The structure and performance of U.S. research joint ventures: inferences and implications from the Advanced Technology Program

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Abstract:

Research joint ventures (RJVs) are projects that combine the research resources of different firms. A sample of RJVs supported by the U.S. Advanced Technology Program shows that the projects yield revenues that are far less than costs. Related to this point, the RJVs are subject to commercialization delays, loss of intellectual property, and product market competition. Partner firms undertake joint research, but if they commercialize at all, they do so separately, to avoid splitting of revenues from new products. Ultimately, difficulties with the RJVs occur because frequently, firms are potential competitors.

Keywords: Limits of the firm | partnerships | research joint ventures | contracts | property rights economics | subsidies | supervision | productivity | innovation | patents | commercialization | Advanced Technology Program

Article:

I. Introduction

The Advanced Technology Program (ATP) was established within the National Institute of Standards and Technology through the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418). ATP was formed:

> … for the purpose of assisting United States businesses in creating and applying the generic technology and results necessary to (1) commercialize significant new scientific discoveries and technologies rapidly; and (2) refine manufacturing technologies …

This charge was later reinforced through the American Technology Preeminence Act of 1991 (Public Law 102-245). ATP fulfilled its mission by supporting enabling technologies that are essential to the development of new products, processes, and services across diverse application areas, and one method used by ATP to support collaborative research was through the funding of research joint ventures (RJVs).

RJVs are partnerships that allow firms to share Research and Development (R&D) resources.[1] While long-lasting joint venture firms do exist, RJVs are usually established to facilitate the conduct of temporary projects designed to solve specific problems. In theory, RJVs (ventures or projects) combine complementary resources to accelerate research, reduce research redundancy and thus the costs of R&D, create new technologies, and bring new products to market. In short, RJVs improve technical efficiency. The very notion of an RJV assumes some control over ideas because any free flow of information would render the ventures unnecessary. For this reason, RJVs are often thought to involve a trade-off between improved technical efficiency and the creation of monopoly positions, both of which are consequences of the venture.

This paper takes a more modest view of RJVs and what they achieve both in concept and in practice through our analysis of ATP-supported RJVs. Most projects may lose money rather than create a monopoly. Related to this, internal conflicts can create commercialization delays, loss of intellectual property, and eventual product market competition among ATP partners. Owing to unique data from the ATP program, we observe interactions among the firms, including conflicts. This leads us to revisit RJVs from the perspective of the limits of the firm literature. For us the more relevant issues concerning RJVs are whether they break even or not, and why they differ in their performance.

Ideal data for a study of RJVs, regardless of their source of financial support, must cover a substantial period because the ventures evolve gradually over time following an internal logic. To portray this evolution effectively, the data should cover all stages of the RJVs from research to invention, to development, and finally to commercialization. Besides these characteristics, the data must include information about RJV structure, which involves project and partner attributes and their interactions that help in understanding performance.

The ATP data that we use meet these requirements. They are a one of a kind sample of government-supported RJVs that includes detailed information on 397 partner firms that participate in 142 RJVs that began between 1991 and 2001. In exchange for a government subsidy, firms were required to answer surveys upon request. The data for this paper were collected through a 2004 survey at the request of the agency that sponsored the RJVs. The data were collected not long before the ATP program was terminated in 2007.

Our analysis not only sheds light on whether the RJVs succeed, but also it probes into the working of the funding agency and thus has elements of being an assessment of the program's method for supporting pre-competitive industrial research which, because of knowledge spillovers and expected low private returns, would not have been undertaken by the private sector. To induce firms to participate in such projects, ATP funded, though competitions, one-half of the costs of the RJVs in exchange for supervision and extensive reporting. From 1991 to

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[1] See Mowery (1995) and Mowery, Oxley, and Silverman (1998) for analysis of the boundaries of the firm in R&D.

2007, ATP awarded more than $2.4 billion for RJV research, with industry contributing an equal amount at the outset and even more through additional investments in the project.

Despite the promise of ATP, our descriptive findings show that its RJVs failed to break even. The central task of the paper is to understand why the projects miscarried. We infer from the evidence that the projects failed because too many partner firms were potential rivals in product markets rather than upstream sellers and downstream customers who would have had a common stake in the projects. Rivalry ruled out collaboration at the development stage, and for this reason excluded many of the benefits from the RJV structure from being realized. Owing to head-to-head competition, technology transfer led to losses of intellectual property as well as reduced revenues from commercialization. This situation contrasts with suppliers and customers, for whom the financial gains from RJVs are mutual.

ATP was enabled by prior legislation whose goal was to encourage manufacturing through cooperative R&D, in part by protecting RJVs from antitrust. The National Cooperative Research Act (NCRA) of 1984 (Public Law 98-462) provided the legal framework for joint research. The NCRA created a federal registration process for RJVs. This was beneficial to firms because if an RJV was subject to litigation, the courts would proceed under a rule of reason rather than as an antitrust violation. If found guilty, the firms in the RJV would be subjected to actual damages rather than treble damages. The National Cooperative Research and Production (NCRPA) of 1983 (Public Law 103-42) expanded this safe harbor for RJVs to include joint production as well as research.

Enabled by the NCRA and the NCRPA, the establishment of ATP was part of this broader effort to legitimize cooperative research. The Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418) created the program, whose goals were to assist firms in commercializing their basic and applied research.

Our main empirical findings are these. Revenues from new products from the RJVs fall well short of project costs, so that, on average, as ATP-funded projects are concluded they do not appear to break even. In addition, we find that failure to protect intellectual property from the RJV is common, and that this failure results in fewer than expected patents. We also find significant delays in commercialization that discourage additional money invested by firms. Moreover, because additional money invested by firms depends on expected future returns, any actions that reduce future revenues feed backward and cause a decline in firm investments that adds to the original decline in future revenues. The role of additional money invested by partner firms is if anything negative, ruling out joint development and commercialization.

Our findings confirm that RJV activity is a sequential process: past delays in commercialization reduce future revenues, while future expropriation of intellectual property reduces past invention. Complementarity of partner R&D is crucial for joint research success, but we find that firms commercialize separately, avoiding sharing revenues from new products, making them unable to benefit from complementarity of late-stage R&D.

One bright spot among these critical findings is that additional money invested by firms amounts to about $1 per federal dollar spent. These follow-on investments do lower the cost share of government in the RJVs. But the broader view continues to hold: RJVs do not repay their costs even including follow-on investments.

