Learning Dynamics in Research Alliances: A Panel Data Analysis[1]

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Abstract: The aim of this paper is to empirically test the determinants of Research Joint Ventures' (RJVs) group dynamics. We develop a model based on learning and transaction cost theories, which represent the benefits and costs of RJV participation, respectively. According to our framework, firms at each period in time weigh the benefits against the costs of being an RJV member. RJV dynamics can then be interpreted as a consequence of this evolving trade-off over time. We look at entry, turbulence and exit in RJVs that have been set up under the U.S. National Cooperative Research Act, which allows for certain antitrust exemptions in order to stimulate firms to cooperate in R&D. Accounting for unobserved project characteristics and controlling for inter-RJV interactions and industry effects, the Tobit panel regressions show the importance of group and time features for an RJV's evolution. We further identify an average RJV's long-term equilibrium size and assess its determining factors. Ours is a first attempt to produce robust stylized facts about co-operational short- and long-term dynamics, a neglected dimension in research co-operations, but an important element in understanding how collaborative learning works.

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1. Introduction

Though being competitors in the product market, firms often cooperate in research and development (R&D). The U.S. National Cooperative Research Act of 1984 (NCRA) was created precisely for this purpose. The NCRA stimulates firms to cooperate in R&D in non-equity ventures on a large scale, thereby aiming to provide a solution to perceived competitive threats to U.S. high-tech industries (Link et al., 2005). As a natural consequence of the goal of promoting such broad and loose co-operations, one characteristic of the NCRA collaborations stands out: firms frequently enter and exit the NCRA research consortia after their initial formation.[2] The aim of this study is to explore the drivers of these in-and-out movements, as a first step in deepening our understanding of the dynamics of research collaborations.

There is growing recognition that instabilities are a central feature of not only the NCRA research consortia, but of inter-firm co-operations in general. Indeed, several empirical studies have provided evidence that collaborative agreements are inherently unstable organizational forms (Barkema et al., 1997; Beamish, 1985; Dussauge et al., 2000; Franko, 1971; Gomes-Casseres, 1987; Killing, 1983; Kogut, 1989; Li, 1995; Park & Russo, 1996; Pennings et al., 1994). These movements, as Ariño and de la Torre (1998) and Doz and Hamel (1998) state, can be an important indicator of the learning processes inside alliances and of the net benefits that firms obtain from participating. According to this line of reasoning, firms enter research collaborations with the expectation of learning, but adapt over time and alter their commitments, which may ultimately lead to exit (Balakrishnan and Koza, 1993; Kogut, 1991; Hamel, 1991; Khanna et al., 1998; Koza and Lewin, 1998; Reuer and Zollo, 2005). Therefore, given the importance of collaborative learning for the NCRA program – and, of course, for research alliances in general – it seems key to identify the drivers of these dynamics, with the idea of giving initial insights on how firms co-operate and learn in research alliances.

Following Reuer and Zollo (2005), we draw upon two different streams of the institutional economics literature for our framework. On the one hand, based on evolutionary economics we argue that learning represents the benefits of alliance membership.[3] On the other hand, through transaction cost theory and industrial economics reasoning, we identify the costs of its

[2] More than 30% of the NCRA alliances in our sample from 1985-1999 experience subsequent firm in-and-out movements, involving more than 75% of participating firms.

[3] There are other reasons for co-operating in R&D, such as risk-sharing, facilitating entry in new market segments, internalizing knowledge spillovers or reducing uncertainty (for an overview of participation determinants, see e.g. Backes-Gellner et al., 2005; Doz et al., 2000; Hagedoorn et al., 2000; Hernan et al., 2003; Roeller et al., 2007). Other motivations, however, would not lead to a substantially different reasoning than ours, as long as firms weigh the advantages of participation against its disadvantages.

participation. Alliance dynamics can then be interpreted as an evolving interplay of these benefits and costs.

First, according to evolutionary economics, organisms evolve through the formation and marginal adjustment of behavioral patterns (Nelson and Winter, 1982). Adapted to organizations, evolutionary economics highlights the role of the tacit accumulation of knowledge through learning (Teece et al., 1997). Research co-operation is then considered a mechanism to facilitate the transfer of certain types of knowledge and to enhance a firm's learning processes (Teece, 1986; Hagedoorn, 1995). Therefore, this reasoning focuses on the *benefits* of alliance participation.

Second, however, co-operative learning in an alliance is complex. The transaction cost view of Williamson (1992) applied to R&D collaborations highlights the particular characteristics of these ventures that give rise to various exchange hazards, such as free-riding or coordination costs among partners (Oxley, 1997; Veugelers, 1998). Thus, transaction cost theory focuses on the *costs* of the involvement in alliances.[4]

We combine these two dimensions –evolutionary economics and transaction cost theory– to analyze drivers of alliance dynamics. We focus on factors that influence the post-formation entry and exit-movements of firms into and out of an NCRA research alliance. The underlying rationale of our framework is that firms at each period of time weigh the (expected) benefits of learning against the (expected) costs of free-riding and coordination in these research collaborations. In particular, we use the following reasoning. If a firm considers the benefits to be higher than the costs, then it enters an alliance.[5] Thereafter, given that firms alter their commitments, change investments and learn from other firms, they re-evaluate the costs and benefits of being in the research collaboration. Thus, if at one point in time the costs of participation are higher than the benefits, the firm exits. Our reasoning is thus reminiscent to Osborn and Hagedoorn's (1997, p273) proposal to study "evolutionary dynamics [of alliances] as a trade-off between transaction cost economies and technological development".

The NCRA research consortia, being non-equity alliances, are a more effective environment for learning than equity forms such as research joint ventures (RJVs), which are more likely to stress control issues (Hagedoorn and Narula, 1996). The negative side of consortia, vis-à-vis equity

[4] We focus on transaction costs inside alliances. We, therefore, do not analyze how alliances potentially reduce transaction costs with respect to external markets (see e.g. Hennart, 1988).
[5] And sitting members allow this new firm in the alliance when they think it is potentially beneficial for them.

ventures, however, is facing a higher uncertainty and having more diffuse goals for undertaking research (Aldrich and Sasaki, 1995). R&D consortia, therefore, have both potentially higher and more volatile costs/benefits than other types of R&D collaborations, which makes them particularly interesting to investigate alliance dynamics. As an aside, it must be noted that, though R&D consortia are different from RJVs because their members pool research resources into loose and relatively long-term projects, R&D consortia are normally labeled RJVs. From now on, we will stick to this terminology.

We focus on the two drivers of dynamics that we believe to be most relevant in our setup. First, evolutionary economics highlights the role of knowledge accumulation and development of routines over time. Therefore, we focus on how the age of the RJV influences its forces. Second, transaction cost analysis focuses on the organizational characteristics that give rise to various exchange hazards. In particular, several scholars have identified these costs as increasing with the number of agents that interact, due to suffering larger coordination costs or to opportunistic behavior becoming more severe (e.g. Holmström, 1982; Milgrom and Roberts, 1992). On the other hand, being a member in a larger RJV gives access to a larger pool of knowledge (Bloch, 1995; Veugelers, 1998), which may increase the benefits of learning. Therefore, we focus on how an alliance's group size, i.e. the number of participants ("insiders"), affects this trade-off and consequently influences its dynamics. We further investigate whether industry characteristics and interactions between different RJVs have an impact on an alliance's evolution.

We identify RJV movements on two levels. First, we analyze how group and time characteristics determine its *short-run dynamics*; i.e. we investigate how the number of insiders and the age of an RJV influence its entry and exit patterns. We find that the group-variables are robust drivers in a non-linear way. Especially the found U-shaped impact of the number of insiders on entry into an RJV may be of interest. This result indicates that the perception of transaction cost problems at first goes up with the number of insiders, i.e. entry initially decreases with size. This is indirect evidence for the classic theory of teams where moral hazard increases with the number of agents (Holmström, 1982), yet in a dynamic rather than a static context. However, those RJVs that are very large, experience *more* entry when they further increase in size. This hints at some RJVs having overcome the typical problems of large groups through an optimal design of their organizational variables. Firms perceive, therefore, entrance into these larger RJVs to be beneficial, given the larger pool of knowledge available. Further, the age of an RJV has a negative effect on both entry and exit, suggesting that RJVs become more stable over their lifespan, which may be due to divergent learning (Nakamura et al., 1996) –and hence firms become more complementary over time– or due to RJVs becoming more effective over time in dealing with transaction cost problems, because of the development of trust and more efficient routines (Chiles and McMackin, 1996; Parkhe, 1993).

