The free-rider problem and the optimal duration of research joint ventures:

theory and evidence from the Eureka program

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Abstract: A research joint venture (RJV) faces a serious free-rider problem because its participants' contributions are mostly unobservable. We first present a model that shows that a RJV solves this problem by pre-committing to its termination date. Our analysis shows that there is an optimal termination date or duration, which increases with the value of the innovation per member and decreases with the R&D flow cost per member. Utilizing data from the European Eureka program, we then examine the factors determining the durations of Eureka RJVs. The empirical results support our hypotheses from the theoretical model.

JEL Classification Codes: L1, L2
Keywords: research joint venture (RJV), free-rider problem, duration, innovation, Eureka projects

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1. Introduction

A research joint venture (RJV) is an agreement whereby its members coordinate research activities and share any subsequent innovations. The literature has examined several incentives to form a RJV; e.g., avoidance of costly duplications of efforts (Katz 1986), internalization of technical spillovers (d'Aspremont and Jacquemin 1988, Kamien, Muller and Zang 1992), and synergy creation (Pastor and Sandonis 2002). Additionally, a RJV can also solve a certain appropriability problem. Since innovation eventually becomes common knowledge and can be adopted by rivals, an innovator fails to appropriate the full value of an innovation. This means that in cases privately funded R&D projects are unprofitable and therefore not undertaken. A RJV solves this problem by having the R&D costs shared upfront by the eventual beneficiaries of the innovation (Miyagiwa and Ohno 2002; Erkal and Piccinin 2010).

However, formation of a RJV comes with its own difficulty – an incentive or free-rider problem. While it appears within any cooperative arrangement, in the case of a RJV the incentive problem becomes particularly acute for two reasons. First, the members' contributions to the venture are mostly in the form of human resources and proprietary technical know-how, the qualities of which cannot easily be assessed by other participants. Second, R&D outcomes are inherently stochastic, thereby making it well-nigh impossible to disentangle lack of success due to shirking from lack of success due to randomness. These two features of a RJV can give rise to opportunism, as participants are tempted, by the lack of detection, to contribute less than the level of R&D inputs stipulated in the agreement (Shapiro and Willig 1990).

In this paper we show that a RJV can overcome the free-rider problem by pre-committing to its termination date. To understand this result intuitively, consider the standard repeated-game setting. If R&D actions are unobservable and shirking goes undetected, a RJV member faces the

same (stationary) continuation payoff, whether it shirks or makes R&D efforts. In contrast, if a RJV has the termination date, the continuation payoffs are no longer stationary. In particular, the continuation payoff falls precipitously when the venture is dissolved and cooperation ends. Therefore, as the termination date approaches, each member feels an increasingly stronger incentive to succeed in order to avert the sharp drop in continuation payoff. We show that in fact there is a unique optimal termination date, i.e., an (ex ante) optimal duration, for a RJV. Furthermore, our model yields two empirically testable results. First, the optimal duration is positively related to the value of innovation per member. Second, the optimal duration is negatively related to the per-member flow cost of R&D.

The model also indicates that the membership size of a RJV affects its optimal duration. However, there are two conflicting effects. On the one hand, an increase in membership size reduces each member's share of the total profit, reducing duration by the first result above. On the other, the presence of strong synergies and spillovers within a RJV can reduce the effective R&D cost per member, increasing duration by the second result above.

In the second part of the paper, using data from the European Eureka program, we examine whether our theoretical model is consistent with the empirical data. Launched in 1985 to promote joint research projects as part of the EU's innovation policy, the Eureka program provides our study with an ideal source of data for three reasons. First, each Eureka RJV is required to include partners from at least two different EU member countries. Since members often conduct research in separate countries, Eureka's RJVs face difficulties in monitoring the quantity and quality of member contributions. Second, each Eureka project applicant is required to provide detailed information about the prospective RJV, including its termination date. This

means that Eureka RJVs pre-commit to their durations. Thus, Eureka RJVs satisfy two most important features of our theoretical model.

The Eureka program has an additional advantage in that its data are publicly available on its website. We thus know that the average Eureka project has the (ex ante) duration of 41.5 months. However, the data exhibit large variations in duration, ranging from six months to 166 months. The central question of our empirical investigation is to explain such variations.

Our theory points to the value of innovation per member as a key determinant of duration. This relation, however, cannot be evaluated directly because the Eureka data set does not provide innovation values. Obvious proxies such as the values of patents issued to Eureka RJVs are also unavailable. Instead, for our primary proxy, we draw upon recent empirical literature in international trade examining heterogeneity among firms within given industries. We do so for two reasons. Firstly, this literature establishes that firms that export earn greater profits than firms that do not. Secondly, more recent research links firm heterogeneity to the types of R&D firms undertake. In particular, Van Beveren and Vandenbussche (2010) show that firms pursuing product-and-process innovations are more likely to export than ones aiming at either purely product or purely process innovations. These two findings suggest that RJVs aiming for product-and-process innovations have higher commercial values than ones targeting purely product or process innovations. If so, our theory implies that product-and-process innovation RJVs commit to longer durations than the other two types of RJVs. Fortunately, the Eureka data set does specify the types of R&D conducted in Eureka projects. Using the product-and-process innovation as a proxy variable for the value of innovation, we find that product-and-process innovation RJVs have longer durations than purely process-innovation or purely product-innovation RJVs, which is consistent with our theory.