The findings in this paper have broader implications for strategic alliances among companies, not just RJVs. Our evidence points to competition for the same market as an important reason why RJVs are more likely to fail. Likewise, horizontal alliances among automobile firms, among computer makers, and among electronics manufacturers entail clashing of rival practices and losses of market share from less successful alliance members to those more successful. Our findings suggest that RJVs are more likely to succeed if composed of suppliers and their customers. Strategic alliances are more likely to succeed under the same conditions. Thus, airline alliances that join complementary parts of a network; public–private mail delivery that combines last mile service with long distance; chemical firms that supply composites to glassmakers; auto parts suppliers that produce components to desired standards for auto makers; and scrap steel suppliers that provide reliable and low-cost recyclables to mini mills – all these are alliances that are more likely to succeed. Therefore, our approach to RJVs has implications for strategic alliances more generally.

The remainder of the paper proceeds as follows. In Section II, we review related literatures from property rights economics (PRE) and management science. Section III describes the sequential nature of RJVs using the methods of PRE, and we identify circumstances under which the RJVs fail. An Appendix, which supports Section III, presents simple models of RJV behavior. The models illustrate how delays, losses of intellectual property and product market rivalry not only prevent collaboration on commercialization of RJVs, but also set a low bar on the outcomes that we observe. An important implication is that if firms commercialize jointly, then additional money invested by partners should increase commercialization. This implication is never supported by our findings, implying that commercialization is undertaken separately. Section IV describes the data. Section V anticipates the regression findings by comparing costs and revenues from new products that result from the RJVs, finding that revenues are far less than costs. The regression results are presented in Section VI. While this section entails some econometric complexity, its objective is merely to quantify why some RJVs perform better than others. Holding constant controls that are necessary for a cross-section of firms, and after taking endogeneity into account, basically the regression findings confirm that variations in delays, losses of intellectual property and product market rivalry strongly contribute to variations in the performance of the RJVs in our sample. Section VII concludes the paper with summary remarks.

II. Related literatures

Our review of the literature begins with a discussion of the limits of the firm, and it concludes with a discussion of the empirical literature related to the performance of partnerships and more specifically of RJVs.

Two dominant lines of economic theory address the limits of the firm. Both point out difficulties with partnerships. Transactions cost economics (TCE) is concerned with the relative cost of transactions within a firm versus the external market, including partnerships. Transactions in partnerships could impose additional costs on each member (Coase 1937; Williamson 1975, 1985). Because of relationship-specific investments, partners could engage in holdups to obtain a larger share of the returns. And, holdups create transactions costs relative to internal work.

PRE stresses a different problem with partnerships. It is concerned with the weakening of incentives to invest because of sharing the returns from partnerships. PRE considers whether to integrate organizations or not by addressing the associated costs and benefits as well as the factors that govern relationships between non-integrated institutions. PRE applies to RJVs because they represent contracts among non-integrated organizations.

Early PRE treats organizational boundaries as a device for encouraging inter-firm investment (Grossman and Hart 1986). It assumes an *ex ante* inability to write contracts so that *ex post* renegotiation of contracts is necessary to execute the partnerships. This step entails splitting the gains under renegotiation and, as a result, investment incentives are weakened thus creating a burden of partnerships.

We are aware of only two papers that apply PRE to innovation. Aghion and Tirole (1994) allocate ownership of an innovation in a vertical relationship between a research unit and its customer according to which organization's R&D is more productive, thus reducing the burden of partnerships. Aghion and Tirole note a problem of RJVs. Because RJVs have short horizons compared with mergers, for example, partners might not share information given weak intellectual property protection. By releasing information, a firm increases its chance of success, but it runs the risk of future competition with former partners in the venture.

Adams, Chiang, and Jensen (2003) apply PRE to Cooperative Research and Development Agreements (CRADAs). CRADAs are joint projects between firms and national laboratories that were enabled by the Stevenson-Wydler Technology Innovation Act of 1980 (Public Law 96-480) and the Federal Technology Transfer Act of 1986 (Public Law 99-502). Adams (2006) highlights complementarities between public and private R&D and the importance of incentives for both parties. CRADAs work if complementarities dominate weakened incentives for investment and if gains from joint research are shared. However, CRADAs are a special case that is favorable to partnerships for commercialization because national laboratories are not competitors with firms, as is not the case among RJV partners.

To sum up, the two dominant theories of the limits of the firm are TCE and PRE. Both emphasize costs associated with partnerships, due to holdups or to reduced incentives to invest. But, in an important critique, Holmstrom and Roberts (1998) offer counter-examples consisting of successful long-term partnerships, usually between customers and suppliers. Their examples suggest that partnerships work well under some conditions, an insight that was not lost sight of by subsequent research.

Hart and Moore (2008) criticize early PRE for its assumption that *ex ante* investments cannot be verified. The lack of verification leads parties to bargain and renegotiate, weakening investment incentives. But it appears that bargaining and renegotiation are rare. In recent PRE studies, *ex ante* contractibility is assumed precisely because *ex post* renegotiation is costly and as a result uncommon. The idea is that deviations from a contract result in 'shading' or a reduction in effort.

Because of this, contracts provide 'reference points' that are valuable because they avoid costly renegotiations.

Hart and Holmstrom (2010) use the reference point approach to replace bargaining with authority. They emphasize a contract that creates a baseline for each party's entitlements. When a party does not realize its expected outcome, it responds by shading. Open-ended contracts lead to more shading and this argues for greater precision in the original contract.[2] Rather than being open-ended, RJVs are contracts written clearly and in advance. Partners earn expected rewards that are broadly consistent with their efforts. Most of the sharing that is observed is not due to bargaining, renegotiation, and weakened incentives; instead, sharing is due to splitting of rewards from joint research that are larger than rewards to the firms separately. This expanded reward provides compensation for knowledge sharing. Our analysis (below) seems to be consistent with behavior under split contracts through which a technology that is a public good to the firms is developed jointly and shared, but based on that shared technology the firms undertake separate commercialization. This branching approach leverages the complementarities of the firms' research, but it also allows for diverse commercialization interests of firms.

Still, there is nothing in this revision of PRE that rules out losses of value, particularly at the end of partnerships when few sanctions remain for the aggrieved firm. Recent PRE also recognizes weak property rights, including for intellectual property.

This overview of TCE and PRE leads in to the empirical management science literature.[3] The management science literature related to RJVs begins with motivations behind forming the venture. These scholars have as a rule emphasized benefits of collaboration as a means of combining complementary assets and of dealing with converging technologies that exceed the capabilities of any one firm.[4]

Teece and Pisano, for example, argue that research partnerships are dynamic and build know-how of firms over time (Teece and Pisano 1994; Teece et al. 1997). Expressed in economic terms, research partnerships rely on strong complementarities among research inputs (core competencies) of different firms to solve technical problems that are too costly for any one firm to solve. By doing so, research costs are reduced, a conclusion reached theoretically nearly a decade earlier by Spence (1984).