Second, once short-run dynamics are analyzed, one can go a step further and investigate whether a *long-term equilibrium size* exists – i.e. if entry and exit evolve around a long-term stable group size. We find that this is indeed the case, which confirms – again in a dynamic rather than static context – RJV-group formation models such as Bloch (1995) that predict an optimal RJV size due to the trade-off between costs and benefits of participation. Moreover, some of the industry characteristics in which the RJV is embedded are found to have a determinant impact on this group size. In particular, factors which both increase the benefits of learning and the possibility of controlling other RJV members – as, for example, the concentration of an industry – lead to larger RJVs in the long-run.[6]

Our study is novel in several aspects. First, although recent theoretical studies have indicated the importance of organizational changes in existing partnerships, very little empirical research has been conducted on these ideas.[7] This small empirical literature takes into account how alliance termination is influenced by either host country characteristics (Contractor, 1990; Franko, 1989; Barkema et al., 1997), degrees of partner rivalry (Kogut, 1989, 1991; Park and Russo, 1996) or partners' previous experiences (Barkema et al., 1997; Reuer and Zollo, 2005).[8] But, although relatively varied, these studies exclusively focus on the *ending* of collaboration.[9] Our study adds to the empirical literature on collaborative dynamics by studying the development of still operating research ventures. This approach offers two main advantages. First, it allows a far more complete picture of an alliance's evolution over time and hence of its learning processes. Second and related, from a statistical point of view our analysis adds true time-variation to the econometric analysis by using panel data methodologies (Wooldridge, 2002). Given the focus of previous work on termination, dissolution has only been analyzed in either cross-sectional

[6] A higher industry concentration should make it more beneficial to apply RJV-generated knowledge in the product market; e.g. cost gains have a higher impact on profits when firms enjoy more market power. Also, when an industry is more concentrated, it is easier to spot defectors – i.e. firms that apply RJV-knowledge in a way that was not agreed upon – since generally fewer firms operate in the market.

[7] Developers of concepts have used learning race models (Khanna et al., 1998), bargaining power ideas (Inkpen and Beamish, 1997) and organization learning frameworks (Koza and Lewin, 1998) to picture and explain an alliance's incremental evolution over time.

[8] It must be noted that, although we focus on post-formation entry and exit dynamics, some of our predictions on post-formation entry will be partly related to the logic of alliance formation, on which the theoretical and empirical literature is vast; we refer to Caloghirou et al. (2003) and Veugelers (1998) for an overview. In the next section we relate specific studies to our framework.

[9] A notable exception is Reuer et al. (2002) who explain governance change in the alliance as a function of firms' previous experience. Their study, however, still focuses on one particular moment of time in the alliance.

studies (e.g. Reuer et al., 2002; Reuer and Zollo, 2005) or hazard rate models (e.g. Barkema et al., 1997; Park and Russo, 1996).

Further, the size and heterogeneity of the NCRA-RJVs allow us to add a novel element to empirical studies that link transaction costs theory to alliance instabilities.[10] Existing empirical works focus mainly on cultural differences (e.g. Contractor, 1990), firms' previous alliance experience (e.g. Reuer and Zollo, 2005) or firms being direct competitors in the product market (e.g. Kogut, 1989) as a source of potential problems. However, seminal papers on transaction costs, such as Holmström (1982) and Milgrom and Roberts (1992), have shown that a key factor in explaining organizational difficulties is the number of cooperating actors. Indeed, problems of coordination and opportunistic behavior typically become more problematic with more interacting agents, as e.g. Holmström and Tirole (1989) and Oxley (1997) argue. At the same time, learning benefits may be higher when the "pool of knowledge" is larger, which makes bigger alliances more attractive (Veugelers, 1998). To our knowledge, this study is the first attempt to link alliance dynamics to the size of RJVs, which should help in understanding how the number of participants impacts the learning versus transaction cost trade-off.

Finally, our focus on group dynamics allows us to determine the long-term stable RJV size, and its dependence on the elements of the industry in which it operates. This serves as a reality check for theory models on RJV formation, such as Bloch (1995) and Cassiman and Greenlee (1999). More importantly, it gives us further insights in exactly how the costs and the benefits of collaborating balance each other out at a certain alliance size. Our approach allows us to identify an "ideal" long-term alliance size in function of these costs/benefits via the characteristics of the industry in which the cooperation is established.

The structure of the paper is as follows. The second section, building on our general architecture, explains our hypotheses. The third section presents the data, while the fourth explains the estimation strategy and the chosen variables. The fifth section shows the econometric results and some robustness checks. The sixth section offers a discussion of the results and possible implications for firms and policy-makers. The seventh section concludes.

2. Theory and hypotheses

Our outline explicitly incorporates costs and benefits for participating firms, and identifies

[10] Indeed, using the same data from the NCRA-program, Doz et al. (2000, p240) state as one of the advantages of the NCRA-RJVs that: "Their multi- party membership provides more complexity than a summation of dyadic relationships."

factors that may influence the incidence of each type. This section provides first a general discussion and then focuses on specific hypotheses.

2.1 General Framework

The learning approach to alliances can be related to the dynamic view of resource and capability accumulation; see Teece and Pisano (1994) and Teece et al. (1997) for seminal contributions and, e.g., Lavie (2006) and Schreyögg and Kliesch-Eberl (2007) for more recent contributions. The primary focus of this theory is on the mechanisms by which firms accumulate new skills and capabilities, and on the contextual factors that influence the rate and direction of these processes. Following this framework, inter-firm collaboration is viewed as a vehicle for learning (e.g. Mody, 1993). Hamel and Prahalad (1990), for example, point to cooperative relationships as a means for internalizing core competencies and enhancing competitiveness. A rapidly expanding literature has emerged during the last decades focusing on which organizational modes facilitate such learning (see e.g. Foss, 1993; Kogut and Zander, 1993). Firms' learning can significantly advance in the context of alliances, and this is especially true for the flexible setting of NCRA cooperative ventures (Hagedoorn, 1995). We therefore take the view that firms participate in these alliances because they expect it benefits them through learning.

However, despite the evident benefits of alliance participation, R&D co-operation via RJVs entails specific problems (Osborn and Hagedoorn, 1997). First of all, other partners' technological know-how may be hard to assess ex-ante (Osborn and Baughn, 1990). Before having entered the alliance, firms cannot know the value of the others' information or the future amount of knowledge to be gained from collaboration. Potential collaborators also cannot show the precise value of information without invalidating the worth itself (Barkema et al., 1997).

In addition, control over the input, transfer and use of know-how may be hard to realize. Indeed, the typically uncertain nature of R&D activities makes it more difficult to disentangle non-compliance of partners from exogenous sources of failure in the R&D process (Veugelers, 1998). Further, R&D co-operations are faced with hidden and unexpected risks, such as delays in development time, failure to reach research goals or changes in the relative power of the partners (Inkpen and Beamish, 1997). Also costs of coordination between RJV members may be problematic (Parkhe, 1993). The disadvantages of joint R&D can be explained by transaction cost theories (Coase, 1937; Pisano, 1990; Williamson, 1989), which identify difficulties to coordinate, manage and control the R&D activities of the different actors in the alliance. Most of these problems could be potentially solved by writing contracts contingent on R&D input and output. However, intangible assets, as are technical knowledge and R&D, are a primary cause for incomplete contracts, i.e. contracts that cannot fully specify the actions of each party in every contingency. Transaction costs are, therefore, typically important when contracts are incomplete (Hagedoorn et al., 2000).

Furthermore, participating firms are often competitors. Co-operation requires that partners contribute their specific know-how and are prepared to share their research results with other firms, but these firms typically are simultaneously competing in product markets (Veugelers, 1998). Therefore, although firms may have an incentive to co-operate ex-ante, once the agreement has been reached, each participant has an incentive to cheat on the agreement and conceal its own technological expertise. What is learned from the expertise of the loyal partner can be used in its own R&D projects to create a competitive advantage.[11]

In sum, we take the view that, although alliance participation is potentially beneficial, firms take into account the costs of participation. The value of knowledge is hard to assess and contingent contracts difficult to write and enforce, which opens the way for coordination problems and opportunistic behavior. In addition, participants are often competitors in the product market, which makes incentives for free-riding even higher.

Based on the above reasoning, one can think of firms making a constant cost-benefit analysis of being in an alliance. Before entering, given that disclosure of tacit know-how is un-contractible, the venture faces the problem of how to induce participants to correctly reveal the private information of their specific know-how. If this issue seems too difficult to be solved, firms may decide not to enter an alliance. Alternatively, insiders may decide not to allow new members in; see von Hippel (1988) and Kesteloot and Veugelers (1995) for a similar rationale. Thereafter, given that firms alter their commitments (Kogut, 1991; Reuer and Tong, 2005), change investments (Reuer and Koza, 2000) and learn from other firms in the alliance (Hamel, 1991; Khanna et al., 1998), members constantly re-evaluate the costs and benefits of being a member in the alliance. If at a given moment in time the net benefits are negative, the firm exits.

It is important to note at this point that an exit may indicate a “failure” or “success” for the firm in question (Gomes-Casseres, 1997; Reuer and Zollo, 2005). A firm may have learned what it needed. Hence, benefits are now small relative to the transaction costs. The firm thus exits due to

[11] Following a game-theoretic approach, the effects of co-operation on the innovation process have been examined predominantly by two-stage models of oligopolistic competition. In recent years, numerous analytical contributions in industrial organization have emerged trying to formalize the incentives of firms to engage in R&D cooperation while firms are competing in product markets (D'Aspremont and Jacquemin, 1988; De Bondt and Veugelers, 1991; Katz, 1986; Motta, 1992; Suzumura, 1992).

successful learning. On the other hand, it may occur that other participants only free-ride and do not deliver what was promised. For example, firms may contribute only less able personnel or withhold their most advanced technology from the venture (Shapiro and Willig, 1990). Participation in this case can be qualified as a failure. But, independent of the outcome, in both cases a firm exits an alliance, since the costs are higher than the benefits. However, as will become clear further on, the fact that an exit means either success or failure makes it particularly difficult to develop an hypothesis on exit.

