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

theory and evidence from the Eureka program

Kaz Miyagiwa, [(a)]Amy Sissoko,[(b)] and Huasheng Song[(c)]

(a) Florida International University, U.S.A., Hitostubashi Institute for Advanced Study,
Hitotsubashi University, Japan, and ISER, Japan
(b) UCLouvain, Belgium
(c) Zhejiang University, China

May 2015

Abstract: In a research joint venture (RJV), members' contributions consist mostly of personnel and proprietary technical know-how. Since the quantity and quality of such contributions are difficult to verify, each member has the temptation to free-ride on others' contributions. In this paper we show that a RJV can resolve this free-rider problem by pre-committing to its duration. Our model predicts, among others, that a RJV chasing a higher-cost innovation tends to have a shorter duration. We then utilize data from the European Eureka program to investigate the factors determining the durations of Eureka RJVs. We find the Eureka data consonant with the prediction of our model.

JEL Classification Codes: D82, L1, L2
Keywords: Research joint venture (RJV), Free-rider problem, Unobservable R&D, Collusion, Stability of RJVs.

We thank Muriel Dejemeppe, Cyriaque Edon, Nicholas M. Kiefer, Ilke Van Beveren, Mahmut Yasar and seminar participants at Zhejiang University and Osaka University for helpful comments. Our special thanks go to Hylke Vandenbussche whose suggestions led to substantial improvements. Errors are the authors' responsibility.

1. Introduction

A research joint venture (RJV) is an agreement whereby its participants coordinate research activities to share the innovation they discover. The literature has identified 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 free-rider problem is particularly acute for two reasons. First, members' contributions to the venture are mostly in the form of human resources and proprietary technical know-how, the quantities and qualities of which cannot easily be assessed by other participants. As a result, a member may "contribute its less able personnel or withhold most advanced technology from the venture" [Shapiro and Willig (1990, p. 114)]. Second, R&D outcomes are inherently stochastic, 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 – unverifiable inputs and random outcomes – can give rise to opportunism. Tempted by the lack of detection, members of a RJV are known 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 this free-rider problem by pre-committing to its duration. To understand this result intuitively, consider the standard repeated-game setting without pre-commitment to the duration. If contributions are unobservable and shirking goes undetected, a member faces the same (stationary) continuation payoff, whether it shirks or makes R&D efforts. In contrast, if a RJV commits to the specific termination date, the continuation payoffs are no longer stationary. When the venture is dissolved and cooperation ends without success, the payoff falls precipitously. Especially, if the project is too expensive for any individual member to undertake, the continuation payoff falls to zero after the venture is dissolved. Therefore, as the termination date nears, each member feels an increasingly stronger incentive to make the venture succeed to avoid a fall in continuation payoff. It follows that with pre-commitment to the duration the incentive to cooperate becomes non-stationary. When the termination date is still far away, members have a greater incentive to shirk because succeeding is not as urgent as when the termination date is near. In fact, when the duration is set too long, the incentive to shirk becomes dominant and a RJV becomes unstable. Thus, there is an optimal duration for a stable RJV.

In later section, we examine whether our theoretical model has empirical support, using data from the European Eureka program to. 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 participants from at least two different EU countries. This requirement makes participants’ contributions more difficult to verify when research is conducted in separate countries. Second, the usual criticism against models of cooperation is that the equilibrium may be time-inconsistent. This criticism also applies to the present model. When a RJV looked profitable when it was formed, it must look just as profitable when the termination date is reached without success. Thus, participants have the incentive to disregard the initial agreement to dissolve the venture and keep going past the termination date. But this means that the initial commitment has no bite. Fortunately, however, this time inconsistency problem is less critical for Eureka projects, because a Eureka RJV is required to provide detailed information about the venture, including its duration, in order to be approved for the subvention. In other words, all Eureka RJVs pre-commit to durations.[1]

Third, the Eureka program has an additional advantage in that its data are publicly available on its website. We thus know that the average duration of Eureka projects is 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 in duration using our theory.

Our theory predicts, among others, that a RJV with a higher (flow) R&D cost has a shorter duration. This is a somewhat surprising result. The more intuitive reasoning would go as follows. If a project is more expensive, it must be that the project is more difficult and hence takes a longer time to complete. We thus take the above hypothesis as the distinguishing feature of our model to be tested empirically. Indeed, as we show more in detail, the Eureka data fails to reject our main hypothesis.

