, and the gain from fully exploiting complementarities through operating two labs and fully co-ordinating research designs.

(vi) *Complementary Products, Additive Research Paths*

From (2) (3) and (5) it follows that

$$G^{ca} ? MAX ? ?x ? \overline{p}.?1 ? \overline{p}?.?? _{11} ? ? _{00} ??, \overline{p}^{2}.?? _{22} ? ? _{11} ? \quad (13)$$

If we compare this with (12) we see that, just as case (ii) above, the fact that products are complementary means that there are no gains from information-sharing.

To understand what (9), (11)-(13) imply for the magnitudes of the gains from forming an RJV, in what follows we will make the *ceteris paribus* assumption that the magnitudes of the numbers $?_{ij}$, $?_{ij}$ $i, j ? 0,1,2$ are independent of whether products are substitutes or complements, and whether research paths are additive or duplicative.

Result 1 *Ceteris paribus*, we have the following ranking of gains from RJV formation:

$$G^{sa} ? G^{ca} ? G^{cd}; \quad G^{sa} ? G^{sd} ? G^{cd} .$$

Corollary 1 Firms are more likely to form an RJV when products are substitutes and research paths are additive

The intuition is as follows. Consider in turn the two types of gain.

Information Sharing When products are complements, there are undoubted gains to be had from sharing information, but, since firms have private incentives to realise these when acting non-cooperatively, there is a smaller gain to be had from forming an RJV than in the case where products are substitutes and there are no such private incentives ti share information voluntarily.

Research Co-ordination When research paths are additive, then the RJV can realise whatever gains there are to be had from avoiding duplication by operating a single lab and avoiding duplication, but can, in addition obtain gains from operating two labs and fully achieving research design co-ordination. It will pursue this option only if these gains exceed the gains from avoiding duplication.

The conclusion that firms are more likely to form an RJV when products are substitutes is in sharp contrast with the conclusion by Roller Tombak and Siebert (1997) that the incentives to form an RJV are higher when firms produce complementary products.

However there are a number of qualifications to be made to this result.

(i) The result depends crucially on the two assumptions that licensing is impossible in the non-cooperative equilibrium, and that the inequality in (1) holds. If licensing is possible then, as Katsoulacos and Ulph (1998c) show , licensing will also take place whenever (1) holds, so there will be no information gain – whether products are substitutes or complements. If (1) does not hold, then there will be no information shared in either the cooperative or the non-cooperative equilibrium – so once again there will be no information gain from being in an RJV.

(ii) The *ceteris paribus* assumption is almost certainly the wrong one. Thus it is hard to think of cases where firms producing complementary products are doing duplicative research – though it is perfectly possible for firms producing substitute goods to be doing additive research. If the gains from exploiting research design complementarities are higher than those from avoiding duplication, then, on average, the gains from joining an RJV may be higher when firms produce complementary goods rather than substitute goods.

(iii) Finally we have ignored the effects of RJV formation on the amount of R&D that firms do.

So it is not very clear how the degree of complementarity of the industry would affect incentives to join an RJV.

Having obtained the results for our core case, in the next sub-section we will consider a number of extensions.

2.3 Extensions

We consider in turn a number of extensions.

2.3.1 Initial Cost Asymmetries

To understand how profits are affected when the firms are initially asymmetric, notice that, because of the leapfrogging assumption, asymmetries will matter only when one firm alone has discovered (and information is not shared), and when neither has discovered.

(i) Only 1 Firm Discovers

This situation can arise in two ways – it can be the initial high-cost or low-cost firm that makes the discovery. Let

$$?_{10}(?) ? \frac{1}{2} ?? ?\underline{c}, \bar{c} ? ? ?? ? ?\bar{c} ? ?, \underline{c}?? ? ?\underline{c}, \bar{c} ? ? ?? ? ?\bar{c} ? ?, \underline{c}?? ? ?_{10} \qquad (14)$$

The first term on the RHS of this expression is the average combined profits of the two firms in each of the two situations where only one of them makes a discovery, (and no information is shared) but now firms have different initial costs. From this we subtract the combined profits of the two firms where only one makes a discovery and no information is shared, but firms have identical initial costs. This can be thought of as a "correction term" to take account of initial asymmetries in the case where only one firm discovers and no information is shared.