In sum, firms continuously make a cost-benefit analysis of alliance participation, which they make in order to decide whether (i) to enter an alliance (or allowing a new firm in) and (ii) to exit an alliance. Based on this general framework, we now turn to our specific predictions.

2.2 Empirical predictions

i) RJV size

Pooling R&D resources in a co-operative RJV may increase a firm's efficiency of production through the learning of new processes (e.g. Grossman and Shapiro, 1986).[12] The information in an RJV, however, also flows from the firm to the other RJV participants, who are often competitors in the product market, and therefore do not have completely aligned interests (e.g., Kamien et al., 1992).

The formation of a co-operative venture induces, therefore, two simultaneous effects: on the one hand, the reduction in a firm's own marginal cost increases its profit. On the other hand, the cost reduction of its competitors triggers more aggressive behavior on their part and leads to a decrease in a participant's profits. As the size of the association increases, the cost reduction experienced by a new member increases with respect to the cost reduction of the standing members. Hence, the incentives to admit additional members may decrease with the size of the association (Bloch, 1995). [13]

[12] Note that some of the ideas we borrow from in our specific hypotheses come from formal transaction cost theories and industrial organization models. The reasoning in most of these models is based on alliance participation leading to lower (marginal) costs, which we take to be the result of learning in alliances without specifying *how* exactly this learning leads to lower costs. Of course, learning may lead to benefits other than lower costs (e.g. the introduction of new products). But the stated aims of the NCRA-RJVs seem to be most conducive towards lowering costs (Link, 1996). In any case, as explained in more detail in Footnote 3, our reasoning also works for alliances bringing advantages other than cost reduction.

[13] Insiders in NCRA-RJVs have the possibility to restrict membership. Most NCRA-RJVs have an initiation fee as well as a variable annual project contribution, which range from $2,000 to $25 million per year. While some RJVs encourage companies to participate by keeping a very low initiation fee, others tend to be very selective. Participation in the SEMATECH-RJV, for example, requires a minimum annual fee of $1 million and full

A second consequence of not having aligned interests is the potential for free-riding, where participants try to benefit from other insiders' efforts, but don't make an effort themselves. This free-riding problem is potentially larger when the RJV is bigger (Holmström, 1982). Furthermore, apart from informational issues, costs of coordination are likely to be higher in a larger RJV as more firms need to agree (Milgrom and Roberts, 1992). Therefore, with only a few insiders, it may be attractive to admit more firms or join as a new member, but these incentives decrease when the RJV becomes larger due to transaction costs becoming more problematic.

However, being a member in a bigger RJV may give access to a larger pool of knowledge (Bloch, 1995; Veugelers, 1998). These higher benefits may offset its associated higher costs, and thus lead to more entry. It may also be that large RJVs show potential entrants that they are successfully managed and have overcome problems of free-riding and coordination, thereby attracting more members.

In sum, RJV size is expected to have a negative effect on entry if collaborations do not manage to overcome the typical problems of free-riding and coordination, at least to the extent that these costs can be offset against the benefits of a larger pool of knowledge. However, if collaborations manage to create an optimal learning-climate (e.g. through efficient control mechanisms), larger RJVs may be more attractive.

***Hypothesis 1 (RJV size)**:*
(i) Larger RJVs have a negative effect on entry if the higher transaction costs outweigh the larger pool of knowledge available.
(ii) Larger RJVs have a positive effect on entry if the larger pool of knowledge outweighs the higher transaction costs and/or if larger RJVs show potential new entrants that they have successfully dealt with transaction cost problems.

The size of the RJV affects firms' exit decisions in similar ways as their entry decisions, but is further substantially complicated by the fact that exit is the outcome of a research process, involving interaction between several agents (Hamel, 1991; Mody, 1993; Reuer and Zollo, 2005). Therefore, since the number of insiders relates to issues of effective learning and altering commitments, informational spill-overs to partners, free-riding and coordination costs, they are also the likely drivers of exit, but in a more complicated way than for entry.

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participation could cost a firm as much as $25 million.

Moreover, as indicated by Gomes-Casseres (1997) and Reuer and Zolo (2005), exit may indicate either participation success (the firm has learned what it wanted to learn) or failure (other insiders learn more from the firm than the firm learns from the other insiders). The expected effect of the number of insiders on exit is thus not clear. Therefore, although we test for the effects of size on exit and discuss these results, no specific hypothesis on this relationship is stated.

Once the impact of RJV size on short-run entry and exit dynamics is analyzed, one can further investigate whether a long-term equilibrium group size exists. Indeed, Bloch (1995) predicts that RJVs reach an optimal size, as negative effects of RJV-participation outweigh positive effects, once a critical number of insiders has been reached. Translated into a dynamic context, one may observe short-term entry and exit, but these dynamics could evolve around an RJV's long-term equilibrium size. In other words, an external shock may lead to a deviation from the equilibrium, but subsequent entry or exit brings the RJV back to its steady state. We analyze whether an equilibrium exists and, if so, which industry factors influence this size; these factors are explained further on.

Hypothesis 2 (Long-term dynamic equilibrium RJV size):
RJVs reach a dynamic long-term equilibrium size, where expected costs and expected benefits of participation balance each other out for a certain number of RJV members.

<u>ii) RJV age</u>

Given that we are interested in how entry and exit dynamics evolve over time, our other key explanatory element is the age of an RJV. Nakamura et al. (1996) develop the hypothesis that RJV participation leads to convergent or divergent learning. With convergent learning, insiders' intangible capabilities become similar and partners do not need each other anymore. If transaction cost problems remain, costs outweigh benefits and firms will exit at this point in time.[14] On the other hand, in a divergent development, capabilities become dissimilar yet complementary; firms will stay. An RJV is then not an extended ground for competition but a true form of co-operation over time that, when successfully implemented, leads to savings in the

[14] See also Roy Chowdhury and Roy Chowdhury (2001) for this reasoning. The concept of strategic alliances, popularized by management scholars like Hamel et al. (1989) and Khanna et al. (1998), supports this view and suggests that RJVs are extended grounds for competition between insiders. The goal for strategic alliances is to learn a partner's capabilities and to become less dependent on the partner over time.

development of competitive capabilities (Teece, 1992). Ties formed within the RJV may then constitute a lock-in for participants. Even when such exclusive stipulations are not explicitly specified, there may still be an implicit expectation of loyalty.

It may further be that members in an RJV manage over time to partly overcome the problems associated with transaction costs. This can happen, for example, through the development of better control mechanisms which make free-riding problems less severe, through a lowering of coordination problems due to repeated interactions, or through an increase in trust among members, which has a positive impact on both free-riding and coordination problems (Chiles and McMackin, 1996; Gulati, 1995; Parkhe, 1993). Lower transaction costs increase the net benefits of staying in the RJV, *all else equal*, and therefore induce less exit.

In sum, RJV dynamics suggest that the objective and the usefulness of staying as an insider can change over time; convergent learning or excessive free-riding leads to more exit over time, divergent learning and lower transaction costs to less out-movement.

Hypothesis 3 (RJV age)*:*
(i) Older RJVs show less exit if learning is divergent or transaction costs decline over time.
(ii) Older RJVs show more exit if learning is convergent and transaction costs do not decline over time.

iii) Other dimensions

We now turn to hypotheses related to other dimensions which are not the main goal of our study, but are still important to include in the analysis as a way to account for observed heterogeneity. Moreover, some factors will also play a role in determining the long-term equilibrium size of an RJV. First, given their presence in several NCRA-RJVs, we include a measure for non-profit organizations. Second, RJVs do not operate in a vacuum, but interact with each other. It is therefore potentially important to control for these interactions when looking at dynamics. There are two different ways to think about interactions between different RJVs. The first type of interaction is how individual members make links with other RJVs, i.e. whether they participate in several RJVs at the same time. The other type is related to how different RJVs interact as groups or "coalitions". We look at both dimensions. Finally, we include industry variables that previous studies have shown to be important factors when investigating RJVs.

Non-profit insiders

Non-profit entities present in RJVs do not compete with firms in the product market. It seems therefore clear that their presence has a positive impact on expectations of learning and a negligible impact on the negative free-rider effects (Sinha and Cusumano, 1991). On the other hand, research collaborations with non-profit entities can be harder than expected: researchers in public laboratories do not respond to the same incentives as engineers in private companies. Recent empirical evidence indicates that although collaborations with non-profit entities are expected to be beneficial, they lead in fact to a higher failure rate (Lhuillery and Pfister, 2007). Therefore, we expect both entry and exit to be positively affected by the number of non-profit entities.

***Hypothesis 4 (non-profit organizations)*:**
More non-profit organizations present in RJVs lead to more entry and exit.

Links on exit

A higher "connectivity" may increase the stability of an RJV because of several reasons: (i) the decrease in informational asymmetries between members through multiple contacts may enhance co-operational efficiencies (Snyder and Vonortas, 2005); (ii) having more links may decrease problems of free-riding through the possibility of punishment in other research co-operations (Kogut, 1989); (iii) more links may also indicate that members have built up more experience in dealing with co-operations (Zollo et al., 2002). All explanations point out to links having a stabilizing impact on exit and turbulence.