Our regression analysis includes some control variables. In particular, R&D costs are likely to be affected by the difficulty of the project a RJV undertakes; the more difficult the project, the longer the duration of a RJV. We need to control this bias for our analysis, but there

---

[1] Eureka can end the subvention for a project if a member or members do not fulfill the agreement made at the time of the RJV formation.

is no natural measure of difficulty in R&D across diverse Eureka projects. We note however that Eureka classifies its projects into the three types of innovation: product-only, process-only and product-and-process innovations. The natural presumption is that product-and-process innovations are more difficult than product-only or process-only innovations. There is indirect evidence for this presumption. Van Beveren and Vandenbussche (2010) find that exporting firms are more likely to chase product-and-process innovations than single-purpose innovations compared with non-exporting firms. It is also well known that exporting firms earn greater profits than non-exporting firms. Since profitable firms can afford better scientists and engineers and pursue more difficult projects, we are led to our presumption that product-and-process innovations are more difficult to discover than product-only or process-only innovations.

Another variable to affect the duration of a Eureka project is the number of its participants. However, the membership size has two conflicting effects on the duration of a RJV. On the one hand, if a RJV consists of a large number of members, each member's contributions are relatively unimportant so shirking by a single member has little impact on the venture's success. Thus, a large membership size implies a greater incentive to shirk. On the other hand, a greater number of participants may generate more synergies and spillovers within a RJV, which can reduce the effective R&D cost per member and lower the incentive to shirk. In the case of Eureka RJVs we discover a positive effect of membership size on duration, suggesting 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. Section 2 presents our theoretical model. Subsections 2.1 and 2.2 discuss the stability of a RJV when R&D efforts are observable and when they are not, respectively. Subsection 2.3 shows how, in the case of unobservable R&D efforts, a RJV can overcome the free-rider problem by committing to its duration. Subsection 2.4 derives the main prediction of the model; a RJV with a high R&D cost has a shorter duration. Section 3 contains the empirical analysis. Subsection 3.1 discusses the Eureka data. Subsection 3.2 explains our methodology. Subsection 3.3 presents the estimation results. Subsection 3.4 checks the robustness of our empirical results. The final section states our conclusions and suggests possible extensions for future research.

2. The optimal duration of a RJV

Consider a RJV with m (≥ 2) symmetric firms, which interact over an infinite number of periods $t = 1, 2, \ldots$. All actions take place at the beginning of periods. In each period t, each firm unilaterally decides whether to invest the amount k or not, conditional on not having discovered innovation yet. If z ($\leq m$) firms choose to make investment at t, at date $t + 1$ the RJV discovers innovation with (conditional) probability $1 - \phi(z)$. That is, $\phi(z)$ measures the RJV's probability of failure to discover innovation. We assume that a RJV has a better chance of success when more firms make investments.

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

To keep thing simple, we assume that firms are incapable of discovering the innovation without formation of a RJV.[2] That is often the case in the real world, where soaring R&D costs is an important motivation for formation of RJVs. We also disregard the effects of synergy and spillovers within a RJV for the moment.

2.1 Observable R&D actions

In this subsection 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 $t = 1$ each firm invests k in R&D, and at all $t \geq 2$, conditionally on innovation not having been discovered, each firm invests k as long as all firms have done so to date; otherwise, they break up the RJV.

Let ϕ_z represent the function $\phi(z)$ to lighten the notation. If all m firms adopt the above strategy, at each date a 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, if π denotes the value of innovation to each firm in $t + 1$'s value, the per-firm expected equilibrium payoff V can be expressed as follows:

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

where $\delta \in (0, 1)$ is the discount factor. The right-hand is the standard expression; investing k in time t yields innovation worth $\delta\pi$ in time t's value with probability $(1 - \phi_m)$ and fails to do so with probability ϕ_m, in which case the firm's expected profit is δV in time t's values. Collecting terms yields

---

[2] This assumption can be relaxed without affecting the main results of the analysis.

(1) $$V = \frac{-k+(1-\emptyset_m)\delta\pi}{1-\delta\emptyset_m}$$

We naturally assume that $V > 0$, i.e., 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 and raises the venture's probability of failure from ϕ_m to ϕ_{m-1}. It also terminates the RJV, yielding the payoff $(1 - \phi_{m-1})\delta\pi$.[3] There is no shirking if and only if $V \geq (1 - \phi_{m-1})\delta\pi$.

2.2. 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 in (1). However, now that shirking becomes undetected, a shirking firm can save the R&D cost without triggering termination of the RJV. The only consequence of shirking is a lower probability of success. Thus, the expected payoff from shirking can be written

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

There is no shirking if and only if

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

where

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

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

---

[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.

Assumption 2: $V < V^s$.

2.3. The optimal duration of a RJV

Under Assumption 2 a RJV is unstable when R&D actions are unobservable. However, firms can still form a RJV if they pre-commit to dissolving the venture at some future date. To demonstrate this case, begin with a one-period RJV, in which 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 the R&D cost k and lowers the probability of innovation, obtaining the payoff

$$R^s(1) = (1 - \phi_{m-1})\delta\pi.$$

There is no incentive to shirk if

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

A comparison with equation (3) implies that

$$R(1) - R^s(1) > V - V^s.$$

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

$$R(1) - R^s(1) > V - V^s.$$

Result 1 says that each firm has a greater incentive to make an R&D effort under Assumption 2. This result has the following intuitive explanation. Since a one-period RJV gets terminated at $t = 2$, at $t \geq 2$ the continuation payoff equals zero instead of V as in subsection 2.2. This drop in continuation payoff motivates firms to succeed at $t = 1$.