Obviously $?_{10}(0) ? 0$. It is straightforward to show that

$$\frac{??_{10}}{??} ? \frac{2? ?4 ? s^2 ?}{?4 ? s^2 ?^2} ? 0$$

so that the correction factor is increasing in the degree of asymmetry.

In what follows we will assume that the analogue of (10) holds when there are cost asymmetries, i.e. that

$$?_{11} ? ?_{10} ? ?_{10} \qquad (15)$$

which will again ensure that the RJV will always fully share information – see Katsoulacos and Ulph(1998a&b).

(ii) Neither firm discovers

Let

$$?_{00} ? ?? ?\bar{c} ? ?, \bar{c} ? ? ?? ? ?\bar{c} ? ?, \bar{c} ? ? ?? ? ?_{00}$$

be the "correction term" that needs to be made to combined profits to take account of initial asymmetries in the case where neither firm has discovered. It is straightforward to show that

$$\frac{??_{00}}{??} ? \frac{4? ?2 ? s?^2}{?4 ? s^2 ?^2} ? 2\frac{??_{10}}{??} ? 0. \qquad (16)$$

The gains from RJV membership now become:

$$G^{sd} ? ?2\bar{p}.?1 ? \bar{p}?.??_{11} ? ?_{10} ? ?_{10}?? ? MAX ??x ? \bar{p}.?1 ? \bar{p}?.??_{11} ? ?_{00} ? ?_{00}??, 0? \qquad (17)$$

$$G^{cd} \; ? \; MAX\left\{ ?x \; ? \; \overline{p}.(1 \; ? \; \overline{p}).?? _{11} \; ? \; ? _{00} \; ? \; ? _{00} ??, 0 \right\} . \tag{18}$$

$$\begin{aligned} G^{sa} \; ? \; & ?2\overline{p}.(1 \; ? \; \overline{p}).?? _{11} \; ? \; ? _{10} \; ? \; ? _{10} ?? \; ? \\ & MAX\left\{ ?x \; ? \; \overline{p}.(1 \; ? \; \overline{p}).?? _{11} \; ? \; ? _{00} \; ? \; ? _{00} ??, \overline{p}^{2}.?? _{22} \; ? \; ? _{11} ? \right\} \end{aligned} \tag{19}$$

$$G^{ca} \; ? \; MAX\left\{ ?x \; ? \; \overline{p}.(1 \; ? \; \overline{p}).?? _{11} \; ? \; ? _{00} \; ? \; ? _{00} ??, \overline{p}^{2}.?? _{22} \; ? \; ? _{11} ? \right\} \tag{20}$$

The effects of initial asymmetries on the incentives to form an RJV can therefore be summarised as follows:

Result 2

(i) An increase in initial asymmetry **reduces** the *information-sharing* gain from RJV formation when firms are producing substitute products.

(ii) When avoiding duplication is the principal gain from research co-ordination, then an increase in the initial asymmetry **increases** the *research co-ordination* gain from RJV formation.

(iii) When firms are in substitute industries, and when avoiding duplication is the principal gain from research co-ordination then an increase in initial asymmetry **increases** the gain from RJV formation.

The intuition is straightforward. Asymmetries allow low cost firms to exploit their cost advantage, and severely disadvantage the high-cost firm. Overall this increases industry profits. This increase in profits arises when firms withhold information and so reduces the gain from information-sharing. On the other hand this reduces the cost of deciding to operate a single lab, since it reduces the gain in profits that would be made by having an extra chance of making a discovery.

Corollary When firms are producing complementary products, increases in asymmetry have a non-negative impact on RJV formation. When firms are producing substitute products, an increase in asymmetry will reduce the incentives to form RJVs when RJVs operate 2 labs, but increase them when RJVs choose to operate a single lab.

2.3.2 Catch-Up

The idea here is that making a given amount of progress simply determines the amount of cost reduction a firm can achieve – but these are just reductions from the initially asymmetric costs – so cost asymmetries are always preserved. Thus, if the high cost firm alone makes progress and no information is shared, the costs of the two firms are $\underline{c} \; ? \; ?, \overline{c} \; ? \; ?$; while if both firms make progress but no complementarities are exploited the costs of the two firms are $\underline{c} \; ? \; ?, \underline{c} \; ? \; ?$, and so on.