Moving beyond strategic motivations for RJVs, there is a second, yet limited, strand of the management science literature that focuses on objective measures of performance of research partnerships. Harrigan (1986) and Gomes-Casseres (1996) view success objectively in terms of the venture achieving its original goals. Branstetter and Sakakibara (2002) study the level of

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[2] For experimental tests that support the hypothesis of greater shading under flexible price contracts compared with fixed price contracts, see Fehr, Hart, and Zehnder (2011).

[3] The foundation for the empirical literature on RJVs is early theoretical work by Spence (1984), Katz (1986), and D'Aspremont and Jacquemin (1988). These papers ask whether R&D competition or cooperation results in higher output and welfare. These were followed by tournament models of Reinganum (1989) and Katsoulacos and Ulph (1997). These papers show that for the same innovation, R&D expenses are less under cooperative R&D, but that innovations under rivalrous R&D reach the market sooner. Martin (1995) has reviewed this literature.

[4] von Hippel (1988, 2005) takes a novel approach. He applies limits of the firm ideas to explaining the allocation of commercialized innovation among manufacturers and suppliers and customers and users.

patenting of consortia as an output indicator of success. They find that the research budget of the consortia is a driver of such performance.

For the remainder of the paper we build on the assumption of complementarities among research inputs of the partners, and we explore the empirical role of complementariness in RJV performance. In addition, we explore the notion that RJVs are intended to solve problems that are closer to basic research.[5]

III. Simple models of RJVs

In this section, we discuss models of RJVs, and we draw implications from them to motivate the empirical analysis that follows. First, the models must address a sequence of outcomes under the ventures. In a sequence of outcomes, past errors in execution feed forward and discourage future investment, while anticipated future errors feed backward and deter past investment. Filling a similar role is a sub-optimal form of an RJV that forces firms to collaborate in development and commercialization: that too can diminish past investment. Most important, the inability to collaborate fully among competitor firms sets a low bar for the partial collaboration that we seem to observe, and in this way, it hinders the performance of the RJVs. The Appendix provides formal details of our argument.

To represent a time sequence of outcomes, we adopt a three-period model. During the first period, firms develop a proposal that produces ideas and a budget that covers costs. If funded, during the second period firms undertake research that creates a new technology. During the final period, firms either terminate the project or develop and commercialize it. We assume two firms are involved in the project. The extension to more firms is straightforward.[6]

Considered in more detail, during the first period research yields knowledge A_T that is available in the second period. Given funding firms undertake research in the second period that incorporates A_T and creates a technology T that is available for development in the third period. No income is earned during the first two periods.[7] We assume that research collaboration is essential in the second period to produce T; therefore, since firms cannot successfully undertake the research separately, gains from the project are calculated from a baseline value of 0.

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[5] Bozeman and Link (1985) point out that firms are more likely to collaborate on R&D that is closer to basic research than to development. In this setting, no member can gain an immediate market advantage through collaboration. While antitrust implications of RJVs have been discussed by Jordan and Teece (1990) and Shapiro and Willig (1990), the U.S. Department of Justice (1980, 3) has long held the view that 'the closer the joint activity is to the basic end of the research spectrum – i.e. the further removed it is from substantial market effect and developmental issues – the more likely it is to be acceptable under the antitrust laws'.
[6] We could instead assume one founder and one contractor. The contractor supplies engineering services in a competitive market. Its services are complementary with research inputs by the founder. But the contractor does not provide ideas, invest additional money, or commercialize. All residual value after compensating the contractor belongs to the founder, who is the risk bearer and entrepreneur.
[7] Under ATP, RJVs were subject to supervision during the research period. Where s is supervision, productivity A_T increases with s. Supervision applies only to the research period: it is thus incomplete under the ATP program.

We assume that funding in the second period is sufficient to complete the research, but this is subject to execution risk so that the observed technology T is a realization. However, because the technology reflects features of underlying basic research, commercial applications are uncertain.

During the final period, firms may or may not develop the technology T. Because of sequential investment in the RJV, the model is a dynamic programming problem, in which most of the interest is in the final period, the period of development and commercialization.[8] We assume that firms participate subject to a Cournot-Nash solution concept for research or development inputs of the firms.[9]

Subject to further risks of expropriation and product market competition, development of the technology results in an expected final value EV^F. If commercialization does not occur, value EV^F derives only from its use in future projects. As we have noted, the key period is this final period, where the decision is made to develop the technology or to terminate the project; that decision is subject to alternative backgrounds of cooperation, independence, or rivalry among the two RJV members.

Do the firms collaborate or not in the final period? The answer to this question is given by which of the two choices maximizes the value of the RJV. In thinking about this decision, it is crucial to consider the possibility that partners might become rivals during the final period rather than simply assume a cooperative solution.

Firms create value by working together or separately to develop and commercialize the technology, depending on which is more profitable, but in each case investments by either partner can detract from returns if there is rivalry for market share – the extended model in the Appendix incorporates this possibility. If the RJV terminates with only joint research having been done, we call this partial collaboration; if it ends with joint development and commercialization, we call this full collaboration. An important signature condition, if joint development dominates, is that final period value for the firm increases with development inputs of partner firms. However, we do not observe this pattern.

Figures 1 and 2 illustrate full and partial collaboration.

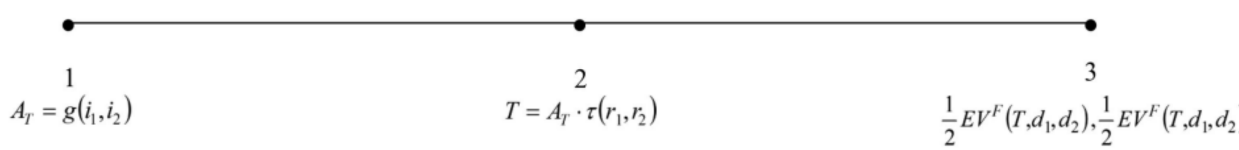

Figure 1. Production under full collaboration in R&D.

[8] This is Bellman's Principle of Optimality. Dreyfus (1965, 8) describes it as follows:

> An optimal sequence of decisions in a multistage decision process problem has the property that, whatever the initial stage, state and decision are, the remaining decisions must constitute an optimal sequence of decisions for the remaining problem with the stage and state resulting from the first decision considered as initial conditions.