Next, supposing that $R(1) – R^s(1) > 0$, consider a two-period RJV. With two periods to cooperate, a failure at $t = 1$ gives firms one more chance to succeed at $t = 2$, where the expected payoff equals $\delta R(1)$. This means that 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. With n periods to cooperate, the expected profit at $t = 1$ 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, whose solution is given by

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

Since $\delta\phi_m < 1$, $R(n)$ is monotone increasing and approaches V as n goes to infinity. Intuitively, terminating a RJV at t = infinity is tantamount to never terminating it and hence the payoff is V.

We next examine the incentive to shirk at $t = 1$ in an n-period RJV. As before, a shirking firm saves cost k but reduces the probability of success, yielding the expected profit

(5) $$R^s(n) = (1 – \phi_{m-1})\delta\pi + \phi_{m-1}\delta R(n – 1).$$

There is no incentive to shirk if the following expression is non-negative

(6) $$R(n) – R^s(n) = – k + \Delta_{m-1}\delta(\pi – R(n – 1)).$$

The right-hand side of (6) is monotone decreasing in n since R(n) is monotone increasing. Thus, the incentive to shirk increases with n. Further, substituting the definition of V^s from equation (2), we can rewrite equation (5) as:

$$R^s(n) = V^s - \phi_m\delta(V - R(n-1)).$$

As n goes to infinity, R(n) approaches V, so $R^s(n)$ approaches V^s. These two limit results together imply that, as n goes to infinity, $R(n) - R^s(n)$ goes to $V - V^s$, which is negative under Assumption 2. Thus, there is a limit to the number of periods in which firms can commit to cooperate as a RJV. Monotonicity implies this limit is unique.

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

$$R(n^*) - R^s(n^*) \geq 0 > R(n^*+1) - R^s(n^*+1). \tag{7}$$

Result 2 says that a RJV can be stable up to n* periods. Since R(n) is strictly increasing, R(n*) represents the maximal expected payoff per firm.

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

The foregoing analysis shows that, even if cooperation in R&D is inherently unstable, firms can still form a stable RJV by pre-committing to its duration.

We next ask: what determines the optimal duration of a RJV. The preceding analysis shows that the R&D cost plays a key role. An increase in k increases the payoff from shirking, making shirking more attractive. Curbing this rise in opportunism requires a shortening of the duration. This leads to the next proposition (proof in Appendix 1).

Proposition 2. The higher the R&D cost per firm, the shorter the optimal duration of a RJV.

As we discuss more in detail in section 3, we take this as the distinguishing feature of our model to be tested empirically.

The *ex ante* duration of a RJV also depends on its membership size m. We show, in Appendix 2, that an increase in m generates two opposing effects. On the one hand, an increase in m means that each firm's contribution has a lesser impact on the venture's probability of success. This gives each firm more of the incentive to shirk. Furthermore, if the total value of innovation is fixed, an increase in membership size decreases the value of innovation per firm, which further increases the incentive to shirk. Thus, an increase in membership size requires a shortening of duration.

The above conclusion is obtained in the absence of synergy within a RJV. 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. Indeed, we show, in Appendix 2, that introduction of synergy and spillovers into our model can reverse the above result. This makes the effect of membership size an empirical matter. If membership size has a positive impact on duration in our empirical study, we are led to conclude that synergies play an important role in formation of Eureka RJVs.

3. An empirical analysis of durations of Eureka projects

3.1. A description of the data from the Eureka program

In this section we explore empirically the factors determining the duration of a RJV. To that end, we utilize data from Eureka, a European R&D program designed to promote international RJVs for commercial innovations.[4] Since its inception in 1985 and until 2004, the Eureka program spawned 1,716 RJVs, involving 8,520 participants from 38 countries.[5] 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.[6]

More detailed information on individual Eureka RJVs is publicly available on the program's website.[7] The data set includes the initiation years, durations,[8] and costs of all Eureka projects. The main industry designations are also available; the majority of Eureka RJVs are in manufacture, although some are in agribusiness and services sectors.[9] When it comes to individual participants, however, the information is more limited; only the names, addresses and nationalities of participants are available.[10] Thus, the Eureka data set contains only the RJV-level data but not the firm-level data.