Our theoretical model also predicts that a member's (flow) R&D cost has a negative effect on the duration of a RJV. Intuitively, when R&D flow costs are unobservable, there is a greater incentive to shirk. This increase in opportunism can be countervailed by a shortening of duration. To examine this effect we construct a monthly per member R&D cost variable from the Eureka data, and find this variable negatively related to the durations of Eureka projects as expected from our theory.

As for the effect of membership size, our regression results show that membership has a positive effect on the durations of Eureka projects, which according to our theory implies the presence of strong synergies within Eureka RJVs. This finding is consistent with recent empirical work that has identified synergy and spillovers as the important rationales for forming RJVs (e.g., Cassiman and Veugelers 2002, Hernan, Marin and Siotis 2003).

The remainder of the paper is organized as follows. Sections 2 – 4 present our theoretical model. Sections 2 and 3 discuss the stability of a RJV when R&D efforts are observable and when they are not, respectively. Section 4 shows how, when R&D efforts are unobservable, a RJV can overcome the free-rider problem by specifying its termination date. Section 4 also derives the main predictions of the model. The empirical analysis is contained in sections 5 – 8. Section 5 discusses the Eureka data. Section 6 explains our methodology. Section 7 presents the estimation results. Section 8 checks the robustness of our empirical findings. The final section states our conclusions and suggests extensions for future research.

2. RJVs with observable R&D actions

Consider m ($\geq$ 2) symmetric firms interacting over an infinite number of periods. All actions take place at dates t = 1, 2,…. Suppose that firms form a RJV at t = 1. At each t $\geq$ 1, each

firm unilaterally decides whether to invest the amount k or not. If z ($\leq$ m) firms invest k at t, then at date t + 1 there is innovation with probability $1 - \phi(z)$, where $\phi(z)$ measures the venture's (conditional) probability of failure to discover innovation. The innovation yields the flow of profits, the sum of which is worth π to each member firm in t + 1's value. We assume that a RJV has a better chance of success when more members make R&D efforts.

Assumption 1: The RJV's (conditional) probability $\phi(z)$ of failure to discover innovation is monotone decreasing.[1]

We assume that firms are incapable of innovation when acting alone.[2] This may be the case if R&D costs are too high or innovation is too risky (i.e., probability of innovation is too low) for an individual firm. For the moment we disregard the effects of synergy and spillovers within a RJV.

In the remainder of this section, we consider the benchmark case, in which firms can observe one another's R&D actions. Suppose that firms play the following grim trigger strategy; at t = 1 invest k in R&D, and at all t $\geq$ 2, conditionally on innovation not having been discovered, invest k as long as all firms have done so to date; otherwise break up the RJV.

Below we write ϕ_z for $\phi(z)$ to lighten notation. If all m firms adopt the above strategy, at each date t the RJV discovers innovation with the (conditional) probability $1 - \phi_m$. If there is no success at t, firms face exactly the same prospect at t + 1 due to the stationary environment. Thus, the expected equilibrium payoff V satisfies the recursive equation:

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[1] The literature often assumes that $\phi(z) = q^z$, where q is each firm's individual probability of failure. Since $q^z < q$, firms can pool risks by forming a RJV.
[2] This assumption can be relaxed without affecting the main results of the analysis.

$$V = -k + (1 - \phi_m)\delta\pi + \phi_m\delta V,$$

where $\delta \in (0, 1)$ is the discount factor. Collecting terms yields

(1) $V = (-k + (1 - \phi_m)\delta\pi)/(1 - \phi_m \delta).$

We assume that $V > 0$, implying that it is worthwhile to form a RJV.

A (one-period) deviation from the above strategy allows a shirking firm to save the R&D cost k but also increases the venture's probability of failure to $\phi_{m-1} > \phi_m$. In addition, shirking triggers termination of a RJV, meaning that a shirking firm expects the payoff $(1 - \phi_{m-1})\delta\pi$.[3] There is no shirking if and only if $V \geq (1 - \phi_{m-1})\delta\pi$.

3. RJVs with unobservable R&D actions

Now, assume that firms cannot observe one another's R&D actions. If all firms invest in R&D, the expected payoff per firm is still V as defined in (1) above. However, shirking now becomes undetected and hence unpunished. Consequently, shirking only results in an increase in a RJV's probability of failure without triggering its dissolution, thereby yielding the expected payoff

(2) $V_d = (1 - \phi_{m-1})\delta\pi + \phi_{m-1}\delta V$

to a shirker. Therefore, there is no shirking if and only if

(3) $V - V_d = -k + \Delta_m\delta(\pi - V),$

where

$$\Delta_m \equiv \phi_{m-1} - \phi_m > 0$$

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[3] Assume, for simplicity, that other firms cannot exclude a shirker from access to innovation discovered at t. This assumption is inconsequential for the discussion to follow.

due to monotonicity of ϕ_m. While $\pi > V$, the right-hand side of (3) can be negative, if, for example, R&D cost k is sufficiently large. Focusing on such cases, we assume that a RJV is unstable when R&D actions are unobserved.

Assumption 2: $V < V_d$.