[9] Gibbons (1992, Chapter 2) calls this a dynamic game of complete but imperfect information.

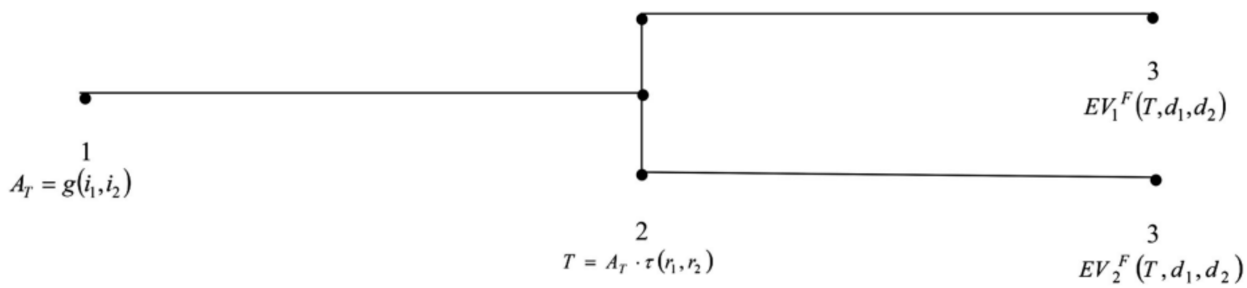

Figure 2. Production under partial collaboration in R&D.

In the first period of both figures, early stage inputs i_1 and i_2 produce productivity according to $A_T = g(i_1, i_2)$. During the second period, technology is produced using research knowledge r_1 and r_2 according to $T = A_T \tau(r_1, r_2)$. And in the third period, as the figures show, firms produce final value using T and development inputs d_1 and d_2 either together or separately. Even if development is separate, competition from former partners can still affect outcomes.

Full collaboration results if it yields a wealth gain to both firms over partial collaboration or if one firm can compensate the other. But if renegotiation is costly and this side payment does not occur, the losing firm will veto full collaboration (Hart and Holmstrom 2010). However, partial collaboration may be more profitable than full collaboration. Moreover, the possibility of rivalry over product markets under either partial or full collaboration could set a low value for the projects.

IV. Database of ATP RJVs

Owing to the richness of our data, we can deploy multiple objective indicators of RJV performance, including aspects of commercialization, and we are able to study their determinants over the course of the projects.

The database combines three sources of information. As mentioned, the first is a 2004 survey conducted for ATP by the private research firm Westat Inc., in Rockville, Maryland. The survey was at the firm-project participant level. Its purpose was to understand motivations and outcomes of ATP-funded ventures. Owing to reporting requirements in return for funding by ATP, the response rate on the survey was close to 100%. Respondents are 397 firm-project participants, many of which founded the RJV. Respondents are a sample out of more than 800 firms. But at the project level, the survey is a near-census because it includes 142 out of the 144 RJVs awarded by ATP during 1991–2001. Eighty percent of the ventures were complete by the time of the 2004 survey.[10] The 2001 cut-off date provided at least three years for project outcomes to be observed.

The second source of data is the archives of the ATP. From this source, we extracted names of participants in the ventures and characteristics of the projects, including the technical area of the

[10] Based on the high response rate to the survey, response bias is not an issue for these data.

research and project budgets. Project data from the ATP archives precede outcomes of the projects and are predetermined.

The third source of data is a match between names of ATP firms and names of parent firms contained in the Dun and Bradstreet ownership database. This unifies the firms under a common parent.

Table 1 presents descriptive statistics on key variables in our sample. It reports numbers of observations, means, standard deviations, minima, and maxima. The notes to the table define the variables and, in the case of outcomes from the RJV projects, our policies for dealing with outliers. In brief, these policies were as follows. If the ratio of a monetary variable to project budget per firm exceeded a cut-off, or if a patent variable per project staff exceeded a cut-off, then we treat that observation as a bad datum. Outliers occur because of exaggeration, use of the wrong units in reporting, or a possible desire to influence sponsors of the survey. In any case, when we vary the cut-offs around the values shown in the notes to Table 1, we observe little variation in our results.

We start with five outcomes from the RJVs. Each is a dependent variable in a separate analysis. The fact that RJVs are a sequential process is emphasized by the order in which we discuss the variables. Patent grants precede patent applications, and patents precede commercialization, which they help to enable. In the case of commercialization, cumulative revenues to date precede future revenues.

Additional money invested occupies a middle place because it is both an input and an outcome. It is an input because it contributes to future commercialization; and it is an outcome because future commercialization as well as prior success or failure of the RJV contribute to it. Finally, additional money invested determines the share of project costs borne by government. In all these ways, additional money invested is a crossroad for the RJV.

Regarding patent grants and applications in the top rows of Table 1, RJV projects yield less than one patent (mean of 0.66) and less than two patent applications (mean of 1.64). Patent applications are probably future patents. They might provide a more accurate measure of the patenting behavior of new projects. Still, applications at the time of the survey exclude future applications.[11]

Table 1. Descriptive statistics from a sample of RJVs.

Variable	Source	*N*	Mean	Std. dev.	Min	Max
Survey-based outcomes[a]						
Patent grants from the RJV	Survey	317	0.659	1.750	0	14
Patent applications from the RJV	Survey	318	1.642	3.710	0	30
Additional money invested by the firm (millions of 1992 $)	Survey	341	1.043	2.451	0	19.105

[11] We can estimate the reasonableness of the patent responses. From Table 1, average budget for a project is $11.6 million and the average number of firms in an RJV is 5.6. So, the average budget per firm is 2.06 million dollars. Means of patent grants equal 0.66 and patent applications equal 1.64. Therefore, patent grants are 0.32 per million dollars (0.66/2.06 = 0.32), and patent applications are 0.80 per million dollars (1.64/2.06 = 0.80). These ratios agree with a privately conducted survey using matched patent data (Adams, Chiang, and Jensen 2003; Adams 2006).