For our empirical analysis we select 1,543 commercial RJVs, which are organized to discover product and/or process innovations. The academic literature distinguishes product

---

[4] Eureka promotes formation of RJVs by existing firms. It does not financially support RJVs that includes new firms.
[5] 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.
[6] Table A1 in Appendix 3 describes the RJV characteristics in details.
[7] www.eurekanetwork.org.
[8] The durations data are obtained from the Eureka website. Not all durations are ex ante, as actual durations are entered as projects are completed. However, the termination of subventions ensures that actual durations do not differ much from the ex ante durations, since RJVs cannot go on forever without subsidies. In fact, from the information available on one third of the database, the difference between ex ante and actual durations is about three months and a half. This small difference suggests that RJVs are allowed to extend their collaboration to complete the final stage of their projects.
[9] 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.
[10] In particular, we have no information on participants' financial and technological contributions as well as their accounting data such as profits, and their goal in entering the RJV.

innovation, which create a new or a better-quality product, from process innovation, which introduces a new cost-reducing technology (Tirole 1988). In reality, however, many innovations have the attributes of both. Recognizing this fact, the Eureka data classify the innovations into three types, namely, product-only innovation, process-only innovation, and product-and-process innovation.

Table 1: Characteristics of all the commercial Eureka RJVs

Variables	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
RJV duration (Months)	1543	42.149	20.315	6	166
Monthly cost per member (€ Million)	1543	0.035	0.128	0.0003	2.7778
Number of members	1543	5.225	8.267	2	196
Number of firms	1543	3.476	4.466	1	96
Product_and_process	1543	0.242	0.428	0	1
Product innovation	1543	0.567	0.496	0	1
Process innovation	1543	0.191	0.393	0	1
Inno_value	1543	2.051	0.656	1	3
Multi-sector RJV	1543	0.677	0.468	0	1
Ratio of firms	1543	0.752	0.256	0.0357	1

Note: Table 1 reports the summary statistics for the 1,543 commercial Eureka RJVs (1985-2004). See the description of the variables in Table A1 in Appendix 3.

Table 1 presents the descriptive statistics of the commercial RJVs in our data set. The average Eureka project consists of 5.2 members, of which 3.5 are firms. The average Eureka project has the duration of about three years and half (42.1 months), and costs 35,000 euros a month per member to run.[11] As for the types of innovations, 24 percent of Eureka RJVs in our data set pursue product-and-process innovations while 57 percent aim at product-only

---

[11] Our data includes some exceptional cases. The most costly Eureka RJV spent 4 billion euros in R&D, involved 19 members and lasted 96 months. The largest Eureka RJV had 196 members, spent 796 000 € and had a duration also of 96 months. The results in subsection 3.3 are not affected by these extreme cases.

innovations; the remaining 19 percent target process-only innovations. The significance of these and other variables in the table are discussed in the next subsection.

3.2. Methodology

Although the average Eureka RJV lasts for 42.1 months, there are significant variations in duration across Eureka projects. We investigate what factors could generate such variations. Initial tests reveal that the error terms of the OLS regressions on the Eureka data are not distributed normally.[12] This rejection of the assumption on the normality of the error terms relates to the time dimension of the dependent variable, i.e. the log of RJV duration.

Consequently, to construct a more suitable model for our study, we turn to survival or duration analysis. More specifically, we use proportional hazard models. The central assumption of proportional hazard models is that the hazard $h_j(t)$, or conditional probability of the termination 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. On the other hand, the exponential component 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 model 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.

---

[12] 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 follow the type 1 extreme value (EV1) distribution.

The most general proportional hazard model is the semi-parametric 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 parametric Weibull model, which allows $h_0(t)$ to be increasing, decreasing or constant over time. More specifically, in the Weibull proportional hazard 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.[13] When p is greater (less) than one, the hazard rate is increasing (decreasing). For p equal to one, the hazard rate remains constant and the Weibull model becomes the exponential proportional hazard (or Poisson) 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 and later check its robustness using alternative specifications.

We next describe our explanatory variables. The first and most important variable for our analysis is the *monthly R&D cost per member* variable, constructed by dividing the total cost by the number of members of a RJV and by its ex ante duration (in months). If this explanatory variable represents the flow R&D cost, Proposition 2 implies that this variable is negatively related to Eureka projects' durations. As emphasized earlier, we take this result as the distinguishing feature of our model, since the intuitive reasoning point to the opposite conclusion; a higher R&D cost is correlated with a bigger and more difficult project, which generally takes a longer duration to complete.

---

[13] This specificity in functional form makes the parametric Weibull model more restrictive but more efficient relative to the semi-parametric Cox model.

The second explanatory variable we consider is the *number of members* of a RJV. As explicated in the preceding 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 the following control variables. Our first control variable comes from the fact that firms are not the only participants in Eureka RJVs. Universities, research institutes, government agencies, and even museums participate in Eureka projects alongside firms. However, since firms are considered more profit-driven than non-firm participants, our theory implies that a RJV that includes proportionately more firms is more susceptible to opportunism and hence exhibits a shorter duration. To represent this notion, we construct the *firm membership ratio* variable by dividing the number of member firms by the total number of members of a RJV. It is expected that this variable is negatively related to the duration of a Eureka project.