It is straightforward to show that in this case the correction to profits that needs to be made in order to take account of asymmetries is $?^{00}$ in situations 00, 11 and 22, and $2?^{00}$ in situation 10. But then asymmetries just raise expected profits in both the cooperative and non-cooperative equilibrium by the amount $?^{00}$ and so have no effect on the incentives to join an RJV.

3. The empirical analysis

There are several results emerging from the theoretical analysis above that can be tested for a sample of European RJVs. In particular, we are able to test the impact of the relative characteristics of product markets and of asymmetries between firms on the incentive to form RJVs. To get familiar with the data set we first describe our sample and derive some descriptive statistics. We then proceed to the econometric analysis.

3.1. Construction of the data base

The sample of European RJVs analysed includes all RJVs supported by the European Commission under the Eureka Programme[14]. Although part of a specific policy programme, Eureka RJVs can to a large extent be considered as market driven. In other words the Eureka programme is not expected to substantially modify the market incentives to form RJVs.

Eureka projects are either non-subsidised or subsidised by National governments. An exhaustive study of the programme shows that the provision of public funding plays a minor role in inducing firms to join the programme (Peterson, 1992) Projects in Eureka just get a 'quality label' from the Commission, which merely promotes networking activities. Moreover, projects in Eureka are proposed by the RJV members following a bottom up approach: research areas are not defined a-priori. Finally, research in Eureka is "near-market" and applied.

The aim of the empirical analysis is to explain why some firms join together to form an RJV and others don't. Consistently with the theoretical model we work under the simplified assumption that RJVs are formed by two firms only. We therefore extract from our database all couples of firms, which have formed a joint venture together in the period 1995 to 1996 for Eureka, and 1996 to 1997 for Cordis. Our counterfactual consists of all the potential couples, which did not take place between firms, which have formed RJVs (thus firms showing a positive propensity to form RJVs). To analyse the characteristics of the firms in our sample we combine the RJVs data base with a data base containing balance sheet and other information on individual firms[15].

The total numbers of couples selected are 148. The counterfactual is given by all the potential couples which did not take place and it is $\left(\frac{n(n-1)}{2}\right)$ times the number of real couples. The total number of counterfactuals is therefore unmanageable. Consequently, five different random samples of counterfactuals were extracted, with size five times larger than the number of the effective couples[16]. Having five different samples it was possible to test whether parameters were stable. As this was the case, we only report results for one sample which consists of 648 total couples in Eureka.

[14] The data set (or data) were retrieved from the "STEP TO RJV" database developed by NTUA/LIEE and SIRN in the context of the STEP TO RJV project, funded by the TSER programme of the EC.

[15] Collected from the Amadeus Data Base

[16] Roller, Tombak and Siebert, 1997 also compare effective couples to a random sample of potential couples.

Table 1
Variables tested

LNJOINTEMP	Log of sum employees of firm i and firm j	
LNJOINTSALES	Log of sum of sales of firm j and firm i	
ASYEMP	$= E_i / E_j$, where $E_{i,j}$: average number of employees of firm i or j over the period 1992-1996 i : the firm with the lower number of employees j : the firm with the larger number of employees	
ASYEMP2	ASYEMP squared	
ASYEMP* *NACE4	ASYEMP mult iplied by the product substitutibility dummy NACE4	
ASYSAL	$= S_i / S_j$, where: S : average sales of firm i or j over the period 1992-1996 i : the firm with lower sales j : the firm with larger sales	
ASYSAL2	ASYSAL squared	
ASYSAL* NACE4	ASYSAL multiplied by the product substitutability dummy NACE4	
ASYROA	Difference between the average return on total assets of the two firms over the period 1992-1996 (in absolute terms)	
SOSO	Geographic dummy variable, where	dummy =0 if both firms are located in Southern Europe i.e. from Spain, Italy and Greece dummy =1 if one firm is located in Northern Europe and the other one in Southern Europe dummy =2 if both firms are located in Northern Europe
NACE4	Product substitutability dummy variable, where	dummy =1 if the firms' products are in the same NACE industry at the four digit level
GNP	$= GNP_i / GNP_j$, where	GNP : Gross National Product of the region where the firm is located source (OECD) i : the region with the lower GNP j : the region with the larger GNP
INPUT	$= INP_{ij} + INP_{ji}$, where	INP_{ij} : percentage of the input of firm's i two-digit-Nace sector which consists of output of firm's j two-digit-Nace sector, measured for the aggregate of Oecd countries INP_{ji} : percentage of the inputs of firm's j two-digit-Nace sector which consists of output of firm's i two-digit-Nace sector, measured for the aggregate of Oecd countries (Source Oecd input-output tables)
INPUT*NACE4	Interacted variable given by the product of the Nace4 and the Input variables	