Variable	Source	*N*	Mean	Std. dev.	Min	Max
Cumulative revenue from the RJV (millions of 1992 $)	Survey	333	0.362	2.468	0	41.532
RJV expected to yield revenue in next five years (1 if yes, 0 if no)	Survey	341	0.425	0.495	0	1
Archival independent variables						
Technical area						
Biotechnology (1 if yes, 0 if no)	Archives	341	0.062	0.241	0	1
Chemicals (1 if yes, 0 if no)	Archives	341	0.264	0.441	0	1
Electronics (1 if yes, 0 if no)	Archives	341	0.267	0.443	0	1
Information technology (1 if yes, 0 if no)	Archives	341	0.097	0.296	0	1
Advanced manufacturing (1 if yes, 0 if no)	Archives	341	0.311	0.464	0	1
Project budget (millions of 1992 $)	Archives	341	11.574	8.599	1.380	56.967
Firms in RJV[b]	Archives	341	5.624	4.513	2	22
Years since project began	Archives	341	7.595	2.367	3	13
Project complete (1 if yes, 0 if no)	Archives	341	0.798	0.402	0	1
Private firm (1 if yes, 0 if no)	Match	341	0.361	0.481	0	1
Survey-based independent variables[c]						
RJV new direction for the industry (1 if yes, 0 if no)	Survey	340	0.815	0.389	0	1
Founder of the RJV (1 if yes, 0 if no)	Survey	340	0.703	0.458	0	1
New intellectual property from RJV not protected (1 if yes, 0 if no)	Survey	339	0.310	0.463	0	1
Partner R&D complementary (1 if yes, 0 if no)	Survey	341	0.815	0.389	0	1
RJV enhances value of earlier R&D (1 if yes, 0 if no)	Survey	338	0.734	0.443	0	1
Commercialization delay (years from start of the project)	Survey	333	5.000	2.732	1	15
Most important partner is a customer (1 if yes, 0 if no)	Survey	340	0.344	0.476	0	1
Most important partner is a supplier (1 if yes, 0 if no)	Survey	340	0.235	0.424	0	1
Most important partner is a competitor (1 if yes, 0 if no)	Survey	340	0.056	0.230	0	1

Notes: Before missing values and outliers are removed, data are a sample of 397 firms participating in 142 RJVs funded by the ATP in years ranging from 1991 to 2001.

Source: Survey of Research Joint Ventures 2004.

[a]The notes below explain the data on outcomes derived from the survey. Patent grants are cumulative grants to date from the project. Patent applications are patent applications at the time of the survey. Additional money invested is additional investment in the RJV to date in millions, apart from the original investment by the firm. Cumulative revenue from the RJV equals cumulative revenues to date from the RJV in millions. RJV is expected to yield revenues over the next five years is obtained by setting a value of 1 if the respondent indicates that the revenues are positive, and 0 otherwise. This concludes the explanation of outcomes from the survey. One problem is that data on RJV outcomes contain outliers. The notes immediately following describe our policy for removing the outliers. Observation is treated as bad data if patent grants per project staff exceed 1.66. Observation is treated as an outlier and as bad data if patent applications per project staff exceed 3.75. Observation is treated as bad data if cumulative revenue per dollar of project budget exceeds 5.0. Observation is treated as bad data if additional money invested by the firm per dollar of project budget exceeds 2.62127. These exclusions and other sources of missing data reduced the sample from 397 to 341 observations or by 14%.

[b]Firms in RJVs are a count of all firms listed in the ATP archives. This number exceeds firms covered in the survey, which covered a subset of firms on the RJVs.

[c]The empirical work uses nine independent variables from the survey. Eight are dummy indicators that are recodes of survey questions. The following notes explain the recodes. RJV new direction for the industry equals 1 if a respondent indicates that the RJV represents a new direction industry to a moderate or large extent and 0 otherwise. Founder equals 1 if the company was involved in the proposal to a moderate or large extent; it equals 0 otherwise. New intellectual property from RJV not protected equals 1 if a respondent indicates dissatisfaction with the protection of new intellectual property developed by the RJV and 0 otherwise. We assign partner R&D complementary a value of 1 if a respondent indicates that it was very important or extremely important to partner with firms because of complementary R&D. Otherwise it is coded as 0. RJV enhances value of earlier R&D is coded as 1 if respondent notes that the RJV enhances the value of earlier R&D by the company to a moderate or large

extent. Otherwise it is coded as 0. For each of Partner 1 is a customer, supplier, or competitor, the variable is coded as 1 if respondent selects that relationship with Partner 1; otherwise it is coded as 0. The final survey variable is commercialization delay. It is a count of the number of years from the start of the RJV that the project could first be expected to affect revenues. This concludes the explanation of independent variables taken from the survey.

The next outcome is additional money invested by a firm in the RJV. The mean amount of additional money is $1.04 million. This doubles the contribution of a firm to the project, for the following reason. Initial project budget per firm is $2.06 million, of which ATP funds 50%: thus, the firm pays $1.03 million of initial costs: see note 11. The total contribution per firm is thus $2.07 million ($1.03 million plus $1.04 million) and the total contribution per firm including ATP is $3.10 million. Thus, the true cost share of firms is not 50% but 66.8% (2.07/3.10). The total cost share of firms is at least this, because future additional money invested is not considered.

The next two outcomes reported in Table 1 relate to commercialization of the RJV. These are cumulative revenues to date and a 0–1 indicator of future revenues over the next five years. More than 80% of respondents report $0 revenues to date, and mean revenues are also close to $0. Table 1 shows that mean cumulative revenues to date are $0.36 million with a standard deviation of $2.47 million.

The indicator of future commercialization equals 1 if the project is expected to yield revenues over the next five years and 0 otherwise. Table 1 shows that 42.5% of projects are expected to yield revenues.[12]

Table 1 also includes descriptive statistics on project characteristics that were derived from ATP archives and the company name match. Project archives classify RJV projects into one of five technical areas: biotechnology, chemicals, electronics and photonics, information technology, and advanced manufacturing. Approximately, one-fourth of the RJVs are classified under chemicals, approximately another one-fourth fall under electronics, and nearly one-third of projects are in advanced manufacturing. The remaining RJVs are in biotechnology or information technology. The concentration of projects in manufacturing reflects the fact that the U.S. Congress funded ATP in part to revitalize the manufacturing sector.

Beside technical areas, the archives report project budget, number of firms in the RJV, project age, and completion status. Total budgets average $11.57 million (1992) and they range from $1.38 to $56.97 million.[13] The mean number of firms per RJV is 5.62. Years since the project began is 7.6. At the time of the 2004 survey, 80% of the projects were complete: the contractual research period had ended. Lastly, the name match for firms shows that 36% of firms were privately held, the rest being publicly traded.

The third group of variables is again taken from the survey. Nearly 82% of firm-project participants believe that their project's research sets a new direction for the industry. Founder of the RJV controls for returns to initial investments in the projects. In Table 1, 70.3% of

[12] Link and Scott (2010) show that half the companies funded by the U.S. Small Business Innovation Research (SBIR) program failed to commercialize from their federally funded research projects. As with ATP, an explicit goal of SBIR is to support research to 'increase private sector commercialization of innovations'.