4. The optimal duration for a RJV

Under Assumption 2 a RJV is unstable under the standard repeated-game setting. However, the members can still form a RJV if they pre-commit to dissolving the venture at some future date. To demonstrate this case, consider a one-period RJV. As it gets terminated at t = 2, firms get just one chance to cooperate, namely, at t = 1. If they all invest k in R&D, the payoff to each firm (at t = 1) equals

$$R(1) = - k + (1 - \phi_m)\delta\pi.$$

As before, a shirking firm saves k and lowers the probability of innovation, expecting the payoff

$$R_d(1) = (1 - \phi_{m-1})\delta\pi.$$

There is no incentive to shirk if

$$R(1) - R_d(1) = - k + \Delta_m\delta\pi \geq 0.$$

A comparison of this with equation (3) implies that

$$R(1) - R_d(1) > V - V_d.$$

Result 1: There are a k and a function $\phi(z)$ satisfying

$$\Delta_m\delta\pi \geq k > \Delta_m\delta(\pi - V).$$

so that

$$R(1) - R_d(1) \geq 0 > V - V_d.$$

Result 1 says that each member makes an R&D effort under Assumption 2. We obtain this result for the following intuitive reason. Since a one-period RJV gets terminated after $t = 1$, at $t = 2$ the continuation payoff equals zero instead of V as in section 2. This drop in continuation payoff motivates firms to succeed at $t = 1$.

Next, supposing that $R(1) - R_d(1) > 0$, consider a two-period RJV. With two periods to cooperate, a failure at $t = 1$ gives firms one more chance to succeed at $t = 2$, with the expected payoff $\delta R(1)$. Therefore, investment in R&D at $t = 1$ yields the expected profit

$$R(2) = -k + (1 - \phi_m)\delta\pi + \phi_m\delta R(1).$$

A generalization to an n-period RJV is straightforward. The expected profit is given by this analogous equation:

$$R(n) = -k + (1 - \phi_m)\delta\pi + \phi_m\delta R(n - 1).$$

This is a first-order difference equation with the solution given by

(4) $\qquad R(n) = [1 - (\delta\phi_m)^n]V.$

Since $\delta\phi_m < 1$, $R(n)$ is monotone increasing, approaching V as n goes to infinity. Intuitively, terminating a RJV at infinity amounts to never terminating it, hence yielding the payoff V.

We next examine a member's incentive to shirk (at $t = 1$). As before, shirking saves cost k but reduces the probability of success, yielding the expected profit

(5) $\qquad R_d(n) = (1 - \phi_{m-1})\delta\pi + \phi_{m-1}\delta R(n - 1).$

There is no incentive to shirk if the following difference in payoff is non-negative

(6) $\qquad R(n) - R_d(n) = -k + \Delta_{m-1}\delta(\pi - R(n-1)).$

The right-hand side of (6) is monotone decreasing in n since, as already established, R(n) is monotone increasing. Thus, the incentive to shirk increases with duration n. Further, by substituting the definition of V_d from equation (2), equation (5) can be rewritten as

$\qquad R_d(n) = V_d - \phi_m\delta(V - R(n-1)).$

As n goes to infinity, R(n) approaches V, and hence $R_d(n)$ approaches V_d. These two limit results imply that, as n goes to infinity, $R(n) - R_d(n)$ goes to $V - V_d$, which is negative under Assumption 2. Therefore, there is a limit to the number of periods in which firms cooperate as a RJV. Monotonicity implies that this limit is unique.

Result 2: If $R(1) - R_d(1) \geq 0$, there exists a unique integer $n^* \geq 1$ such that

(7) $\qquad R(n^*) - R_d(n^*) \geq 0 > R(n^* + 1) - R_d(n^* + 1).$

Result 2 says that a RJV can be sustained for the maximal duration of n*. Further, since R(n) is strictly increasing, R(n*) represents the maximal expected payoff per firm. We state this result formally,

Proposition 1: The n*, defined in result 2, represents the optimal duration of a RJV.

We have shown here that, even if cooperation in R&D is inherently unstable, firms can still form a RJV by pre-committing to the termination date.

We next address the question of what determines the optimal duration. According to the model, the key determinants are the profit per firm (π) and the R&D cost per firm (k). Examining the role of π in (6), we observe that, as π increases, the difference, $\pi - R(n - 1)$, increases since R(n - 1) contains π only with positive probability. Therefore, $R(n) - R_d(n)$ increases, and n* can be increased by Result 2. This gives us the following proposition.

Proposition 2. The higher the value of innovation per firm, the longer the optimal duration of a RJV.

Next, an increase in k increases the payoff from shirking, making shirking more attractive. Such a rise in opportunism can be curbed by a shortening of the duration of a RJV. This gives the next proposition (proof in Appendix 1).

Proposition 3. The higher the R&D cost per firm, the shorter the optimal duration of a RJV.

The duration of a RJV also depends on the size m of its membership. We show in Appendix 2 that an increase in m shortens the optimal duration. Two intuitive reasons underlie this result. First, with an increase in m each firm has a lesser impact on the venture's joint probability of success and hence less of the incentive to cooperate. This diminished incentive for cooperation can be redressed by a shortening of duration. Second, for any given total value of innovation, an increase in m decreases the value of innovation per member. Applying proposition 2, this result calls for decreasing the duration.