3.2. Descriptive statistics

Table 1 lists a set of variables describing the joint characteristics of the firms in the couples. We now discuss descriptive statistics for some of these variables

Following the theoretical model, we particularly focus on the characteristic of the product markets - whether products are complements or substitute – on the characteristics of research paths – whether they are additive or duplicative - and on various indicators of asymmetry pertaining to the characteristics of the firms. To capture factors which have not been explored in the theory, but which could also be relevant we also include various variables relating to the location of the firms (more precisely to the location of their headquarters)

Of course we can only get very approximate indicators of some of our theoretical variables.

- ?? Product substitutability we take to be captured by the NACE4 variable where we assume that NACE4 =1 corresponds to $s > 0$, while those cases where $s < 0$ will arise when NACE4 = 0.
- ?? We take the INPUT variable to give us some indication of the degree to which research paths are likely to be additive rather than duplicative, since it provides some indicator of whether firms are engaged in activities that are likely to be mutually useful.
- ?? We have no direct measure of cost asymmetries, but can measure only asymmetries in either sales or employment. While, *ceteris paribus,* cost asymmetries will imply asymmetries in these variables, there could be other factors driving these observed asymmetries.

Table 2 reports mean values of the explanatory variables for effective and potential couples (which did not in fact form a RJV). The picture is consistent with the theoretical predictions.

For *product substitutability*, we see that, on average, firms are more likely to join together in a RJV if they are part of the same industry and therefore their products are substitute. The share of firms in the same industry is on average larger for real than for potential couples.

Turning to *research path complementarity*, this is measured by the share of each firm's inputs which are products of the other firm[17]. This is also on average larger for real couples.

These results are in line with theory, as the model predicts that in both cases firms gain from co-operation. For substitute products there are two sources of gains: from sharing information and from co-ordinating the research effort. For complementary products there are only gains from co-ordinating research. This does not imply, though, that gains are necessarily larger when firms are in substitute industries, as the model does not make any prediction on the relative magnitude of the different gains in different circumstances.

For asymmetries in size and production costs, the model shows that it is not possible to draw general conclusions. The impact of asymmetries depends on the interaction between product substitutability and research path complementarity. Indeed, the average indicators of asymmetries differ just mildly for real and potential couples. It is quite remarkable, though, that the average value of the indicator is low, showing large asymmetries between firms in the sample. On average the small partner's output or employment varies between 23% to 30% of the other partner's output or employment. If we look at figures 1 and 2 we can see that a remarkable share of real couples is between firms with large asymmetries. The distribution does not change substantially if we consider potential couples.

Finally, we examine where partners' headquarters are located. We consider whether couples are from Northern or Southern countries. There is no prediction on this in our model, albeit indirect ones, as far as we assume that Northern countries are technologically more advanced than Southern ones. The level of development of the

[17] Note that, differently from the theoretical model, the empirical analysis does not use the same measure (the cross elasticity of substitution) for substitutibility and complementarity. Here they are measured in terms of the technical characteristics of the products. We can therefore analyse their effect separately.