[13] Only total project budget is known and not its allocation among the partner firms.

respondents were founders. Thirty-one percent of respondents report that new intellectual property from the RJV is not protected. This suggests difficulties with the project. Almost 82% of respondents confirm the complementarity of partner R&D, an indicator of meshing of R&D among partners. RJV enhances value of earlier R&D is selected in 73.4% of all cases, indicating that the project is related to prior research. For all the beneficial indicators in RJV performance, a substantial minority of participants report that these factors do not apply to them. For example, nearly 19% report that the RJV is not a new direction for the industry, and so on.

The next variable is commercialization delay. Greater commercialization delays indicate years after the start of an RJV when an impact on company revenues is expected. Mean commercialization delay is five years, a large value compared with mean project age of 7.6 years. Delays increase discounting of returns from the RJV. They could signify missed opportunities to build or maintain market share and they could reduce incentives to commercialize. Because commercialization delays are hard to predict we treat them as exogenous.

Table 1 concludes with three indicators of the identity of the firm's most important partner. If this is a customer, implying that the firm is an upstream manufacturer or supplier, then the customer indicator equals 1; otherwise it is 0. If the most important partner is a supplier, suggesting that the firm is a customer, then the supplier indicator equals 1; otherwise it is 0. And if the most important partner starts out as a competitor, the competitor indicator equals 1, but is otherwise 0. Other categories of the most important partner are omitted.

The most common case is that of partner as customer, with supplier second. As one would expect, competitor is rare. But notice that a partner can become a competitor because of the RJV, which is the case of a potential competitor. For the empirical work, the principal behavioral variables are: new intellectual property is not protected, commercialization delay, a third, derived variable, the logarithm of additional money invested by other firms in the RJV; and most important partner is a customer.

V. Total returns versus total costs

Table 2 reports returns and costs summed over the RJVs. This is done for early projects begun during 1991–1995, late projects begun during 1996–2001, and all projects over 1991–2001. Consider the various measures of returns and costs in order of their appearance.

The top row of the table records total project budget per firm. Following this are descriptive statistics on additional money invested by the firm. Additional investment by the firm predicts future returns because a firm invests expecting that the money will be recovered. Overall, the proportion of positive cases, where additional investment is positive, equals 59%, and this percentage is higher for late projects. Overall, additional money invested is 26.5% of project budget per firm. The percentage is higher for late projects, suggesting that more lies ahead in the case of more recent RJVs.

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Table 2. Additional investment and commercialization: compared to initial cost: sums over RJV projects.

	Period		
Variable	**1991–1995**	**1996–2001**	**1991–2001**
Total project budget per firm (millions of 1992 $)	790.890	552.565	1343.545
Additional money invested by the firm			
Total additional money (millions of 1992 $)	185.601	170.048	355.649
Proportion of positive cases	0.55	0.64	0.59
Percent of project budget per firm	23.5	30.8	26.%
Cumulative revenue (to date) from the RJV			
Total cumulative revenue (millions of 1992 $)	101.271	19.335	120.606
Proportion of positive cases	0.26	0.17	0.22
Percent of project budget per firm	12.8	3.4	9.0
RJV expected to yield revenue in the next five years[a]			
Proportion of positive cases	0.301	0.574	0.425
Required future revenue (millions of 1992 $)[b]			
$r = 0.20$	1070.625	847.801	1918.427
$r = 0.10$	972.967	775.539	1748.507
$r = 0.00$	875.309	741.948	1578.588
Required future revenue/cumulative revenue			
$r = 0.20$	10.571	43.848	15.907
$r = 0.10$	9.608	40.111	14.498
$r = 0.00$	8.643	38.373	13.089

Notes: Data are sums over RJV projects by the time intervals show at the top. Notice that additional money invested by the firm, cumulative revenue from the RJV, and RJV is expected to yield revenue in the next five years are all measured at the firm-project participant level. Because separate project budgets are not available for individual firms, cost per firm-project participant is approximated by total project budget divided by the number of firms in archival records for the project. Project budget per firm consists 50–50 of government and firm expenditures. Source: Survey of Research Joint Ventures 2004.

[a]RJV expected to yield revenue in the next five years is a dummy indicator equal to 1 if yes, 0 if no.

[b]Required future revenue is derived from an equation stating that the ratio of cumulative revenue plus future revenues divided by all costs equal one plus the assumed rate of return (r). See the text for a discussion.

Next, Table 2 reports statistics for cumulative revenue from new products. Cumulative revenue is the realized market return on the RJVs. Cumulative revenue is positive in 22% of all cases, but this percentage is lower for late projects. Cumulative revenue is 9.0% of the project budget per firm. Again, it is lower for late projects, implying that more returns lie ahead for these RJVs.

Over the next five years, 42.5% of respondents expect the projects to yield future revenue. This percentage is higher for late projects. Note that cumulative revenues are greater for early projects but the likelihood of future revenues is less. This implies that revenues from the projects are realized over a few years.

The descriptive statistics suggest that RJVs do not recover their costs, at the time of the 2004 survey, because cumulative revenues are 9.0% of costs. But what of future returns? We cannot know the future of the projects in years following the 2004 survey, but we can project the required future revenues needed to yield a 20%, 10%, or 0% rate of return on project costs: project budget per firm plus additional money invested.[14] We can then consider how likely it is that these future revenues will be realized.

These calculations are shown in the final six rows of Table 2. Required future revenues range from \$1 to \$2 billion at a 20% rate of return. These fall only slightly at a 10% or 0% rate of return because cumulative revenues are small. At a 20% rate of return, required future revenues are in the following ratio to cumulative revenue (to date): 10.57, 43.85, and 15.91. Stated differently, even for projects over 10 years old in 2004, which are the RJVs begun in 1991–1995, future revenues must be an order of magnitude larger than cumulative revenues to date. The situation changes little, even assuming a 0% return, where the ratios of future revenues to cumulative revenues are 8.64, 38.37, and 13.09. It seems implausible that future revenues will meet these requirements, especially since production costs are unknown and ignored in these calculations. Of course, firms stand to do better than this privately, given that they pay only half of project budget per firm. In other words, firms receive a subsidy for projects that on average lose money.

The above calculations represent the market return. An estimate of the nonmarket return is found first by assuming that the project yields the monopoly price on the new product. Let the demand curve be linear and assume that marginal production cost is constant. Under these circumstances, consumers' surplus is less than half of revenues.[15] Unless knowledge spillovers considerably increase the social returns, the projects seem unlikely to repay their cost inclusive of taxpayer cost.[16]

VI. Variation in RJV performance

In this section, we study why some RJVs perform better than others. We measure performance for the sequence of outcomes from early to late, beginning with patents and ending with commercialization. Tables 3 and 4 cover patents, Table 5 covers additional money invested, and Tables 6–8 cover commercialization. In all the tables, observations are at the firm-project participant level.