The above result is obtained without consideration of possible synergy that may arise from cooperation among RJV members. As noted in the introduction, however, recent empirical studies emphasize the generation of synergy and spillovers as the main rationale for forming RJVs. There is no reason to believe that Eureka RJVs are exceptions to those findings. In fact, as shown in Appendix 2, introduction of synergy and spillovers into our model can reverse the above conclusion. Therefore, determining the effect of membership size on the duration of a RJV is an empirical matter. If m has a positive impact on duration in our empirical study, we conclude that synergies play an important role in the formation of Eureka RJVs.

5. A description of the data from the Eureka program

In this section we begin our empirical examination of the factors influencing the optimal duration of a RJV. As stated already, our empirical analysis utilizes the data from the European Eureka program. Since its inception in 1985 and until 2004, the Eureka program spawned 1,716 RJVs, involving 8,520 participants from 38 countries.[4] Among those participants, 4,698 were European firms, and 1,937 were European universities, research centers and national institutes; the remainder came from outside EU-15 member countries.[5]

More detailed information on individual Eureka RJVs is publicly available on the program's website.[6] The Eureka data set includes the initiation years, durations, and costs of all Eureka projects. The main industry designations of the RJVs are also available; the majority of

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[4] Our data exclude RJVs initiated after 2004 as well as the ones that were launched between 1985 and 2004 but have not been completed to date.

[5] Table A1 in the appendix describes the RJV characteristics in details.

[6] www.eurekanetwork.org.

the Eureka RJVs are in manufacture, with some in agribusiness and services sectors.[7] When it comes to Eureka's participants, however, the information is scanty; only their names, addresses and nationalities are available. Thus, the Eureka data set provides us with only the RJV-level data but not the firm-level data.

For our empirical analysis we select 1,641 commercial RJVs, i.e., RJVs organized to discover product and/or process innovations. In the academic literature it is customary to classify innovations into two types: product innovation which creates a new product or one of better quality and process innovation which introduces a new cost-reducing technology. In reality, however, many innovations have attributes of both. Recognizing this fact, the Eureka data classify the innovations into three types, namely, product innovation, process innovation and product-and-process innovation.

Table 1 presents the descriptive statistics of the commercial RJVs in our data set. The average RJV consists of 5.1 partners, of which 3.4 are firms, and costs 34,000 euros a month per partner to run.[8] The average duration is 41.5 months.[9] This average is based on the duration data taken from the applications submitted to the Eureka program, so it is the average over the ex ante durations. As for the type of innovations, 23 percent of Eureka RJVs in our data set pursue product-and-process innovations while 59 percent aim at product innovations; the remaining 18 percent target process innovations.

[Table 1 about here]

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[7] Defined by two-digit NACE categories. NACE is the European economic activities classification system, similar to the American SIC system. The NACE classification is available from the EUROSTAT website: http://ec.europa.eu/eurostat/ramon.

[8] Our data includes some exceptional cases. The most costly Eureka RJV spent 4 billion euros in R&D, involved 19 partners and lasted 96 months. The largest Eureka RJV had 196 partners, spent 796 000 € and had a duration also of 96 months. The results in section 7 are not affected by these extreme cases.

[9] Time is expressed in months.

6. Methodology

Although the average duration of a Eureka RJV is 41.5 months, there are significant variations in duration across Eureka projects. We investigate what factors could generate such variations. Initial tests reveal that the residuals of the OLS regressions on the Eureka data are not distributed normally.[10] Consequently, we construct an empirical model based on survival or duration analysis in the same way as in Vandenbussche and Zanardi (2008). In our survival analysis, the 'death' of a RJV is considered an event.

More specifically, we use proportional hazard models in our analysis. The central assumption of these models is that the hazard $h_j(t)$, or conditional probability of death of an individual RJV j, is split into two parts as in

$$h_j(t) = h_0(t) \, exp(x_j \beta_x).$$

The first term, $h_0(t)$, is the baseline hazard, i.e., the common hazard assumed to be faced by all Eureka RJVs. The exponential part captures the idiosyncratic characteristics of individual RJVs j, where x_j represents the row vector of all the explanatory variables for RJV j and β_x the column vector of the coefficients of the explanatory variables. The proportional hazard function assumes that at each date t RJV j's hazard is a constant proportion of the baseline hazard $h_0(t)$; that is, each individual RJV's hazard is "parallel" to the baseline hazard.

The most general proportional hazard model is the Cox model, which does not impose a specific functional form on $h_0(t)$. If a prior reason exists to believe that $h_0(t)$ follows a particular form, the Cox model can be further specified. For example, the belief that the baseline hazard follows a Weibull distribution leads to the Weibull proportional hazard model, which allows $h_0(t)$

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[10] The Jacque-Bera normality test performed on the error terms in OLS residuals is rejected for our Eureka data. It is found that the error terms of the regression on the log of RJV durations follows the type 1 extreme value (EV1) distribution.

to be increasing, decreasing or constant over time. More specifically, in the Weibull model $h_0(t)$ takes the form $pt^{p-1}exp\ (\beta_0)$, where p is the ancillary parameter determining the shape of the hazard function.[11] When p is above (below) one, the hazard rate is increasing (decreasing). For p equal to one, the hazard rate remains constant and the Weibull model becomes an exponential proportional hazard model. In our case, there is evidence to suggest that the baseline hazard for RJVs is increasing over time (see Kogut, 1989). Therefore, we choose the Weibull model as our basic empirical model.