***Hypothesis 5 (RJV links)*:**
Better-linked RJVs show less exit.

Other RJVs' impact on entry and exit

A second way of thinking about interactions between RJVs is to consider them as interacting groups or coalitions. Following the logic of Bloch (1995) and Cassiman and Greenlee (1999), who find that typically multiple stable RJVs form in the same product market, we group RJVs in industries. Theoretical papers on the formation and stability of RJVs are sensitive to different assumptions on the membership rules, objective functions, and the process of coalition formation (see Greenlee, 2005, for an overview). These studies do coincide, however, in finding that the resulting stable structure is characterized by having relatively large RJVs and by large asymmetries in RJVs' sizes.[15] We test therefore whether RJV structures with larger but more dispersed RJVs in the same industry are more stable, all else equal.

***Hypothesis 6 (RJV coalitions)**:*

RJV structures in an industry that include on average larger RJVs, but are more heterogeneous in terms of size lead to less entry into and exit out of RJVs.

Industry characteristics

As RJVs are embedded in product markets, it makes sense to further control for a product market's characteristics on RJVs' dynamics as a way to account for observed heterogeneity among RJVs. As indicated by previous empirical studies on RJVs (Cassiman and Veugelers, 2002; Hernan et al., 2003; Roeller et al., 2007), we include industry variables like industry size and industry dynamics, plus measures that are potentially important in an R&D context, such as R&D intensity of the industry.

Bloch (1995), Poyago-Theotoky (1995) and more recently Greenlee (2005) predict that when industries become larger, the negative effect on downstream product market competition of taking in an additional firm in the RJV becomes smaller. As a consequence, a larger industry in terms of number of firms induces RJVs to be relatively larger. Assuming that RJVs do not instantly reach their optimal size, one may therefore expect more entry in RJVs when an industry includes more firms.

One can make this argument more dynamic. If a particular industry enjoys more entry -or less exit- this should be reflected in additional entry in existing RJVs. At the same time, a more turbulent industry may create less certainty on what the expected rewards of research co-operation are, since it is less clear how these translate into higher profits.[16] In sum, more firms entering (less exiting) in the product markets make RJV participation more attractive, but more turbulence in product markets may make it less interesting.

[15] Bloch (1995), Cassiman and Greenlee (1999) and Greenlee (2005) find similar outcomes for quite different modeling assumptions. Firms first form a large RJV, but do not want to include all firms in the industry (see the previous section for this argument). The firms that are excluded from this association have an incentive to form competing groups. Members of the first association, preferring dispersed rivals, then choose to admit more members as a way to reduce the size of rival associations. In equilibrium, the association structure is asymmetric, since the first associations formed comprise more members than the last.

[16] It certainly makes product market collusion a less attractive motivation for RJV participation. See Ivaldi et al. (2003) for the rationale of how stable product markets and high barriers to entry and exit facilitate collusion.

A similar reasoning can be applied to an industry's concentration. The higher an industry's concentration, the greater the scope for effective internalization of potential research spillovers and the more beneficial it is to apply generated knowledge (Hernan et al., 2003). In addition, a greater concentration makes it easier for firms to identify appropriate research partners. Thus, a higher concentration is expected to generate more entry.

A firm's size is often connected to research co-operation. The argument goes that larger firms have a higher absorptive capacity and suffer relatively less from any fixed costs that co-operation brings. Larger firms therefore benefit more from research spillovers in an alliance (Sinha and Cusumano, 1991). Further, larger firms may also more effectively exert influence over what happens to the research output of the RJV, i.e. they have more power to punish potential free-riders, both in the RJV and in the product market. Therefore, when the average size in an industry is larger, one may expect more RJV entry. On the other hand, differences in firms' sizes may lead to the larger firms having less incentive to participate in research collaborations, as Roeller et al. (2007) show.[17]

Cost reductions and product innovations resulting from a successful RJV will be more important in R&D intensive industries, all else equal. Indeed, Hernan et al. (2003) obtain a positive and significant effect of R&D intensity on the probability of RJV formation. Kogut (1989) further suggests that RJVs in R&D-intensive sectors are more likely to involve large-scale and long-term joint R&D projects.

Growth opportunities as measured by Tobin's Q, i.e. firms' market value relative to their book value, are included as a further explanatory variable, as well as asymmetries in Tobin's Q. Growth options may generate more entry in RJVs, as there are more learning and application opportunities in growing sectors. Barlevy (2007), for example, shows that R&D and growth indeed go hand in hand.

Finally, to account for the fact that high-tech industries may be different from others – especially with respect to the size of spillovers – we characterize types of high-tech industries. One could expect that firms have more incentives to join RJVs when they are in high-tech industries, due to higher gains from co-operation and internalization of spillovers (Cassiman and Veugelers, 2002;

[17] They reason that research collaboration may make participants more symmetric, which damages especially larger firms. This reasoning, however, hinges on the assumptions that firms co-operate in order to avoid duplication of R&D expenses and they become more symmetric over time. If firms with complementary skills cooperate and firms stay that way over time, then large firms may want to co-operate with small firms, since these will be less likely to become aggressive competitors in the product market (Sinha and Cusumano, 1991).

Poyago-Theotoky, 1995). We summarize our predictions on industry factors in the next hypothesis.

Hypothesis 7 (Industry factors)*:*
RJVs experience more entry when embedded in industries that are characterized by
(i) a higher number of firms,
(ii) more entry, less exit and less turbulence,
(iii) a higher concentration,
(iv) a larger firm average size but a smaller size dispersion,
(v) a higher R&D expenditure,
(vi) more growth opportunities, and
(vii) making high-tech products.

3. The Data

Our data comes from merging two data sources: the NCRA-RJV database with information on RJVs and its participants under the NCRA (1985-1999), and the Compustat North America database containing firm-specific information on about 22,000 public U.S. firms (1986-1999).[18] Although the NCRA-RJV data are explained in detail in Link (1996) and Vonortas (1997), we give here a short overview of the main issues. The enactment of the National Cooperative Research Act (NCRA) in 1984 and its amended version, the National Cooperative Research and Production Act (NCRPA) were created to stimulate R&D in the U.S.. In particular, this law allows American firms to establish consortia that conduct pre-competitive R&D and was implemented by the U.S. Congress as part of an industrial policy to improve international competitiveness of American industries and companies.[19] Under the terms of the NCRA, a notice must be filed with the U.S. Department of Justice disclosing the RJV’s principal research content and its initial members; subsequent notifications of changes in membership or research content of RJVs are also required. In return, certain antitrust exemptions are granted to the NCRA-RJVs.

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[18] We thank Nicolas Vonortas from George Washington University for making the NCRA data available to us.
[19] Both Japan and the European Union previously used active industrial policies to create comparative advantages for their strategic industries, such as the semiconductor industry and the commercial aircraft industry, and the U.S. felt it was lagging behind.

The NCRA-RJV database thus contains information on all RJVs that have registered with the Department of Justice under the auspices of NCRA and its sequel, the NCRPA. Both U.S. and foreign organizations – including firms, universities, and government agencies and laboratories – participate in NCRA-RJVs. Most U.S.-based entities are business firms and about 43 percent of these are publicly traded firms. The remaining firms are mostly unclassified in terms of ownership and are most likely privately held. The very nature of the NCRA implies that the RJVs in this dataset can be seen as research consortia; consortia have typically more than two participants and maintain a low degree of joint commitment by the members. In the remainder of this section, we go into more detail on the specific data used in our analysis. We first explain the characteristics of the dynamic RJVs, then we discuss inter-RJV interactions and finally consider the industry characteristics in which the RJVs are embedded.

Dynamic RJVs

The aim of the paper is to find the main drivers of in-and-out movements in an RJV, which naturally restricts our interest to those RJVs that experience some activity. Therefore, the sample used for our analysis consists of all RJVs that in at least one year of existence – after their initial setup – experienced entry or exit of firms, i.e. the dynamic RJVs.[20] Table 1 presents some characteristics of these RJVs, where from here on we omit the adjective "dynamic" for expositional ease. A first stylized fact of our sample is the steady rise in the number of RJVs – from 17 in 1986 to 237 in 1999 – proving both the popularity of the NCRA and the dynamism of its RJVs. The average number of for-profit firms or 'insiders' in an RJV over its years of existence is around 50, while the median is about 13 firms/RJV, which clearly indicates that the size distribution of the RJVs is skewed towards the left. Indeed, the number of insiders ranges from 1 to 408 firms**.**[21] Figures 1a and 1b show a first aggregate picture of this study's main variables of interest: a) the average number of firms entering into a RJV per year and b) the average number of firms exiting from an RJV per year, both in relation to the RJV's age. On average, almost four for-profit firms enter an RJV yearly, while we observe about 1.6 exits every

[20] For an analysis on the differences between dynamic and non-dynamic RJVs, see Seldeslachts, Duso and Pennings (2007). Non-dynamic RJVs are shown to be typically very small, consisting of two or three firms that have specific knowledge and work together on a particular project.

[21] Further, on average, there are between 1 and 2 non-profit organizations participating in an RJV (1.65); their number ranges from 0 to 85.

year.[22] Both the average entry and exit –and their variability– roughly decrease with the RJV's age.