Secondly, we already mentioned the three types of innovations in the Eureka data. From that data we construct the *product_and_process* variable. This variable takes the value one if a RJV targets a product-and-process innovation and the value zero if a RJV pursues a product-only or process-only innovation.[14] This has the following explanation. Since more difficult projects generally take longer times to succeed, it is a reasonable presumption that a RJV targeting a more difficult project tends to have a longer duration than one chasing an easier project. Although there is no natural measure for project difficulty, we conjecture that product-and-process innovations are inherently more difficult than product-only or process-only

---

[14] 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.

innovations. We thus expect the *product_and_process* dummy variable to have a positive impact on the duration of a RJV.

Finally, we remove the bias due to unobservable heterogeneities by employing a fixed effect model. More specifically, we control the following three variables. The *multi-sector RJV* dummy variables take the value one if a RJV has members from more than one industry and the value zero otherwise.[15] The *main industry* dummy variable captures the characteristics of the main industry of a Eureka RJV. The *RJV initiation year* dummy variable reflects the economic environment prevailing the year when the RJV was launched.

3.3. Empirical results

Columns 1 through 6 of Table 2 report the regression results from various Weibull specifications. Consistent with the standard procedure of duration analysis, these estimates are expressed in terms of the hazard ratios, instead of the coefficients, of the explanatory variables.[16] The null hypothesis is that the hazard ratio of the explanatory variable equals one, i. e., the explanatory variable has no significant effect on the duration of a RJV. If the hazard ratio is statistically less than (greater than) one, the explanatory variable has a positive (negative) impact on the duration. Our preferred model is in column 6, which contains all the explanatory variables discussed in subsection 3.2.

We now discuss our findings. First, the hazard ratios of the logarithm of the *monthly RJV cost per member* variable, displayed in Columns 1 through 6, clearly exceed unity,

---

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

[16] 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 $\exp(\beta_2)$.

implying that a RJV with a higher flow R&D cost exhibits a shorter duration. In particular, column 6 states that a one-percent point increase in the *monthly RJV cost per member* variable decreases the duration of a Eureka RJV by 0.06%.[17] Thus, the Eureka data fail to reject the main hypothesis of our theoretical model.

Table 2: The duration of Eureka RJVs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Monthly cost per member	1.045*	1.049**	1.020	1.067**	1.028	1.061**	-0.0324***
	(0.0255)	(0.0251)	(0.0245)	(0.0285)	(0.0260)	(0.0283)	(0.0117)
Number of members		0.952***	0.957***	0.966***	0.957***	0.964***	0.00783***
		(0.0110)	(0.0107)	(0.0096)	(0.0110)	(0.0102)	(0.0023)
Multi-sector RJV		0.980	0.992	1.001	0.868**	0.946	0.00507
		(0.0595)	(0.0605)	(0.0567)	(0.0573)	(0.0590)	(0.0240)
Firm membership ratio			1.427***	1.562***	1.423***	1.545***	-0.214***
			(0.1836)	(0.1906)	(0.1868)	(0.1950)	(0.0476)
Product_and_process		0.856**	0.860**	0.876**	0.844**	0.857**	0.0789***
		(0.0562)	(0.0562)	(0.0534)	(0.0591)	(0.0543)	(0.0241)
Initial year	NO	NO	NO	YES	NO	YES	YES
Main sector	NO	NO	NO	NO	YES	YES	YES
Shape parameter p	8.502***	8.976***	8.991***	10.59***	9.355***	10.96***	
	(0.1779)	(0.1844)	(0.1829)	(0.2259)	(0.1918)	(0.2282)	
Constant							4.476***
							(0.1152)
Observations	1543	1543	1543	1543	1543	1543	1543

*Note: Table 2 summarizes the regressions results of the Weibull proportional hazard models (column 1 to 6). A hazard ratio statistically less than (greater than) one shows that the explanatory variable has a positive (negative) significant impact on the duration of a RJV. Table 2 also presents the coefficients of the OLS model (column 7). 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.*

---

[17] The RJV cost variable is in million euros.

The models in Columns 2 through 6 contain the hazard ratio of the *number of member* variable. These estimates are clearly less than one, thereby suggesting the presence of strong synergy and spillovers within 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. Cassiman and Veugelers (2002) find similar results for Belgian firms.

Turning to the firm membership ratio, we conjectured earlier that firms are more profit-driven than non-firm entities so firm-led RJVs have shorter durations than non-firm-led RJVs. This conjecture turns out to be correct in our analysis. As seen in Column 6, the hazard rate of the *firm membership ratio* variable clearly exceeds unity; more specifically, a one-percent increase in the proportion of firms within a RJV decreases the duration by 0.55%.[18]

The hazard ratios of the *product_and_process* variable are given in Columns 2 through 6. They are clearly significant and less than one. In particular, column 6 indicates that a RJV that targets a product-and-process innovation has a 14.3% longer duration than a RJV chasing a product-only or a process-only innovation. This is consonant with our conjecture that a RJV chasing a higher-valued innovation tends to have a longer duration.