We next discuss our choice of explanatory variables. Our theoretical model suggests innovation value, flow R&D costs and membership size as key explanatory variables. As already mentioned in the introduction, however, the values of innovations are not available for Eureka projects, so they must be proxied. As our proxy, we choose the *product-and-process innovation* dummy variable, which takes the value one if a RJV targets a product-and-process innovation and the value zero otherwise.[12] The selection of this proxy variable is, as we briefly mentioned in the introduction, motivated by recent evidence from the international trade literature investigating firm heterogeneity within industry categories. This literature shows that firms that export their products tend to have higher productivity, employ more workers, and pay higher wages than ones that do not export.[13] More recent studies attribute this firm heterogeneity to the types of R&D undertaken by the firms.[14] In particular, Van Beveren and Vandenbussche (2010) find that firms targeting product-and-process innovations are more likely to export than ones

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[11] This specificity in functional form makes the Weibull model more restrictive but more efficient relative to the Cox model.

[12] This variable is constructed from *the description of the RJVs available on the Eureka website: www.eurekanetwork.org*, not from the Community Innovation Survey (CIS) data.

[13] See for instance Aw and Hwang (1995), Roberts and Tybout (1997) and Bernard and Jensen (1999), Melitz (2003), Yeaple (2005) and Bustos (2011).

[14] See for instance Ebling and Janz (1999), Becker and Egger (2009), Damijan et al (2010) and Cassiman et al (2010).

targeting only product or process innovations.[15] These findings suggest that Eureka RJVs with product-and-process innovations expect higher returns from their R&D than ones with the other types of innovations. Thus, proposition 2 suggests this dummy variable to have a positive impact on the duration of a RJV.

The second explanatory variable to consider is the *monthly R&D cost per member* variable, constructed by dividing the total cost by the number of the members of a RJV and by its ex ante duration (in months). If this variable captures the flow R&D input stipulated in the RJV agreement, Proposition 3 implies that it has a negative impact on the duration of a RJV.

The third explanatory variable is the *RJV membership*. As discussed in section 4, the theoretical model cannot pin down the effect of this variable. As we explicated in the previous section, if strong synergies are present within Eureka RJVs, we expect this variable to have a positive effect on the duration of a RJV.

The Eureka data contains other interesting information, from which we construct three types of control variables. The *multi-sector RJV* dummy variable takes the value one if RJV has members drawn from more than one industry and the value zero otherwise.[16] The *main industry* dummy variables capture the characteristics of the main industry of the Eureka RJV, while the *RJV* initiation year dummy variable reflects the economic environment prevailing in the year when the RJV was launched.

7. Empirical results

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[15] Van Beveren and Vandenbussche (2010) focus on new exporters to control for the endogeneity associated with the relationship between innovation and exports. In a study on innovation in the U.K., Simonetti, Archibugi and Evangelista (1995) suggest that the number of product-and-process innovations in the U.K. is underestimated. Van Beveren and Vandenbussche (2010) address this issue by making the distinction between single product or single process innovations on the one hand and product-and-process innovations on the other.

[16] The definition of the multi-sector variable is taken from Bernard *et al*. (2010).

Columns 1 through 5 of Table 2 display our regression results from five empirical models. Consistent with the standard procedure in duration analysis, the estimates are expressed in terms of the hazard ratios, instead of the coefficients, of the explanatory variables.[17] The null hypothesis is that the hazard ratio of the explanatory variable equals one, i. e., the explanatory variable has no effect on duration of a RJV. If the hazard ratio is less than (greater than) one, the explanatory variable increases (decreases) the duration of a RJV. Our preferred model is in column 5, which contains all the explanatory variables discussed in section 6.

[Table 2 about here]

Each row in Table 2 displays the hazard ratio of the named explanatory variable. In all the columns, the hazard ratio of the *product-and-process innovation* variable is clearly significant and less than one as predicted by Proposition 2. In particular, the result in column 5 indicates that a RJV targeting a product-and-process innovation has a duration 13.8% longer than a RJV aiming for a purely product or process innovation.

Columns 2 through 5 show the hazard ratios of the logarithm of the *monthly RJV cost per partner* variable. They are significant and clearly exceed unity as expected from Proposition 3. In particular, the value in column 5 implies that a one-percent increase in the *monthly RJV cost per partner* variable decreases the RJV duration by 0.125%.[18]

The *RJV membership size* variable has a hazard ratio of less than one in all columns 2 through 5. According to our theory, this suggests the presence of strong synergy and spillovers

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[17] The hazard ratio of the logarithm of a continuous variable represents the effect of a one-percent change in value of the continuous variable. As for a discrete variable, say, x_2, as it is incremented by 1, its hazard ratio is given by the rate $h_0(t) \exp(\beta_1 x_1 + \beta_2 (x_2 + 1))$ over the 'initial' hazard rate $h_0(t) \exp(\beta_1 x_1 + \beta_2 x_2)$, and hence equals $\exp(\beta_2)$.
[18] The RJV cost variable is in million euros.

within the Eureka RJVs. This finding is consistent with recent empirical work. For example, Hernan, Marin and Siotis (2003) find that Eureka firms have greater incentives to form RJVs in industries in which knowledge spillovers proceed more quickly. Likewise, Cassiman and Veugelers (2002) find similar results for Belgian firms.