------------------------------------ Insert Table 1 and Figures 1a-b about here-----------------------------

Inter RJV-Interactions

RJVs do not operate in a vacuum, but interact with each other. It is therefore potentially important to account for these interactions. According to the original NCRA files, a SIC2 industry code is assigned to each RJV. We therefore group the RJVs in SIC2 industries and create RJV-cluster variables related to RJVs' median size and size asymmetries per industry. Furthermore, we create a variable that measures the importance of individual firm links with other RJVs (see Table 2 for a more precise definition).

Industry Characteristics

Industry characteristics might be a useful way to account for observable heterogeneity among RJVs. The Compustat North America database is used to construct industry variables at the SIC2 level. For each industry and for each year, we calculate a measure of concentration – the Herfindahl-Hirschman Index (HHI) – as well as medians and standard deviations for several other indicators, such as number of employees, R&D intensity and Tobin's Q. Subsequently, each NCRA-RJV is linked to an industry by using the RJV's assigned SIC2 code and the year as matching keys. To account for high-tech industries – and their potentially high spillovers – we include dummies for high-tech communications, high-tech manufacturing and high-tech software and computer-related services respectively, as indicated by the AeA.[23]

4. Estimation and Choice of Variables

Two main methodological features differentiate our study from previous ones, as discussed in the introduction. Most notably, we look at dynamics in terms of variation over time by using a panel data approach. Further, we choose the RJV as the unit of observation rather than the single firm.

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[22] The distribution of entering and exiting firms is skewed towards the left; median entry and exit are zero, indicating that many RJVs do not experience any entry or exit in a given year.

[23] The AeA (formerly the American Electronics Association), is a U.S. nationwide non-profit trade association that represents all segments of the technology industry and is dedicated to helping our members' top line and bottom line. SIC codes indicated to be high-tech can be found on http://www.aeanet.org/Publications/IDMK_definition.asp

This approach, we believe, has several advantages. First, it allows us to better capture dynamics, i.e. how the alliance as a group evolves and transforms over time. If we took the single firm as a unit of observation, we would not have observed a flow of entry and exit processes but rather a maximum of two discrete decisions made by the single firm: entry and exit. When aggregating entry and exit at the RJV level, we have the advantage of enjoying more variation in the group data as compared to individual firm data. Second, given that we observe the aggregate entry into and exit from one RJV, our dependent variables straightforwardly incorporate the subtle and complex strategic interactions between individual firms. Third, to use the RJV as the unit of observation allows us to use the entire population of dynamic RJVs set up under the NCRA and to avoid the possible problems of sample selection.

The dynamics of the for-profit entities are expressed in rates.[24] Using absolute numbers of entry and exit could be problematic due to the significant size differences across RJVs. An entry into an RJV with two firms is different from the same entry into an RJV with more than 100 members. We therefore chose to use relative measures and use entry and exit rates. The entry rate into RJV *i* in industry *j* at time *t* is defined as the ratio between current entry and past RJV's size (number of insiders): $entry_{ijt} = \#\,\text{firms that enter}_{ijt} / \text{insiders}_{ijt-1}$. Similarly, we define exit rate as $exit_{ijt} = \#\,\text{firms that exit}_{ijt} / \text{insiders}_{ijt-1}$. This definition of entry and exit has the additional advantage of solving the integer problem and allows us to use estimation techniques other than count data methods. We further construct a third dependent variable which we call turbulence, defined as the sum of entry and exit rates. The main use of this variable is that it captures the total dynamics of the RJV.

The dependent variables in our regression are expressed as the logs of the entry rate, exit rate and turbulence. To be more specific, since the rates can take the value of zero, we use the transformation $DYN_{ijt} = \log(x_{ijt} + 1)$, where x_{ijt} represents our different measures of dynamics (entry rate, exit rate and turbulence). The estimation method we apply is the random effect panel Tobit regression since our dependent variables are left censored at zero (Wooldridge, 2002):

[24] We also observe entry and exit for non-profit entities, but since the objectives and incentives of these organizations are less well-defined, we include the non-profit entities only as a control variable.

although our sample consists of the dynamic RJVs, these RJVs still often experience neither entry nor exit in a given year.[25] The empirical specification is therefore the following panel model:

$$DYN_{ijt} = \alpha_0 + \alpha\ RJV_{i,t-1} + \beta\ INTER_{ij,t-1} + \gamma\ IND_{j,t-1} + \eta_t + \xi_i + \varepsilon_{i,t}, \qquad (1)$$

where RJV_i is a vector of the RJV's characteristics. Other independent variables are grouped into two vectors: the vector $INTER_{ij}$ contains the variables related to how RJVs interact with each other, and the vector IND_j contains the industry characteristics. Finally, η_t are time fixed effects, whereas the error term is partitioned into an RJV specific random component ξ_i and an i.i.d. and normally distributed error term $\varepsilon_{i,t}$. The exact content of each vector of variables (RJV_i, $INTER_{ij}$ and IND_j) is explained in Table 2 and their descriptive statistics are shown in Table 3. The variables are discussed in the remainder of this section.

--- Insert Tables 2-3 about here---------------------------------------

First, we construct a set of variables that measure the main characteristics of the RJV as a group (vector RJV_i in equation (1)). Our prime variable of interest is the number of for-profit firms in an RJV or "insiders" (see our hypotheses 1 and 2). To measure these effects and to account for possible non-linearities, we include the variables *INSIDERS* and $INSIDERS^2$. Furthermore, given that we are also interested in how entry and exit dynamics evolve over time (hypothesis 3), our other key explanatory variable is the age of an RJV (variable *AGE*). We include as an additional RJV-variable the number of non-profit entities. Non-profit entities (variable *INSIDERS NP*) present in RJVs do not compete with firms in the product market, and are expected to have a positive impact on both entry and exit (see hypothesis 4).

Second, we construct variables related to the interaction with other RJVs in the industry. We include a variable that measures the average number of links that RJV members have with other RJVs (variable *LINKS*). A second way of thinking about interactions between RJVs is considering them as interacting groups or coalitions. Given our hypothesis 6, we include the

[25] A standard Tobit fixed effect model would be inconsistent since the fixed effects cannot be treated as incidental parameters in non-linear models without biasing the other model coefficients.

variable *GROUP-SIZE*, which measures the average RJV-size in the industry and the variable *GROUP-SIZE_sd*, wich measures the standard deviation of RJV-sizes in that same industry.

Finally, in accordance with hypothesis 7, we construct industry variables like industry size and dynamics, as well as measures that are potentially important in an RJV context – such as R&D intensity and potential spillovers. We take the industry to be defined at the SIC2 level to be as inclusive as possible with respect to participating firms' primary level of activity. In particular, the variables we include are the number of firms (variable *FIRMS SIC2*), the entry and exit rate in that same industry (variables *ENTRY SIC2* and *EXIT SIC2*), the industry concentration, measured as Herfindahl index (variable *HHI*), the averages and standard deviations of the industry's firm size (variables *FIRM SIZE*, measured in number of employees, and *FIRM SIZE_sd*), R&D intensities (variables *R&D INTENSITY* and *R&D INTENSITY_sd),* and growth opportunities, as measured by Tobin's Q (variables *TOBIN'S Q* and variables *TOBIN'S Q_sd*). Finally, to account for the fact that high-tech industries may be different from others – especially in terms of having higher spillovers we include dummies for three types of high-tech industries as defined by the AeA.

5. Results

We first discuss how the RJV characteristics determine short-run dynamics and then report the impact of the other explanatory variables. Next, we investigate whether a long-term equilibrium exists and which industry factors influence this equilibrium.

5.1 Impact of RJV Characteristics on Short-Run Dynamics

Table 4 presents the results of the panel Tobit regressions where we use only an RJV's size and age as our main explanatory variables. The results indicate a U-shaped impact of the number of insiders on entry, i.e. the coefficient of *INSIDERS* is negative and significant while the coefficient for $INSIDERS^2$ is positive and significant. The marginal effect of the number of insiders on the entry rate is negative up to approximately 121 for-profit firms,[26] and turns positive for larger numbers of insiders. Thus, larger alliances attract less entry, though only up to a critical size. For the RJVs that at some point in time constitute more than 121 for-profit members – which is around 10% of our observations – becoming larger induces even more entry.

[26] Note that our variables are in logs.

These results indicate first that, in general, larger RJVs incur higher transactions costs. On the other hand, very large RJVs seem to have shown that they are successfully managed and have overcome problems of free-riding and coordination, thereby attracting even more members, given their larger pool of knowledge. Therefore, joining firms perceive either rather small or very large RJVs as best environments for learning.

--- Insert Table 4 about here---

For exit on the other hand, the observed pattern is different; the larger the RJV, the more we observe firms to exit, although at a decreasing rate (in our sample, the inflection point is never reached). Given that we cannot distinguish between success and failure of RJV participation, it is difficult to perfectly identify the meaning of this result. Larger RJVs either induce a faster learning due to its members having access to a larger pool of knowledge (success) or increase transaction costs faster than the size of the knowledge pool. Firms, once having entered in the RJV, realize that net gains are too low and exit again (failure). Both explanations are compatible with the observed pattern of larger RJVs inducing a higher exit rate.