Finally, we present the estimates based on the OLS regressions in Column 7. As mentioned earlier, the error terms on the OLS regressions are not normally distributed, implying possible bias in the OLS estimates. However, the OLS estimates can still illustrate the issue on hand more intuitively. Indeed, the monthly RJV cost per member variable has a negative coefficient while the *number of members* and the *product_and_process* variables have

---

[18] Although the effect of this variable is only marginally significant in the specification in column 6, for the majority of the specifications, the effect is quite significant.

positive coefficients (note that the entries in Column 7 are the standard OLS coefficients). These findings are consistent with our results based on the parametric Weibull specifications. The *firm membership ratio* variable has a negative coefficient, also confirming our finding from the Weibull specifications. However, the OLS estimates are less robust, as they follow the type 1 extreme value (EV1) distribution and hence violate the normality hypothesis of the error terms of the regression on the log of RJV durations.

3.4. Robustness

In this subsection we apply alternative model specifications to check the robustness of our results in Table 2. We begin with the robustness of the baseline hazard following the Weibull distribution. To that end we consider the semi-parametric Cox proportional hazard model. Since the Cox model imposes no functional form of the baseline hazard, if the Weibull model is a good representation of Eureka RJVs, it should yield results similar to those in Table 2.

The estimates with the Cox model are displayed in column 8 of Table 3, where Column 6 from Table 2 is also shown for comparisons' sake.[19] A remarkable similarity of the results between these two columns confirms the appropriateness of the Weibull model as our main empirical model.

We turn to the possibility that our data fails to capture every characteristic of Eureka RJVs, that is, any two RJVs that appear identical have different durations due to some

---

[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 Appendix 4, 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).

unobserved heterogeneity. To check this possibility we first compute the conditional probabilities of RJV deaths from our sample population. The results are shown in Figure A1 in Appendix 5.[20] If these conditional probabilities are regarded as a non-parametric approximation of the baseline hazard of the population, then the non-monotonic hazard rates shown in Figure A1 imply that shorter-duration RJVs and long-duration RJVs may exhibit different baseline hazards (Cleves *et al.*, 2010). To examine this possibility we turn to the frailty Weibull model.[21] The frailty Weibull model 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.[22] The procedure yields the results in column 9 of Table 3. They are remarkably similar to those in column 6 obtained from the Weibull model.

We next examine the possibility that the results based on the Weibull model in Table 2 may be driven by time. To address this issue, we run regressions using the exponential hazard model, in which the baseline hazard remains constant over time. The estimation results, presented in column 10 of Table 3, are again quite similar to those in column 6.

Table 3: Robustness check with alternative baseline hazards

	(6)	(8)	(9)	(10)
Monthly cost per member	1.061^{**} (0.0283)	1.055^{**} (0.0264)	1.076^{**} (0.0328)	1.009^{***} (0.0031)
Number of members	0.964^{***} (0.0102)	0.968^{***} (0.0095)	0.965^{***} (0.0109)	0.998^{***} (0.0006)
Multi sector RJV	0.946 (0.0590)	0.958 (0.0558)	0.949 (0.0656)	0.999 (0.0065)
Firm membership ratio	1.545^{***} (0.1950)	1.546^{***} (0.1816)	1.674^{***} (0.2454)	1.063^{***} (0.0135)

---

[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.
[22] The unobserved individual characteristics are assumed being not correlated with the explanatory variables.

Product_and_process	0.857^{**}	0.871^{**}	0.840^{**}	0.979^{***}
	(0.0543)	(0.0515)	(0.0589)	(0.0063)
Initial year	YES	YES	YES	YES
Main sector	YES	YES	YES	YES
Shape parameter p	10.96^{***}		11.91^{***}	
	(0.2282)		(0.4791)	
Observations	1543	1543	1543	1543

*Note: Table 3 summarizes the regressions results from the Weibull model (column 6), the Cox model (column 8), the frailty Weibull model (column 9), and the exponential model (column 10). Column 6 is reproduced from table 2. A hazard ratio statistically less than (greater than) one shows that the explanatory variable has a positive (negative) significant impact on the duration of a RJV. Robust standard errors are in brackets. *** denotes significance at the 1 percent level, ** at the 5 percent level and * at the 10 percent level.*

Finally, we reconsider the classification of innovation types. In the preceding section we used the simple binary system, namely, whether the innovation is a product-and-process type or not. Here, we use a three-way classification system. That is, we define the value of innovation variable (denoted by *inno_value*) and assign the value 3 for product-and-process innovation, 2 for product-only innovation and 1 for process-only innovation. This is based on the assumption that a new product generates a greater value than a new technology to produce an existing product. This alternative classification yields results quite similar to the ones we obtained earlier (the details are presented in Table A2 in Appendix 4).[23]

To sum up this section: the alternative model specifications yield the regression values that are quite similar to those obtained from the basic Weibull model, confirming the robustness of our results in the preceding subsection.