8. Robustness

In this section we apply alternative model specifications to check the robustness of our results in Table 2. A first check concerns the assumption that the baseline hazard follows the Weibull distribution. To address this issue, we employ the Cox proportional hazard model. If the Weibull model is a good representation of Eureka RJVs, then the Cox model should yield results similar to those in Table 2, since it imposes no specific functional form on the baseline hazard. The results with the Cox model are displayed in column 6 of Table 3.[19] A remarkable similarity of the results in column 6 and column 5 of Table 2 (which is reproduced in Table 3) confirms the appropriateness of the Weibull model as our main empirical model.

[Table 3 about here]

We next consider the possibility that our data does not capture every characteristic of Eureka RJVs, i.e., the possibility that any two RJVs appearing completely identical have different durations due to some unobserved heterogeneity. To check this, we first compute the conditional probabilities of RJV deaths from our sample population. The results are displayed in

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[19] If the Cox model fits the data, the Cox-Snell residuals form a 45-degree line. The goodness of fit of our Cox model is demonstrated in figure A2 of the appendix, where it is seen that the empirical Nelson-Cumulative hazard function (a proxy for the Cox-Snell residuals) closely follows the 45-degree line. For more details, see Cleves *et al*. (2010).

Figure 1.[20] If these conditional probabilities are regarded as a non-parametric approximation of the baseline hazard of the population, then Figure 1 displays non-monotonic hazard rates, implying that shorter-duration RJVs and long-duration RJVs may have different baseline hazards (Cleves *et al.*, 2010).

[Figure 1 about here]

To examine this possibility, we employ the frailty Weibull model.[21] This version modifies the basic Weibull model by assuming that the baseline hazard takes the form $Zh_0(t)$, where Z is the multiplicative random variable capturing unobserved individual characteristics. The procedure yields the results in column 7 of Table 3, which show remarkable similarity to the values reported in column 5.

Our next robustness check concerns the possibility that the results based on the basic Weibull model in Table 2 may be driven by time. To address this issue, we run regression using the exponential hazard model, in which the baseline hazard remains constant over time by assumption. Our estimation results are presented in column 8 of table 3 and are qualitatively the same as those in column 5.

Summarizing this section, we observe that the alternative model specifications yield regression values quite similar to those of the basic Weibull model, thus supporting our results in the preceding section.

9. Concluding remarks

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[20] Note that each period represents a two-year interval.
[21] The frailty model in duration analysis is comparable to the panel data model with random effects.

The members' contributions to a RJV consist mostly human resources and proprietary technical know-how, and these qualities and quantities are not easily verifiable by other members. This means that a RJV often encounters a serious incentive problem. In this paper we first develop a model in which a RJV overcomes this problem by pre-committing to the date of dissolution. We characterize the optimal termination date or duration of a RJV. We then show that the optimal duration increases with the value of innovation per member and decreases with the flow R&D cost stipulated in the agreement. These results provide us with empirically testable hypotheses.

In the second half of the paper we examine the factors determining the duration of RJVs in the European Eureka program. First, drawing on recent empirical literature in international trade, we choose the *product-and-process innovation* dummy variable as a proxy for per-firm innovation values. We find that this variable has the hazard ratios significant and less than unity, as is consistent with Proposition 2 of our theoretical model. Second, the *monthly R&D cost per partner* dummy has the hazard ratios exceeding unity, implying that a higher flow cost leads to a shorter duration, as predicted by Proposition 3. In addition, the membership size variable has the hazard ratios less than one, which according to our theory implies the presence of strong synergy within a Eureka RJV. This result is also consistent with other recent empirical work.

A couple of extensions suggest themselves for future work. Firstly, our theoretical model assumes symmetry among member firms, but in reality RJVs often include quite diverse members. It is worth exploring the effect of such heterogeneity as regards the venture's optimal duration. Member heterogeneity also gives rise to a new set of incentive and policy questions. For example, which member is most likely to defect and hence is the most critical in the stability of a RJV? Secondly, this paper takes the formation of a RJV as given. It is worthwhile to

consider how a RJV is formed, given a large number of potential members. In the same vein, it is also a worthwhile exercise to extend the analysis to the case in which a RJV competes with outside firms or a rival RJV.

Our empirical analysis can be extended in several directions. Firstly, broader firm-level databases should be built for testing whether additional firm characteristics affect the stability of RJVs. Secondly, our analysis can also be extended to other R&D programs. For example, while the Eureka program is designed to promote commercial innovations, the EU has a sister program called the European Framework program, designed to subsidize firms and research institutes engaged in basic research. An extension of this research to the latter program may well uncover interesting differences in the ways basic and commercial innovations affect the behavior of RJVs. Thirdly, the U.S. Department of Commerce, under the ATP (Advanced Technology Program), used to collect detailed information, including durations, from perspective RJVs which seek exemption from antitrust investigations. Although this program is now defunct, our analysis should be able to throw light on the determination of the RJV durations under this program.

Tables and Figures

Table 1: Characteristics of all the commercial Eureka RJVs

	Obs	Mean	Std. Dev.	Min	Max
RJV duration (Months)	1641	41.54	20	6	166
Product-and-process innovation	1641	0.23	0.4		
Product innovation	1641	0.59	0.5		
Multi-sector RJV	1641	0.68	0.5		
Number of partners	1641	5.1	8	2	196
Number of partner firms	1641	3.4	4	1	96
Monthly cost per partner (€ Million)	1641	0.035	0.1	0.001	2.7

Note. Table 1 reports the summary statistics for the 1,641 commercial Eureka RJVs (1985-2004).