The age of an RJV has a negative and highly significant impact on both entry and exit, indicating that RJVs become more stable over time. Both effects suggest that divergent learning takes place when RJVs mature, leading to more stable RJVs over time (see hypothesis 3).[27] Additionally, these findings suggest that transaction cost problems become less severe in more experienced RJVs, indicating that their members eventually develop mechanisms that overcome the typical problems of co-operative research through an increased trust and better routines.

5.2 Impact of other dimensions on Short-Run Dynamics

Non-profit participants

We find, perhaps surprisingly, the number of non-profit participants (variable *INSIDERS NP*) to have no significant effect on entry, which runs against our expectation (hypothesis 4). However,

[27] In theory, an additional explanation for this finding might be that there exist "sleeping" RJVs; some older RJVs may experience no research activity and hence no new firms want to enter. At the same time, the insiders may not exit when being a member has negligible costs. However, when we exclude those RJVs that have not experienced entry or exit for either at least 3 or 5 years, the results of age on entry, exit and turbulence stay identical. This indicates that sleeping RJVs do not drive our results.

we find non-profit organizations to significantly induce more exit, which may indicate that co-operation between profit and non-profit entities is hard to be successful.[28]

Interaction Effects

Table 5 shows that the results for our main variables are robust to adding the explanatory variables related to the interaction among RJVs; both the level of significance and magnitude of coefficients for insiders and age do not change. Further, we find a negative effect for our *LINKS* variable on exit, which conforms to our hypothesized effect (hypothesis 5). It seems that insiders that have more links with other RJVs are more likely to benefit from co-operation. Moreover, we find some support for the argument that RJVs act as interacting coalitions in the same product market: the *GROUP SIZE* variable has a significant and negative effect on a RJV's turbulence, as predicted in hypothesis 6. However, larger group size asymmetry (variable *GROUP SIZE_sd*) has a positive effect on the RJV's turbulence, contrary to what was expected.

-- Insert Table 5 about here-------------------------------------

Industry Effects

In Table 6, we report the results when adding the industry characteristics as explanatory variables. First of all, the results for our main variables – age and number of insiders – stay robust to the inclusion of industry controls. In the following, we summarize how some of the industry variables matter for an RJV's short-run dynamics.

--- Insert Table 6 about here--

First, in line with our predictions in hypothesis 7, the number of firms in the industry (variable *FIRMS SIC2*) positively affects the entry rate and the coefficient is highly significant. Moreover, the dynamics of the product market appear to play some role as well, especially on entry into an RJV. In particular, a less stable product market has a negative effect on the entry rate in an RJV – although *ENTRY SIC2* is only significant at the 10% level – which weakly supports part (ii) of hypothesis 7 that an unstable product market increases uncertainty about gains of RJV-

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[28] Again, however, it must be noted that we cannot distinguish between failure and success. Therefore, more exit may also indicate that firms learn faster in the presence of non-profit organizations.

participation. In line with Hernan et al. (2003) – though their setting is static rather than dynamic – we find that both an increase in product market concentration (variable *HHI*) and an increase in firm size (variable *FIRM SIZE*) have a positive and significant effect on entry into an RJV (parts (iii) and (iv) of hypothesis 7). More asymmetries in firm size (variable *FIRM SIZE_sd*) have a negative impact on the entry rate, which is similar to the results in Roeller et al (2007). Yet, while Hernan et al. (2003) obtain a positive impact of R&D intensity on the formation of an RJV, we do not find support for such an effect. Instead, our results suggest asymmetries in R&D intensity (variable *R&D INTENSITY_sd*) to have a significant and positive effect on entry. Also, the industry average of *TOBIN'S Q* has a positive effect on entry, suggesting that industries with higher growth opportunities attract more entry into RJVs (part (vi) of hypothesis 7). Finally, as proposed in part (vii) of hypothesis 7, the high-tech dummies for the software and communication industries (dummies *HightechS* and *HightechC*) have a positive and significant impact on entry dynamics, which may indicate that higher industry spillovers induce more participation in RJVs, where such spillovers can be better internalized. In high-tech manufacturing industries *(HightechM)*, however, we observe a more active exit pattern, which may indicate that the dummies not only capture high industry spillovers.

5.3 Long-Term Dynamic Equilibrium

To determine whether a long-term dynamic equilibrium exists on average, one should look at whether the net entry (entry minus exit) in function of the size variables *INSIDERS* and $INSIDERS^2$ is stable around zero. This condition can be written as

$$(\hat{\alpha}_1^{Entry} - \hat{\alpha}_1^{Exit}) * (\mathrm{INSIDERS})^2 + (\hat{\alpha}_2^{Entry} - \hat{\alpha}_2^{Exit}) * (\mathrm{INSIDERS}) + (\hat{A}^{Entry} - \hat{A}^{Exit})\overline{\mathrm{X}} = 0,$$

where $\overline{X}$ is the vector of the mean value of the independent variables and $\hat{A}_{entry}$, $\hat{A}_{exit}$ the vectors of estimated coefficients of the entry and exit equations respectively. Using the coefficients from the entry and exit equations from Table 6 and the mean values from Table 3, one must solve

$$0.0585 * (INSIDERS)^2 - 0.5986 * (INSIDERS) + 1.0450 = 0.$$

It is easy to see that this binomial has a U-shaped form, which produces two solutions for the number of insiders, I_1 and I_2, where $I_1 < I_2$ and I_1 is the only stable solution.[29] As shown in Table 7, this results in an average stable size of slightly more than 9 insiders in an RJV, indicating that, indeed, a long-term dynamic equilibrium exists. This prediction is relatively close to the median RJV size of our sample – which is equal to 11 – giving additional empirical validity to our modeling approach. The existence of an equilibrium dynamic size confirms our hypothesis that a long-term equilibrium number of insiders exist in an RJV. Thus, benefits of learning and transaction costs balance each other out at a given size.

Once it is confirmed that a dynamic long-term equilibrium exists, one can identify which factors play a determinant role on this equilibrium size. Since we have estimated both equations separately, however, it is not known what the resulting variance-covariance matrix from the entry and exit equations is. Yet, one can impose an intermediate correlation of zero; under this assumption, we find four factors to have a significant positive impact and one factor to have a significant negative impact on the long-term equilibrium size. An industry's concentration (variable *HHI*), belonging to a high-tech communications industry (dummy *HightechC*), and the number and average size of firms in an industry (variables *FIRMS SIC2* and *FIRM SIZE*) have a positive impact on an RJV's equilibrium size. More entry in the industry in which an RJV is embedded (*ENTRY SIC2)*, on the other hand, induces an RJV to be smaller on average.[30]

Therefore, first, one can tentatively conclude that we empirically confirm that a stable equilibrium exists and the number of firms in an industry has a positive impact on this equilibrium size, thereby giving a dynamic flavor to predictions from theoretical RJV formation models (as e.g. Bloch, 1995, and Greenlee, 2005). Second, our results indicate that larger firms that compete in more concentrated and stable product markets seek to co-operate in larger RJVs. All three factors – larger firm size, higher industry concentration and less entry into the industry – may contribute to larger RJVs in two ways. First, they induce a more beneficial learning in RJVs. Larger firms have a higher absorptive capacity and it is easier to apply the obtained RJV-

[29] Given its U-shaped form, a shock that decreases the size of the RJV below I_1 will have as a consequence that net-entry becomes positive, moving the RJV forward again to the long-term equilibrium I_1. On the other hand, a shock that increases the size of the RJV above I_1 induces a negative net entry and the number of insiders moves back to I_1. For the solution I_2, it is easy to see that this is not a stable equilibrium. For example, a shock that increases the size above I_2 induces a positive net-entry, thereby drifting further away from I_2.

[30] One can also apply the most stringent condition and assume a negative correlation of minus one. We then find that only the variable *HHI* and the dummy *HightechC* have a significant impact.

knowledge in a more concentrated and stable industry. Second, all three factors may allow for a better control of potential free-riders. Indeed, larger firms operating in more concentrated and stable industries have more possibilities to detect – and punish – any potential free-riding of other insiders.

Finally, in Table 7 we report the predicted long-term equilibrium sizes for the most represented industries and compare these with the actual median sizes. Taking into account that we estimated average coefficients over all industries, our predictions provide a reasonable assessment, both in terms of predicting the actual values and in terms of predicting the relative sizes across industries. E.g. both predicted and median values point towards SIC48 'Communications' as harboring the largest RJVs and SIC13 'Oil and Gas Extraction' the smallest. Therefore, one may interpret our results as having some predictive power in terms of distinguishing relative RJV sizes across industries, and why these differences exist (i.e. the determining factors of an RJV equilibrium size).

-- Insert Table 7--

5.4 Robustness Checks

In order to check the robustness of our findings, we performed a number of alternative specifications and tests that we thought relevant.