---

[23] Table A2 in Appendix 4 replicates the models in Columns 2 through 7 of Table 2 with the alternative proxy for the difficulty of innovation. The columns in Table A2 are labeled with (‘) to indicate the corresponding columns in Table 2.

4. Concluding remarks

A research joint venture often encounters a serious incentive problem because members' contributions to the venture consist mostly of human resources and proprietary technical know-how, the qualities and quantities of which are difficult to measure and verify. In this paper, we develop a model in which a RJV can overcome this free-rider problem by pre-committing to its termination date. Our analysis shows that there is an optimal termination date, or an optimal duration, for a RJV. We show further that the optimal duration decreases with the flow R&D cost. This is a counter-intuitive result because normally one would associate a high R&D cost with a difficult project and such a project usually takes a longer time to succeed. Thus, we take this result as the key hypothesis to test in our empirical analysis.

In the second half of the paper we examine the factors determining the duration of RJVs in the European Eureka program. We choose this data set because Eureka projects satisfy two crucial conditions for our analysis. Firstly, Eureka RJVs must include members from at least two different countries. If members conduct R&D in separate labs in different countries, this requirement makes it more difficult to monitor members' contributions. Secondly, the commitment to end a RJV at the future termination date can be time-inconsistent. However, time inconsistency is not so critical with the Eureka program because a Eureka RJV is required to indicate its duration in the application form to be approved and to be qualified for the subvention.

Our regression analysis shows that the *monthly R&D cost per member* variable has the hazard ratios exceeding unity as expected, implying that a higher flow R&D cost results in a shorter duration. Thus, Eureka data fails to reject the main hypothesis of our model. We also find that the membership size variable has the hazard ratios less than one. This implies the presence of strong synergy within a Eureka RJV and is consistent with recent empirical work. Our results also indirectly support the conjecture that RJVs chasing more valuable projects have relatively longer durations than those chasing less valued innovations.

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 be extended to other R&D programs. For example, while the Eureka program is designed to promote commercial innovations, the EU has sister programs called the European Framework programs designed to subsidize firms and research institutes engaged in basic research. An extension of the present paper to the latter programs may 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 seeking exemption from antitrust investigations. Although this program is now defunct, our analysis should be able to throw light on the determination of durations of RJVs under this program.

Appendices

***Appendix 1**: Proof of Proposition 2*

Differentiating (6) yields

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

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, $d[R(n) - R_d(n)]/dk < 0$. □

Appendix 2: We evaluate the effect of membership size m on the duration of a RJV in the presence of synergy and spillovers. We assume that their presence 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. Assume that z is continuous and $s(z)$ and $\phi(z)$ are differentiable. 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 ϕ(.) 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. □

Appendix 3:

Table A1: Description of RJV characteristics

Variables	**Description**
RJV duration	Duration, in months, of the Eureka RJV
RJV monthly cost per member	Total cost of the Eureka RJV divided by the number of members and by the number of months of duration, inclusive of subsidies
Number of firm members	Number of firms in the Eureka RJV
Number of members	Number of firms, research centers, universities and national institutions in the Eureka RJV
Firm membership ratio	Number of firms divided by the total number of members within a RJV
Product_and_process	Dummy variable taking the value one if the expected outcome of R&D is product-and-process innovation
Inno_value	Rank of innovation type, product and process innovation = 3; product innovation = 2; process innovation = 3.
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).

Appendix 4:

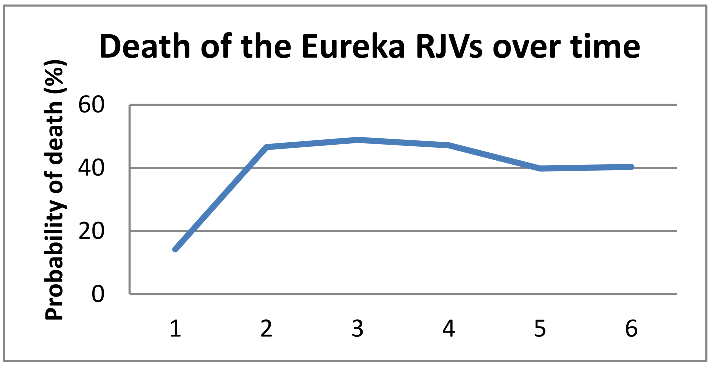
Table A2: Robustness check with alternative innovation value proxy