See the description of the variables in Appendix.

Table 2: The durations of Eureka RJVs

|	Weibull model				
	1	2	3	4	5
Product-and-process innovation	0.565***	0.848**	0.893*	0.817*	0.862**
	(0.100)	(0.063)	(0.059)	(0.070)	(0.059)
Number of firms		0.925***	0.935***	0.935***	0.930***
		(0.014)	(0.015)	(0.020)	(0.016)
Monthly cost per partner (in natural log)		1.095***	1.134***	1.209***	1.125***
		(0.030)	(0.030)	(0.050)	(0.029)
Multi-sector RJV		0.983	0.971	0.909	0.896*
		(0.066)	(0.057)	(0.074)	(0.055)
Initiation year dummies	NO	NO	YES	NO	YES
Main sector dummies	NO	NO	NO	YES	YES
Shape parameter p	2.191***	2.293***	2.809***	3.831***	2.911***
	(0.052)	(0.052)	(0.061)	(0.156)	(0.057)
Observations	1641	1641	1641	1641	1641

Note. Table 2 summarizes the regressions results of the Weibull proportional hazard models where the product-and-process innovation is used as the proxy variable for the innovation value. Robust standard errors are in brackets. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level. The ancillary parameter p of the Weibull model is reported with the robust standard errors.

Table 3: Robustness

	Robustness checks			
	5	6	7	8
Product-and-process innovation	0.862**	0.880**	0.817**	0.941***
	(0.059)	(0.051)	(0.069)	(0.210)
Number of firms	0.930***	0.945***	0.935***	0.982***
	(0.016)	(0.014)	(0.020)	(0.005)
Monthly cost per partner (in natural log)	1.125***	1.103***	1.209***	1.050***
	(0.029)	(0.025)	(0.050)	(0.010)
Multi-sector RJV	0.896*	0.920	0.909	0.974
	(0.055)	(0.051)	(0.074)	(0.021)
Initiation year dummies	YES	YES	YES	YES
Main sector dummies	YES	YES	YES	YES
Shape parameter p	2.911***		3.830***	
	(0.057)		(0.156)	
Observations	1641	1641	1641	1641

Note. Table 3 summarizes the regressions results from the Weibull model (column 5), the Cox model (column 6), the frailty Weibull model (column 7), and the exponential model (column 8). Column 5 is reproduced from table 2. The product-and-process innovation dummy variable serves as a proxy for the RJV innovation value. Robust standard errors are in brackets. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.

Figure 1: Conditional mortality rates of the Eureka RJVs population over time

Death of the Eureka RJVs over time
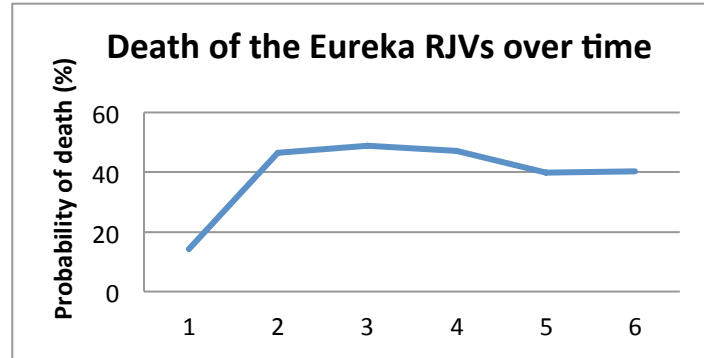
Note: Time intervals are in the unit of two years.

Appendices

Appendix 1: Proof of proposition 3

Differentiating (6) yields

(A1) $\qquad d[R(n) - R_d(n)]/dk = -1 - \Delta_m \delta dR(n-1)/dk$

By (4)

$$dR(n-1)/dk = [1 - (\delta\phi_m)^{n-1}]dV/dk = -[1 - (\delta\phi_m)^{n-1}]/(1 - \delta\phi_m).$$

Substituting into (A1), we obtain

$$d[R(n) - R_d(n)]/dk$$

$$= -1 + \Delta_m \delta[1 - (\delta\phi_m)^{n-1}]/(1 - \delta\phi_m).$$

$$= -(1 - \delta\phi_m - \Delta_m \delta + \Delta_m \delta^n \phi_m^{n-1})/(1 - \delta\phi_m)$$

The expression in parentheses in the numerator of the last expression is written, after substituting