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[14] The equation is $\frac{Cumulative\ revenue + Required\ future\ revenues}{Project\ budget\ per\ firm + Additional\ money\ invested\ by\ firms} = 1 + r$, which is solved for required future revenues given an assumed value for the rate of return, r.

[15] Let the demand curve be linear, so $q = a - b \cdot p$, with a maximum price $p_{Max} = a/b$. Let marginal cost be $MC_0 > 0$. Monopoly quantity and price are $q_0 = a/2 - b \cdot MC_0/2$ and $p_0 = a/2b + MC_0/2$. Revenue is $R_0 \equiv p_0 q_0 = (a/2b + \mathrm{MC}_0/2)(a/2 - b \cdot \mathrm{MC}_0/2)$. Ignoring income effects, consumers' surplus is $CS_0 = (1/2) \cdot (p_{\mathrm{Max}} - p_0) \cdot q_0$ or $CS_0 = (1/2) \cdot (a/2b - \mathrm{MC}_0/2) \cdot (a/2 - b \cdot \mathrm{MC}_0/2)$. Taking the ratio of consumers' surplus to revenue yields $CS_0/R_0 = \frac{1}{2} \cdot \frac{a/2b - MC_0/2}{a/2b + MC_0/2} < \frac{1}{2}$.

[16] We find no evidence of knowledge spillovers among ATP projects. In regressions that include investment by partners on previous projects in patent equations, the regression coefficient is insignificant. See Table 8.

Table 3. Dependent variable: patent grants from the RJV.

	Negative binomial regression				GMM[a]	
	(3.1)		(3.2)		(3.3)	(3.4)
Variable or statistic	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient	Coefficient
Log (project budget per firm)	0.797**	0.227**	0.930**	0.277**	0.707**	0.778**
	(0.165)	(0.054)	(0.189)	(0.064)	(0.189)	(0.204)
Years since project began	0.184**	0.052**	0.172**	0.051**	0.131**	0.124**
	(0.054)	(0.017)	(0.053)	(0.017)	(0.037)	(0.038)
RJV new direction for the industry (1 if yes, 0 if no)	2.029**	0.358**	1.975**	0.365**	2.119**	2.016**
	(0.807)	(0.078)	(0.766)	(0.085)	(0.746)	(0.740)
Founder of RJV (1 if yes, 0 if no)	0.774*	0.192**	0.839*	0.210**	0.687	0.721
	(0.354)	(0.071)	(0.424)	(0.081)	(0.386)	(0.467)
New intellectual property from RJV not protected (1 if yes, 0 if no)	−0.916**	−0.226**	−1.086**	−0.270**	−0.733**	−0.851**
	(0.306)	(0.067)	(0.342)	(0.070)	(0.265)	(0.283)
Partner R&D complementary (1 if yes, 0 if no)	1.059**	0.226**	0.990**	0.224**	0.649	0.612
	(0.383)	(0.072)	(0.399)	(0.078)	(0.524)	(0.511)
Log (additional money invested by the firm)	0.032	0.009	0.013	0.004	0.052	0.040
	(0.039)	(0.011)	(0.040)	(0.012)	(0.050)	(0.051)
Log (additional money invested by other firms)			−0.016	−0.005		−0.008
			(0.013)	(0.004)		(0.011)
Number of observations	314		290		314	290
Alpha	2.388		2.361			
Log pseudo-likelihood	−268.040		−251.753			
Chi-square Statistic	76.55		80.04			
P-value for chi^2	.000		.000			

Notes: RJV, research joint venture. All equations include dummy variables for technical area of the project. All estimates use standard errors clustered by RJV project.
[a] GMM equations are just identified. For this reason, there is no test of the over identifying restrictions to report. Excluded instruments are the logarithms of project budget per firm and additional money invested by the firm, from the closest respondent whose project is in a different industry and does not share ownership with the project in question.
*Variable is significant at the 5% level.
**Variable is significant at the 1% level.

Table 4. Dependent variable: patent applications from the RJV.

	Negative binomial regression		GMM[a]	
Variable or statistic	(4.1)	(4.2)	(4.3)	(4.4)
Log (project budget per firm)	0.760**	0.701**	0.882**	0.899**
	(0.171)	(0.192)	(0.148)	(0.161)
Years since project began	−0.045	−0.068	−0.080*	−0.089*
	(0.048)	(0.046)	(0.037)	(0.038)
RJV new direction for the industry (1 if yes, 0 if no)	0.599	0.651	0.907*	1.182*
	(0.543)	(0.593)	(0.439)	(0.539)
Founder of RJV (1 if yes, 0 if no)	1.436**	1.420**	1.256**	1.294**
	(0.362)	(0.417)	(0.448)	(0.557)
New intellectual property from RJV not protected (1 if yes, 0 if no)	−0.718**	−0.837**	−0.642**	−0.734**
	(0.288)	(0.295)	(0.214)	(0.229)
Partner R&D complementary (1 if yes, 0 if no)	0.776	0.653	0.822*	0.679
	(0.421)	(0.396)	(0.387)	(0.366)

Variable or statistic	Negative binomial regression (4.1)	(4.2)	GMM[a] (4.3)	(4.4)
Log (additional money invested by the firm)	0.072*	0.066*	0.079*	0.069
	(0.033)	(0.033)	(0.040)	(0.039)
Log (additional money invested by other firms)		0.015		−0.001
		(0.013)		(0.010)
Number of observations	315	291	315	291
Alpha	2.215	2.094		
Log pseudo-likelihood	−428.677	−403.476		
Chi^2 statistic	111.56	93.50		
P-value for chi^2	.000	.000		

Notes: RJV, research joint venture. All equations include dummy variables for technical area of the project. All estimates use standard errors clustered by RJV project.
[a]GMM equations are just identified. For this reason, there is no test of the over identifying restrictions to report. Excluded instruments are the logarithms of project budget per firm and additional money invested by the firm, from the closest respondent whose project is in a different industry and does not share ownership with the project in question.
*Variable is significant at the 5% level.
**Variable is significant at the 1% level.

Table 5. Dependent variable: log (additional money invested by the firm).