Size Subsamples

We divided the sample into three sub-groups, according to size, and ran all our specifications on each.[31] For the entry equation, first remember the observed pattern in the full sample: Entry is lower for a higher number of insiders until a critical level of 121 insiders; then entry increases with size. Given that this critical size level is reached in the subsample of large-sized RJVs, we should observe this U-shaped effect only for the largest RJVs and a negative effect of size on entry in the subsamples of small and medium-sized RJVs. This expectation is indeed confirmed; we find a U-shaped pattern for large RJVs and a negative relation between size and entry –

[31] We define 'small RJVs' as the first quartile of the RJVs' size distribution (number of for-profit firms ≤ 7), 'medium-sized RJVs' as the second and third quartiles (7 < number of for-profit firms ≤ 22), and 'large RJVs' as the top quartile (number of for-profit firms > 22).

though not significant – for small and medium-sized RJVs. For the exit equation, we estimate a positive effect of size for small and medium RJVs and an inverse U-shaped effect for large RJVs. Although it must be mentioned that the found effects are not significant, results are consistent with our average findings. Further, for all three subsamples, age has a negative and significant impact on both entry and exit, as was also found in the full sample.

Industry Subsamples

We ran each of the proposed regressions at the industry level as defined by the SIC2 codes. As expected, we lose some precision in the coefficients' estimates since the subsamples are much smaller. Overall, the found average effects of size and age on entry/exit dynamics are largely confirmed in each separate industry, which indicates that the found patterns, although averages across industries, reflect mostly patterns of the individual industries. We report only the industries where the found patterns differ. The industries SIC13 'Oil and gas extraction' and SIC28 'Chemicals and Allied Products show an inverse U-shaped relationship between size and entry, though the coefficients are not significant. Further, the industries SIC28 and SIC36 'Electric Equipment and Components' present a U-shaped impact of size on exit.

6. Discussion and Implications

In this section we shortly discuss the implications of our findings and provide some prescriptions for firms and public policy on R&D. From our short-run dynamics analysis we learn that small and very large RJVs attract relatively more new entrants. One may thus tentatively deduce that both small RJVs and very large RJVs are ex-ante perceived by potential entrants as successful learning environments. Small RJVs subsequently lead to less exit, due to divergent learning and/or lower transaction costs. Therefore, combining observations on entry and exit, one can safely conclude that relatively small RJVs are good environments for learning. Yet, very large RJVs lead to more subsequent exit by its members, which can be explained through convergent learning of its members (success) or excessive transaction costs (failure). Therefore, whether very large RJVs are effectively good learning environments remains an open question, and needs additional testing. Further, divergent learning seems to take place in more experienced RJVs, leading them to become more stable, thus in line with the reasoning of becoming good learning environments for insiders but offering minor learning opportunities for potential entrants.

Moreover, as our long-run analysis suggests, the equilibrium size, and therefore the timing of the entry decision, is crucially determined by industry characteristics. In particular, industry factors that matter are related to elements that (i) increase the benefits of learning, such as larger firm size and higher industry concentration, and (ii) raise the possibility of control on RJV members, such as a more stable product market.

These findings suggest the necessity of a pro-active behavior of firms by closely monitoring co-operation dynamics in their industries. In light of our results, firms should try to enter in relatively small RJVs when they are still young. Once RJVs reach a certain size, they are at their stable long-term equilibrium size, indicating that these RJVs are optimal learning environments for insiders, but relatively more closed entities towards potential entrants.

From a policy perspective, our results suggest that public support for the NCRA RJVs has been successful. In fact, the substantial observed short-run dynamics that we impute to learning activities go together with a stable long-run equilibrium size, which we interpret as the alliances' well-functioning. Our prescription for the design of such programs as the NCRA would be that the policy should be organized so that it benefits smaller RJV start-ups. Finally, policy-makers, when developing programs to incentivise R&D, should take into account that the optimal RJV size depends on the industry characteristics; indeed, what is the "right" collaborative learning environment differs across industries.

7. Conclusions

This paper aims to test the determinants of the NCRA-RJVs' group dynamics after their initial setup. The underlying rationale of our analysis is that firms, at each period of time, weigh the benefits of learning against the costs of free-riding and coordination in these research collaborations. Alliance dynamics can then be interpreted as an evolving interplay of these benefits and costs. Given the importance of collaborative learning, our study, therefore, addresses two significant but neglected issues. First, it is an attempt to have a first look at RJV dynamics, by meaningfully including the element of time through the use of a panel data approach. Second, we focus on group dynamics of co-operations, as opposed to an individuals firm's behavior in isolation. As research co-operation is inherently a dynamic and a group-driven process, we believe that our study opens an important dimension in the knowledge on research co-operations. In particular, the uncovered patterns give us first insights about the learning processes inside RJVs. Through our framework, rather small RJVs are identified as successful environments for learning, whereas, for very large RJVs, this may potentially be the case.

Given the lack of both theoretical and empirical research on RJV dynamics, our study should be seen as explorative in nature, with the goal of producing robust stylized facts as a base for more structural future theoretical and empirical research. For example, in order to have a better understanding of why firms exit an RJV, one could use detailed firm-level data in a more structural setup to identify whether this is due to a failure or a success. The main point of this paper is that group dynamics add an extra and important dimension to questions about research co-operation and collaborative learning. The robust stylized facts that we generated indicate dimensions that matter for such movements, and should be interpreted as a starting point for further research.

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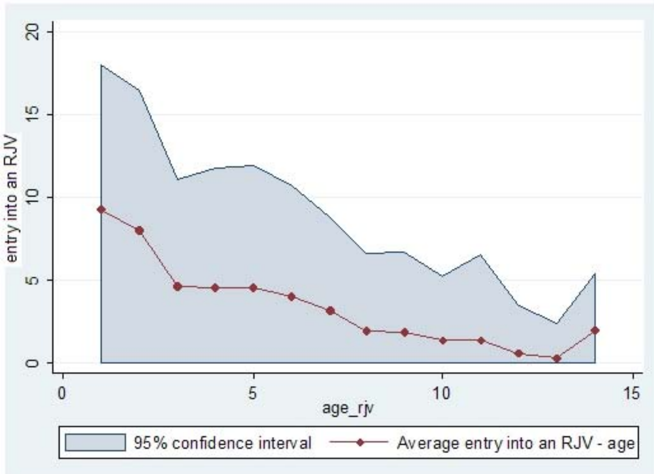
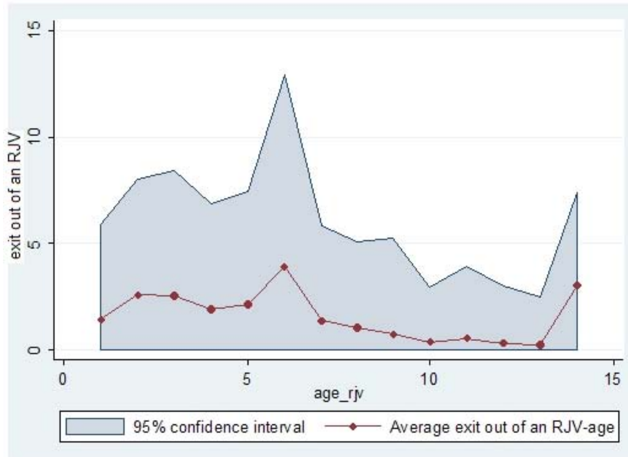
Figures and Tables

Figure 1. Average Number of Entry and Exit in a Dynamic RJV





a) Average Number of Entry over the RJV's age

b) Average Number of Exit over the RJV's age

Table 1. Descriptive Statistics – Characteristics of Dynamic RJVs

	Mean	Median	St. Dev.	Min	Max
Number of RJVs	119.47	119	68.48	1	237.
Number of participants in an RJV	30.24	11	53.64	2	478
Number of for-profit firms	28.59	11	49.91	1	408
Number of non-profit firms	1.67	0	8.30	0	85
Entries of for-profit firms (excluding formation year)	3.88	0	11.72	0	122
Exits of for-profit firms (excluding formation year)	1.57	0	7.80	0	205
Age of the RJV	5.86	6	3.97	0	14
Links	26.91	12.83	29.18	1	136.33
Median RJV size in a SIC2 industry	18.00	14	14.63	4	103
St. Dev. of RJV size in a SIC2 industry	32.08	26.70	29.92	0	95.33