$\Delta_m = \phi_{m-1} - \phi_m$ and collecting terms, as

$$1 - \delta\phi_m - \Delta_m \delta + \Delta_m \delta^n \phi_m^{n-1}$$

$$= 1 - \delta\phi_{m-1} + \phi_{m-1}\delta^n \phi_m^{n-1} - \phi_m \delta^n \phi_m^{n-1}$$

$$= 1 - \delta\phi_{m-1} + \delta^n \phi_m^{n-1} \Delta_m > 0.$$

Hence, $d[R(n) - R_d(n)]/dk < 0.$ $\qquad \square$

Appendix 2: We evaluate the effect of the size m on the duration of a RJV in the presence of synergy and spillovers. We assume that they affects the venture's probability of failure, and write the extended probability of failure as $F(z) = s(z)\phi(z)$, where $s(z)$ denotes the effect of synergy or spillovers. Treating z as continuous and $s(z)$ and $\phi(z)$ as differentiable, and letting primes denote derivatives, we impose the following conditions: $s(1) = 1$ and $s'(z) < 0$ and $s''(z) < 0$. Synergy

decreases probability of failure at increasing rates. On the other hand, by assumption 1 $\phi'(z) < 0$ and $\phi''(z) > 0$. Therefore, $F'(z) = s'\phi + s\phi' < 0$ but the sign of F" is indeterminate. Now, using F_z for $F(z)$ and substituting $F(.)$ for $\phi(.)$ in (6) we obtain

$$H(m; n) \equiv R(n) - R_d(n)$$

$$= -k + \delta F_{m-1} - F_m)(\pi - R(n - 1))$$

$$= -k + \delta(F_{m-1} - F_m)\{\pi - [1 - (F_m\delta)^{n-1}]V\}$$

where the final expression comes from substitution for $R(n - 1)$ from (4). Differentiating yields

(A2) $dH(m; n)/dm = \delta(F_{m-1}' - F_m')(\pi - R(n - 1)) + (n - 1)\delta^n V(F_{m-1} - F_m)F_m^{n-2}F_m'$

$$+ \delta(F_{m-1} - F_m)\{\pi - [1 - (F_m\delta)^{n-1}]dV/dm.$$

With $F_m' < 0$, the second term on the right is negative. The third term is also negative since a straightforward calculation yields

$$dV/dm = -\delta F_m'[k + (1 - \delta)\pi]/(1 - \delta F_m)^2 > 0.$$

The sign of F_m'' is indeterminate, which makes the first term on the right of (A2) indeterminate in sign. If it is non-positive, $dH(m; n)/dm < 0$, implying that a larger RJV has a shorter duration. In particular, this occurs in the absence of synergy or spillovers or $s(m) = $ constant. On the other hand, the presence of strong synergy and spillovers (in the sense that $s''(z) < 0$ as assumed above) can make $dH(m; n)/dm$ positive.   □

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Table A1: Description of RJV characteristics

| Variables	Description
RJV duration	Ex ante duration, in months, of the Eureka RJV,
Product-and-process innovation	Dummy variable taking the value one if the expected outcome of R&D is product-and-process innovation.
Number of RJV firms	Number of firms in the Eureka RJV
Number of RJV partners	Number of firms, research centers, universities and national institutions in the Eureka RJV
RJV monthly cost per partner	Total cost of the Eureka RJV divided by the number of partners and by the number of months of duration, inclusive of subsidies
Multiple-sector RJV	Dummy variable taking the value one if participants of the Eureka RJV come from separate industries as defined by the two-digit NACE category
RJV initiation year dummy	Dummy variable taking the value one for the year in which the Eureka RJV was launched
RJV main sector dummy	Dummy variable taking the value one for the main two-digit NACE category of the Eureka RJV

Source: Eureka database built from the Eureka website (www.eurekanetwork.org).

Table A2: Correlation matrix for the all Eureka RJVs

	RJV duration	Product-and-process innov.	Multi-sector RJV	Number of partner firms	Monthly cost per partner
RJV duration	1				
Product-and-process innov.	0.069	1			
Multi-sector RJV	0.018	-0.020	1		
Number of partner firms	0.257	0.019	0.037	1	
Monthly cost per partner (€Mio)	0.088	0.107	0.022	0.167	1

Note: The matrix displays correlations for the 1,641commercial Eureka RJVs (1985-2004). The product-and-process innovation variable indicates whether the outcome expected from the RJV is product combined with process innovation. The multi-sector dummy shows whether the RJV involves more than one two-digit NACE category. The number of RJV partners and the product dummy are excluded from the regressions as they are highly correlated with the other variables.

Figure A1: Fit goodness of the Cox model
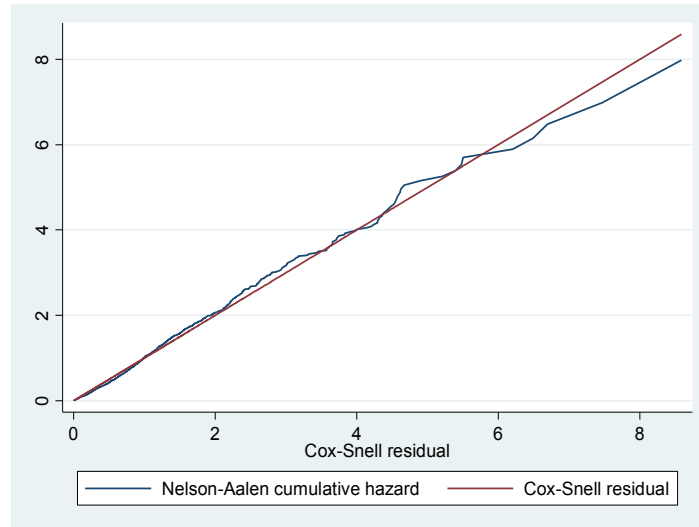
Note: Figure A2 displays the Cox-Snell residuals and the Nelson-Aalen cumulative hazard, confirming the goodness of fit of the Cox proportional hazard model in column 7 of table 3.