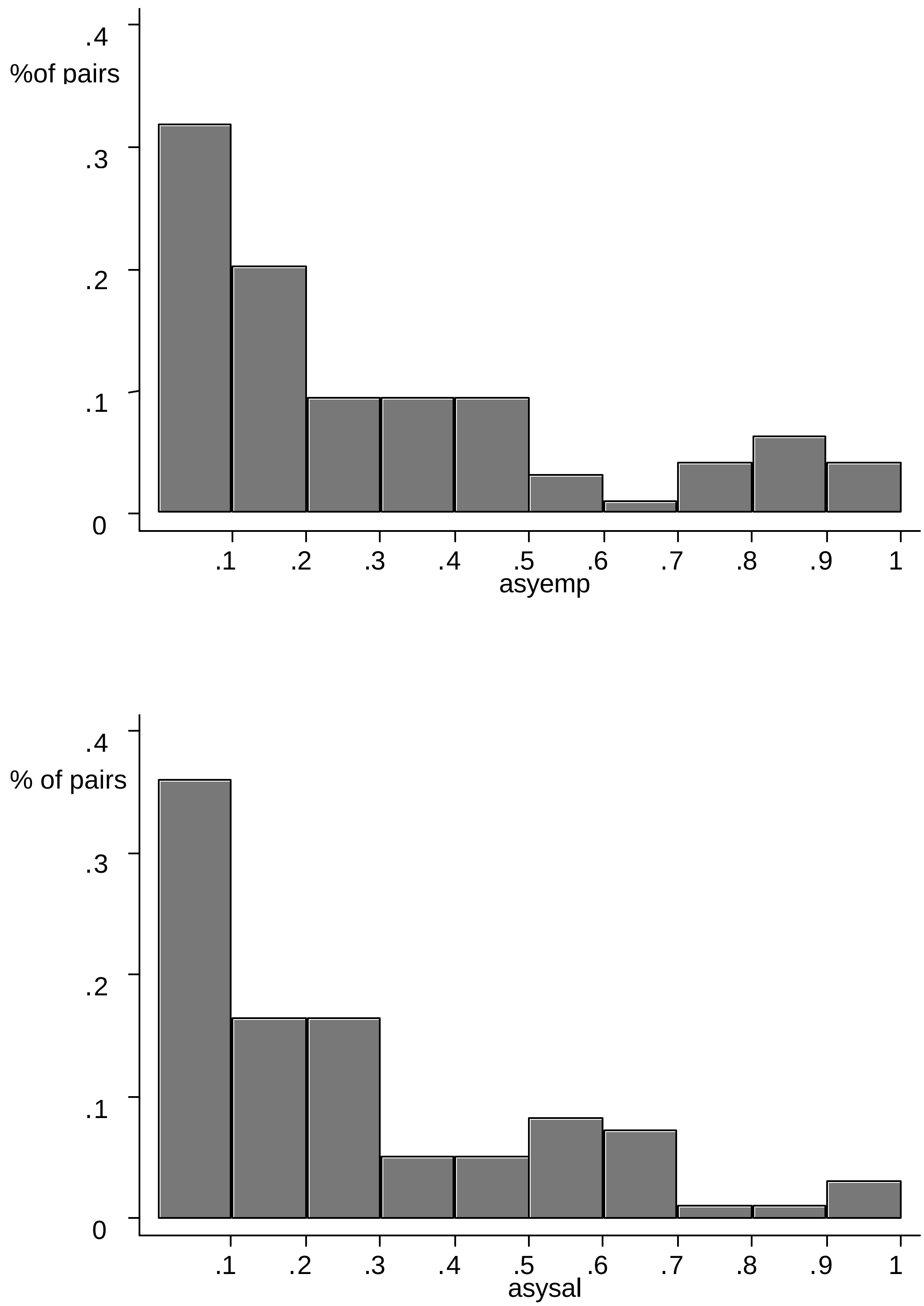
country where the firm is located could affect production costs, because of externalities and infrastructure. Consequently, this is an indirect measure of asymmetry. By far the larger share of couples are between firms both located in Northern countries. South-South RJVs are rare[18].

Table 2: Mean characteristics of real and potential couples

	Asyemp (mean)	Lnjointemp (mean)	Asysal (mean)	Lnjointsales (mean)	Input (mean)	% firms in substitute industries	% couples South-South	% couples North-South	% couples North-North
Pairs that formed an RJV	0.2996	8.4028	0.2533	13.2993	0.0535	34.94	0	8.05	91.95
Pairs that did not form an RJV	0.2695	8.1001	0.2493	13.2161	0.0331	5.37	2.24	25.95	71.81

[18] This result may reflect a bias in our sample, as the number of firms which may potentially form an RJVs is probably larger in Northern countries than in Southern ones. Moreover, Northern countries have probably more national programmes supporting RJVs.