Table 2. Description of the Variables Used in the Regressions

Variable	Description	Vectors
ENTRY	Log of (entry rate of for-profit firms + 1) , where the entry rate is defined as $entry_{ijt} = \#entries_{ijt} / \#insiders_{ijt-1}$	x_{ijt}
EXIT	Log of (exit rate of for-profit firms + 1) , where the exit rate is defined as $exit_{ijt} = \#exits_{ijt} / \#insiderss_{ijt-1}$	
TURBULENCE	Log of (entry rate + exit rate + 1)	
INSIDERS	Log of the number of for-profit participants in the RJV at a given point in time	RJV_{it}
INSIDERS NP	Log of the number of non-profit participants in the RJV at a given point in time	
AGE	Log of the RJV's age expressed in years	
LINKS	Log of the average number of links (i.e. average number of other RJVs where insiders in RJV i are present in time t) of all firms active in RJV i at time t	$INTER_{it}$
GROUP SIZE	Log of the median number of for-profit participants among RJVs in the same SIC2 industry	
GROUP SIZE_sd	Log of the standard deviation of the number of for-profit participants among RJVs in the same SIC2 industry	
FIRMS SIC2	Log of the number of firms in a given SIC2 industry	IND_{jt}
ENTRY SIC2	Log of the entry rate ($entry\_rateSIC2_{jt} = \#entrySIC2_{jt} / \#firmsSIC2_{jt-1}$) into a SIC2 industry in period t	
EXIT SIC2	Log of the entry rate ($exit\_rateSIC2_{jt} = \#exitSIC2_{jt} / \#firmsSIC2_{jt-1}$) into a SIC2 industry in period t	
HHI	Hirschman Herfindahl index (HHI) in a SIC2 industry based on sales. The HHI of an industry i is calculated as $HHI_i = \sum_{j=1}^{N} s_j^2$, where *j=1,..,N* are the firms in industry *i* and s_j are the sales for firm *j*.	
FIRM_SIZE	Log median employees at the SIC2 industry level	
FIRM_SIZE_sd	Log of the standard deviation of employees at the SIC2 industry level	
R&D INTENSITY	Log median R&D intensity (R&D expenditures/sales)	
R&D INTENSITY_sd	Log of the standard deviation of R&D intensity (R&D expenditures/sales) at the SIC2 industry level	
TOBIN'S Q	Log median Tobin's Q (Total asset/market value) at the SIC2 industry level	
TOBIN'S Q_sd	Log of the standard deviation of Tobin's Q (Total asset/market value) at the SIC2 industry level	
HightechM	Dummy=1 if the industry was a high-tech manufacturing industry (SIC4 codes: 3571, 3572, 3577, 3651, 3663, 3669, 3671, 3672, 3678, 3679, 3821, 3823, 3825, 3826, 3829, 3827, 3861, 3812, 3844, 3845) according to the AeA	
HightechC	Dummy=1 if the industry was a high-tech communications industry (SIC4 codes: 4812, 4813, 4822, 4841, 4899) according to the AeA	
HightechS	Dummy=1 if the industry was a high-tech software industry (SIC4 codes: 7371, 7372, 7373, 7375, 7376, 7379) according to the AeA	

Table 3. Preliminary Statistics – Variables used in the Regressions

Variable	Obs	Mean	Std. Dev.	Min	Max
ENTRY	1657	0.11	0.25	0	2.86
EXIT	1657	0.03	0.08	0	0.69
TURBULENCE	1657	0.13	0.27	0	2.86
INSIDERS	1567	2.75	0.99	0.69	5.98
INSIDERS NP	1549	0.28	0.76	0	4.45
AGE	1558	1.62	0.76	0	2.64
LINKS	1567	2.57	1.23	0	4.89
GROUP SIZE	1567	2.08	0.61	0.69	4.42
GROUP SIZE_sd	1509	0.85	0.28	0	1.74
FIRMS SIC2	1567	5.43	1.19	0.69	7.17
ENTRY SIC2	1550	0.09	0.07	0	1.38
EXIT SIC2	1787	0.06	0.04	0	0.51
HHI	1567	0.09	0.08	0.01	0.95
FIRM_SIZE	1561	-0.87	-1.35	4.96	2.47
FIRM_SIZE_sd	1564	2.55	-0.97	4.55	4.69
R&D INTENSITY	1542	0.07	0.08	0	0.44
R&D INTENSITY_sd	1542	1.55	1.52	0	5.05
TOBIN'S Q	1566	0.73	0.25	0.10	1.23
TOBIN'S Q_sd	1561	1.75	1.10	0.17	5.14
HightechM	1804	0.06	0.23	0	1
HightechC	1804	0.06	0.24	0	1
HightechS	1804	0.14	0.35	0	1

Table 4. Panel Tobit Regression – RJV's characteristics

	Turbulence			Entry rate			Exit rate		
	Coef.	Std. Err		Coef.	Std. Err		Coef.	Std. Err	
Constant	0.5316	0.1647	***	0.9204	0.1498	***	-0.4755	0.0932	***
INSIDERS	-0.1821	0.1001	*	-0.3587	0.0915	***	0.1953	0.0546	***
INSIDERS ^{2}	0.0327	0.0145	**	0.0373	0.0131	***	-0.0156	0.0079	**
INSIDERS NP	0.0062	0.0259		0.0058	0.0233		0.0229	0.0114	**
AGE	-0.3682	0.0259	***	-0.3227	0.0241	***	-0.0975	0.0135	***
obs	1540			1540			1540		
uncensored	468			440			273		
groups	234			234			234		
Wald chi2(15)	295.83			365.69			128.55		
Prob>chi2	0.0000			0.0000			0.0000		
Log likelihood	-671.42			-628.89			-344.74		

All regressions include year dummies. Significance level at the 1%, 5%, 10% are represented by ***, **, * respectively.

Table 5. Panel Tobit Regression – Interaction effects

	Turbulence			Entry rate			Exit rate		
	Coef.	Std. Err		Coef.	Std. Err		Coef.	Std. Err	
Constant	0.5076	0.2006	**	1.0431	0.1838	***	-0.4715	0.1076	***
INSIDERS	-0.1845	0.0990	*	-0.3798	0.0904	***	0.1852	0.0548	***
INSIDERS ^{2}	0.0293	0.0142	**	0.0357	0.0128	***	-0.0168	0.0079	**
INSIDERS NP	0.0008	0.0254		0.0026	0.0228		0.0210	0.0113	*
AGE	-0.3339	0.0269	***	-0.2903	0.0248	***	-0.0830	0.0139	***
LINKS	-0.0269	0.0241		-0.0338	0.0229		-0.0191	0.0115	*
GROUP SIZE	-0.0622	0.0369	*	-0.0680	0.0339	**	-0.0488	0.0170	***
GROUP SIZE_sd	0.2302	0.0890	***	0.1496	0.0829	*	0.1703	0.0460	***
obs	1482			1482			1482		
uncensored	452			425			265		
groups	227			227			227		
Wald chi2(18)	291.71			364.14			131.59		
Prob>chi2	0.0000			0.0000			0.0000		
Log likelihood	-630.47			-593.77			-312.65		

All regressions include year dummies. Significance level at the 1%, 5%, 10% are represented by ***, **, * respectively.

Table 6. Panel Tobit Regression – Industry Characteristics

	Turbulence			Entry rate			Exit rate		
	Coef.	Std. Err		Coef.	Std. Err		Coef.	Std. Err	
Constant	-0.6792	0.4142		0.0782	0.3881		-0.8528	0.2169	***
INSIDERS	-0.1362	0.1014		-0.3889	0.0906	***	0.2097	0.0563	***
INSIDERS ^{2}	0.0219	0.0149		0.0366	0.0130	***	-0.0219	0.0082	***
INSIDERS NP	0.0068	0.0250		0.0100	0.0227		0.0200	0.0115	*
AGE	-0.3171	0.0282	***	-0.2718	0.0263	***	-0.0735	0.0152	***
LINKS	-0.0444	0.0255	*	-0.0410	0.0244	*	-0.0200	0.0130	
GROUP SIZE	-0.0213	0.0487		-0.0432	0.0443		-0.0352	0.0245	
GROUP SIZE_sd	0.1028	0.1185		0.0233	0.1080		0.1708	0.0656	***
FIRMS SIC2	0.1914	0.0587	***	0.1781	0.0557	***	0.0486	0.0289	*
ENTRY SIC2	-0.6257	0.4279		-0.7333	0.3843	*	0.1646	0.2634	
EXIT SIC2	-0.9311	0.6339		-0.8738	0.5709		-0.1259	0.3855	
HHI	4.2197	0.8537	***	3.3055	0.7967	***	1.0063	0.5093	**
SIZE	0.1693	0.0461	***	0.1475	0.0433	***	0.0455	0.0260	*
SIZE_sd	-0.1500	0.0509	***	-0.1425	0.0496	***	-0.0592	0.0270	**
R&D INTENSITY	-0.3788	0.4369		-0.1980	0.3981		-0.3801	0.2500	
R&D INTENSITY_sd	0.0469	0.0171	***	0.0346	0.0151	**	0.0124	0.0102	
TOBIN'S Q	0.3878	0.1563	**	0.3096	0.1432	**	0.2400	0.0963	**
TOBIN'S Q_sd	0.0021	0.0220		0.0007	0.0196		-0.0176	0.0141	
HightechM	0.1183	0.0897		0.1055	0.0832		0.1152	0.0403	***
HightechC	0.4020	0.1022	***	0.5123	0.0951	***	0.0840	0.0504	*
HightechS	0.0201	0.1301		0.2065	0.1225	*	-0.0244	0.0685	
obs	1460			1460			1460		
uncensored	444			417			259		
groups	227			227			227		
Wald chi2(30)	342.60			441.21			143.58		
Prob>chi2	0.0000			0.0000			0.0000		
Log likelihood	-597.63			-562.78			-296.66		

All regressions include year dummies. Significance level at the 1%, 5%, 10% are represented by ***, **, * respectively.

Table 7. Long-Term Equilibrium size

Industry	Description	Equilibrium size	Median Sample size
SIC 13	Oil and Gas Extraction	5.87	9
SIC 28	Chemicals and Allied Products	8.60	14
SIC 29	Petroleum and Coal Products	6.27	9
SIC 35	Industrial and Commercial Machinery and Computer Equipment	8.15	16
SIC 36	Electric Equipment and Components	10.96	14
SIC 37	Transportation Equipment	7.93	11
SIC 38	Measurement Analyzing, Control Instruments and Related Products	13.06	8
SIC 48	Communications	28.94	39
SIC 73	Business Services	19.44	31
Full sample		9.32	11