	(2’)	(3’)	(4’)	(5’)	(6’)	(7’)
Monthly cost per member	1.049** (0.0248)	1.021 (0.0243)	1.065** (0.0286)	1.029 (0.0257)	1.059** (0.0284)	-0.0302** (0.0118)
Number of members	0.951*** (0.0110)	0.956*** (0.0108)	0.966*** (0.0097)	0.955*** (0.0112)	0.963*** (0.0104)	0.00786*** (0.0024)
Multi-sector RJV	0.977 (0.0589)	0.989 (0.0598)	1.000 (0.0564)	0.868** (0.0566)	0.948 (0.0590)	0.00236 (0.0240)
Firm membership ratio		1.421*** (0.1821)	1.567*** (0.1917)	1.423*** (0.1871)	1.557*** (0.1976)	-0.219*** (0.0478)
Inno_value	0.880*** (0.0349)	0.883*** (0.0352)	0.936* (0.0364)	0.868*** (0.0357)	0.919** (0.0373)	0.0325** (0.0155)
Initial year	NO	NO	YES	NO	YES	YES
Main sector	NO	NO	NO	YES	YES	YES
Shape parameter p	9.002*** (0.1837)	9.015*** (0.1824)	10.59*** (0.2248)	9.384*** (0.1907)	10.96*** (0.2283)	
Constant						4.426*** (0.1215)
Observations	1543	1543	1543	1543	1543	1543

*Note: Table A2 replicates the models of Table 2 (column 2 to 7). (‘) indicates the corresponding model in Table 2. A hazard ratio statistically less than (greater than) one shows that the explanatory variable has a positive (negative) significant impact on the duration of a RJV. Table A2 also presents the coefficients of the OLS model (column 7’) 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.*

Appendix 5:

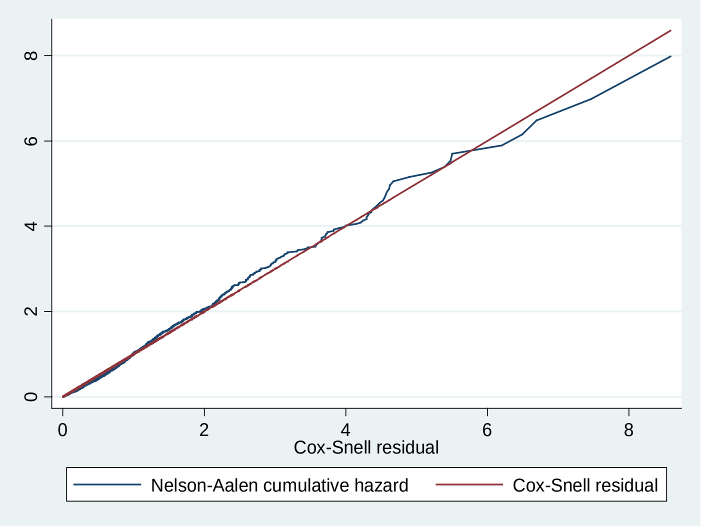
Figure A1: Conditional mortality rates of the Eureka RJVs population over time



Note: Time intervals are in the unit of two years.

Appendix 6:

Figure A2: 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 14 of table 3.

References

Cassiman, B. and R. Veugelers, 2002. R&D cooperation and spillovers: some empirical evidence from Belgium. *American Economic Review* 92, 1169-1184.

Cleves, M., W. Gould, R. G. Gutierrez, and Y. Marchenko, 2010. *An introduction to survival analysis using Stata*, College Station, TX: Stata Press.

d'Aspremont, C., and A. Jacquemin, 1988, Cooperative and noncooperative R&D in duopoly with spillovers. *American Economic Review* 76, 1133 - 1137.

Erkal, N., and D. Piccinin, 2010, Cooperative R&D under uncertainty with free entry. *International Journal of Industrial Organization* 28, 74 - 85.

Hernan, R., P. Martin, and G. Siotis, 2003, An empirical evaluation of the determinants of research joint venture formation. *Journal of Industrial Economics* 51, 75 - 89.

Kamien, M., E. Muller, and I. Zang, 1992, Research joint ventures and cartels. *American Economic Review* 82, 1293 - 1306.

Katz, L. M., 1986, An analysis of cooperative research and development. *RAND Journal of Economics* 17, 527 - 543.

Kogut, B., 1989, The stability of joint ventures: reciprocity and competitive rivalry. *Journal of Industrial Economics* 38, 183 - 198.

Miyagiwa, K., and Y. Ohno, 2002, Uncertainty, spillovers and cooperative R&D. *International Journal of Industrial Organization* 20, 855 - 876.

Pastor, M., and J. Sandonis, 2002, Research joint ventures vs. cross licensing agreements: an agency approach. *International Journal of Industrial Organization* 20, 215 - 249.

Shapiro, C., and R. Willig, 1990, On the antitrust treatment of production joint ventures. *Journal of Economic Perspectives* 4, 113-130.

Tirole, J., 1988, *Theory of industrial organization*. Cambridge, MA: MIT Press

Van Beveren, I., and Vandenbussche, H., 2010, Product and process innovation and firms' decision to export. *Journal of Policy Reform* 13, 3 - 24.