Figure 1. Distribution of real pairs (Pij=1) according to values of ASYEMP and ASYSAL



3.3. Econometric analysis

We test the probability that a couple is formed against a set of combined characteristics of the partners. We therefore run the following cross-section probit model[19], where P_{ij} is equal to 1 if firms i and j join the same RJV and 0 otherwise:

$$P_{ij} \; ? \; ?_0 \; ? \; ?_1 . X_{ij} \; ? \; ?_{ij}$$

X_{ij} is a vector of combined characteristics of real and potential partners listed in table 1

The test of the econometric model, confirms the preliminary conclusions derived from descriptive statistics. Results are reported in Table 3. Regression 1 uses relative employment as a measure of asymmetry and regression 2 relative sales.

Given that the shares of effective couples on potential couples are much larger in the estimated samples than for the total population, there is a risk of sample selection bias. To take into account this problem, the regressions have been estimated using a pseudo maximum likelihood estimator: the pseudo maximum likelihood estimator of the parameters ? is the solution to the weighted sample estimating equation (i.e. the sample log-likelihood equation with weights), where weights are the proportions of 1 and of 0 over the total number of possible couples $?\frac{n(n ? 1)}{2}?$. Weight for 1s is $?\frac{n_1}{?n(n ? 1)/2?}?$ where n_1 is the total number of 1 in our sample and n is the total number of couples. This estimation is adequate for handling random samples where the probability of being sampled varies. The methodology improves the efficiency of the estimator (Amemya (1985), Greene (1990).

Moreover, to check for the robustness of our results, we carried out tests considering different proportions of 1s and 0s. The results of the regressions are robust to different sample proportions, both for the Cordis and the Eureka samples. The change in sample proportions only affects the significance of some variables in the Eureka case, when the proportion of 0s is increased with respect to that of 1s. Because of the persistence in the results we think there are no serious selectivity bias due to the sample selection of the possible couples that could have been formed. In other words, the probability to form a couple is independent of the numerosity of the real couples with respect to that of the possible couples.

The probability of forming a couple is larger when firms are in the same industry and when their research paths are more likely to be additive. This result is robust and significant, although the coefficient is larger and more significant in the case of substitute firms. It confirms the strongest prediction of the theory, namely that the incentive to form an RJV can be particularly high if firms produce substitute products as information gains arise only in this case.

Note that when we interact the input and the Nace 4 variables we get a negative and significant sign. This would suggest that when firms are in substitute industries the magnitude of gains from exploiting potential research complementarities is lower. Put

[19] The regression has been estimated using a pseudo maximum likelihood estimator and considering samples with different proportions of 1 and 0. More details can be found in the Appendix.

somewhat differently, this just indicates that our *ceteris paribus* assumption in Result 1 is not valid.

Asymmetries are only significant when relative size is measured in terms of sales of the two firms. Note that we have a positive sign for the linear coefficient and a negative sign when we square the asymmetry variable. This implies that the relationship between asymmetry and the probability of forming an RJV takes an inverted U shape. If we start from the symmetric case the probability of forming an RJV increases with asymmetries, reaches a maximum and then starts declining. Thus, the probability is highest for intermediate levels of asymmetry.

This result is perfectly consistent with theoretical predictions for the case when avoiding duplications is the main gain from co-ordinating R&D and therefore when firms tend to merge their research activities in one lab.

The sign of the other firm-specific indicator of asymmetry (the difference between returns on assets - ASYROA) is negative and significant. This is consistent with the results for the linear coefficient of the size asymmetry variable. Indeed, the negative sign implies that the smaller the difference (thus the lower the asymmetries) the higher the probability of forming a couple.

Finally, we look at the role of the countries of origin of the two partners. The econometrics confirms that Eureka couples are more likely to take place between firms both based in Northern countries. As the geographic location (North and South) reflects mildly the level of development, we also control for relative GNP of the region where the headquarters of the partner firm are based. Couples are more likely to be formed the more similar the GNP of the regions of origin.

Table 3: Econometric results

EUREKA	**Reg1: X=EMP**	**Reg2: X = SAL**
LNJOIN X	0.0164	0.024
	0.375	**0.570**
	0.0007	*0.001*
ASY X	1.228	1.731**
	1.437	**2.112**
	0.053	*0.081*
ASY X2	-0.9852	-2.049**
	-0.967	**-1.979**
	-0.043	*-0.097*
ASY X*NACE4	-0.6245	-0.1697
	-0.851	**-0.224**
	-0.027	*-0.008*
ASYROA	-0.0149*	-0.0141*
	-1.701 *-0.0006*	**-1.725** *-0.0006*
SOSO	0.6660***	0.6617***
	3.424	**3.477**
	0.029	*-0.0313*
GNP	1.325***	1.09***
	3.123	**2.709**
	0.058	*0.051*
NACE4	1.5437***	1.3417***
	5.448	**4.903**
	0.241	*0.193*
INPUT	1.598**	1.633*
	1.943	**1.865**
	0.07	*0.077*
INPUT*NACE4	-2.779* **-1.749**	-2.698* **-1,669**
	-0.121	*-0.127*
Constant	-4.593***	-4.533***
	-6.660	**-5.793**
No of obs	489	502
Chi2	65.24	61.78
Pseudo R2	0.17	0,15
Log Likelihood	-59.11	-63.24

*significant at 90% **significant at 95% ***significant at 99%

z values in **bold**

dF/dX in *italics*

4. Conclusions and policy implications

This paper examines which firms from a heterogeneous pool are more likely to join together and form a RJV. It differs from previous contributions as it introduces a set of realistic hypothesis on the characteristics of research co-operation and information sharing. Research paths can be substitute or complementary. This affects the nature of and consequently the gains from co-operation. If research is substitute, then firms co-operate so as to avoid duplication of research costs. If research is complementary, then firms co-operate so as to exploit synergies. In the first case they will just use one lab, in the second one they will co-ordinate the activities of two labs

Previous contributions assume that firms do not share information voluntarily if they do not co-operate. In this paper we assume that this is the case only when firms' products are substitute. If firms' products are complementary there may be gains in sharing information also under non co-operation. This eliminates the gains from co-operation arising from information sharing. This result provides a strong rational explanation of why firms competing in the production of substitute products carry out RJVs cooperatively.

The empirical analysis carried out on a sample of RJV formed under the Eureka programme supports this theoretical predictions. Pairs of firms forming RJVs predominantly produce substitue and/or complementary products.

The model also carefully explores the role of asymmetries in costs between the two firms. It shows that under given circumstances the incentive to form RJVs is higher when asymmetries between pairs of firms are in their intermediate ranges. Also this result is confirmed by the empirical analysis.

Finally, it is found that most pairs of firms forming RJVs are based in Northern European regions with relatively close levels of GNP per capita.

From these findings we derive important policy implications. The European Commission directly or indirectly supports the RJVs in our sample. As we do not have a counterfactual of RJVs not supported by the Commission we cannot say how our RJVs compare to purely market driven RJVs. However, we can argue that the features of EU supported couples of firms forming RJVs do not differ from what we theoretically expect from market driven RJVs.

There is often a presumption the RJVs should only be formed between firms producing complementary products, as though co-operation in R&D should come as a spin-off of vertical integration. In contrast, this paper shows that gains form co-operation are also large and possibly larger, for firms producing substitute products. It is therefore an appropriate policy goal to also favour RJVs between competitor firms. However, concerns for competition policies are more likely to arise and the relationship between RJVs and market share should be carefully explored.

There is no way of controlling in our data how RJVs organise their R&D activities. However, the fact that most pairs of firms are in substitute industries and the impact of asymmetries on the probability of forming an RJV makes it likely that concentrating R&D activities so as to avoid duplications is a dominant pattern in our sample. Therefore, there may be concerns about the location of research activities. As far as research is characterised by strong localised externalities, RJVs would then lead to a concentration of research activities in few locations within the EU. This is probably the opposite of what the Commission is trying to achieve by supporting RJVs, i.e. the diffusion of research capacity also to peripheral areas of the Union.

Finally, there are contradictory findings on whether RJVs will succeed in reducing differences in efficiency at the firm and country levels. In general, we find some, not extremely robust, evidence that asymmetries are lower for firms that get together than for firms that don't. Yet, we have striking evidence that asymmetries are on average very large both for real and for potential couples. In this respect, the EU support programmes seem to be able to promote research linkages between small and large firms (high and low cost firms). On the other hand, it appears that most firms getting together are based in Northern countries rather than in Southern ones and, perhaps more importantly, in countries with a similar level of development as measured by GDP per capita. Thus, the involvement of firms based in peripheral areas is small.

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