Variable or statistic	Tobit (5.1)	(5.2)	IV Tobit[a] (5.3)	(5.4)
Log (project budget per firm)	0.891*	1.013*	1.057**	1.235**
	(0.396)	(0.483)	(0.424)	(0.489)
Years since project began	0.153	0.125	0.136	0.104
	(0.118)	(0.126)	(0.121)	(0.128)
RJV new direction for the industry (1 if yes, 0 if no)	2.672**	2.574**	2.662**	2.557**
	(0.761)	(0.802)	(0.799)	(0.852)
Founder of RJV (1 if yes, 0 if no)	2.063**	2.303**	2.063**	2.326**
	(0.638)	(0.705)	(0.643)	(0.730)
New intellectual property from RJV not protected (1 if yes, 0 if no)	−0.743	−1.269	−0.756	−1.298*
	(0.629)	(0.676)	(0.604)	(0.658)
Partner R&D complementary (1 if yes, 0 if no)	2.823**	2.640**	2.802**	2.628**
	(0.902)	(0.991)	(0.785)	(0.842)
Commercialization delay	−0.157	−0.181	−0.159	−0.185
	(0.093)	(0.097)	(0.107)	(0.112)
RJV expected to yield revenue over the next five years (1 if yes, 0 if no)	3.806**	3.693**		
	(0.553)	(0.569)		
Closest neighbor: RJV expected to yield revenue over the next five years (1 if yes, 0 if no)			3.771**	3.640**
			(0.576)	(0.615)
Log (additional money invested by other firms)		−0.006		−0.010
		(0.028)		(0.026)
Number of observations	329	304	329	304
Left-censored observations	142	134	142	134
Sigma	4.266	4.348		
Log pseudo-likelihood	−633.175	−581.807		
F-statistic	19.04	18.26		
P-value for *F*	.0000	.0000		
Wald chi^2			120.25	109.83

	Tobit		IV Tobit[a]	
Variable or statistic	**(5.1)**	**(5.2)**	**(5.3)**	**(5.4)**
P-value for chi^2			.0000	.0000
Test for exogeneity				
Chi^2 (1)			1.27	1.74
Probability > chi^2 (1)			.261	.187

Notes: RJV, research joint venture. All equations include dummy variables for technical area of the project. Estimates report standard errors clustered by RJV project.
[a]IV Tobit uses the two-step efficient estimator developed by Newey (1987). Excluded instruments are the logarithms of project budget per firm and additional money invested by the firm from the closest firm-project participant whose project in a different industry and does not share ownership with the project in question.
*Variable is significant at the 5% level.
**Variable is significant at the 1% level.

Included in each of the tables are controls that handle variations in outcomes which have nothing to do with behavior under the RJV, the most important part of our analysis. Frequently used controls include indicators of technical area, the logarithm of project budget per firm, years since the project began, RJV new direction for the industry, founder of RJV, and partner R&D complementary. In order, these take care of variations in technological practice and opportunity by area, project resources per firm, project age, technological opportunity at the project level, investment by the firm, and meshing of partner R&D. Later, in the commercialization equations, we introduce indicators for private firm and R&D enhances value of earlier R&D, which matter for commercialization.

Besides the above, we introduce measures of behavior. As above, these include an indicator of new intellectual property from RJV not protected, the logarithm of additional money invested by other firms in the RJV, commercialization delay, and an indicator of most important partner is a customer. The first affects earlier stages of the RJV consisting of patents and additional money invested while the last three affect commercialization, at the later stages of the RJV. We shall discuss signs for the controls and the behavioral variables when we describe the individual tables.

The econometric method used depends on the outcome variable, but there are common themes to our procedures. First, all equations report standard errors clustered by RJV. This avoids underreporting of standard errors for grouped data.[17] Second, three variables appear as covariates but could be correlated with the error term in the regressions, making the variables endogenous and leading to potentially biased coefficients. These are the logarithm of project budget per firm, the logarithm of additional money invested by a firm, and an indicator for RJV expected to yield revenue over the next five years. The Instrumental Variables (IVs) for the endogenous variables are taken from the 'closest neighbor' to a project. The instruments (see Section VI.A.2) are subject to two restrictions: the closest neighbor does not share ownership with a project and it is from a different industry. For example, if a project includes firms in biotechnology, the instrument comes from a different set of firms and from projects that are not in biotechnology.

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[17] Recall that 397 company participants respond to the survey, but that respondents belong to 142 RJVs. We cluster errors by project to pick up errors specific to an RJV. An alternative is to cluster the errors by firm. But this is infeasible. RJVs are projects for which the mix of firms changes as different partners join a different venture. There is no single firm that is the only firm shared by several projects. Also, each RJV is defined by a given set of researchers and a given location within each firm. Firms do not uniquely define it.

The IVs are highly correlated with the original variables but they are free of common shocks due to shared ownership and industry.

A. Evidence on patent grants

A.1. Single equation estimates

Table 3 reports findings for patent grants. As in the tables to follow, single equation results are on the left while IV results are on the right. In column (3.1) of Table 3 consists of single equation estimates using negative binomial regression. The first column reports regression coefficients while the second reports marginal effects.[18] Because marginal effects add to the reporting burden, we present them only in Table 3, to illustrate the effect on patents of changes in the covariates.[19]

The logarithm of project budget per firm measures size of the RJV.[20] Its coefficient of 0.797 is significant at the .01-level. This is the elasticity of patent grants with respect to budget per firm. In the second column, the marginal effect, evaluated at means, is 0.227. This is the change in patent grants per 1% change in the project budget per firm.

The variable, years since the project began, indicates an older project. Older projects accumulate more patents. The coefficient of 0.184 is significant at the .01-level. It means that with each additional year, projects earn 18.4% more patents. In the second column, the marginal effect is 0.052 evaluated at means. Thus, an additional year results in 0.052 additional patents.

The variable, RJV is a new direction for the industry, captures technological opportunity. Its effect on patents is large. For this discrete variable, the coefficient is 2.029 and it is significant at the .01-level. It implies more than a sixfold increase in patent grants ($exp(2.0929) - 1 = 6.607$). The marginal effect, evaluated at means, is 0.358. This is the increase in patents for projects that represent a new direction in industry compared to other projects.

These calculations illustrate regression coefficients and marginal effects for logarithmic, arithmetic, and discrete variables. Given these, we briefly work through results for the other variables. Founders of RJVs receive more patent grants and this is significant at the .01-level. We find a negative and highly significant (.01-level) effect of failure to protect new intellectual property from the RJV.[21] Failure to protect intellectual property implies rivalry between one-time partners. At means the marginal effect on patents of this negative shock is –0.226. To assess

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[18] For negative binomial regression (see Cameron and Trivedi 2013, Chapter 3) the mean of a count variable given the covariates is $E(y|x) \equiv \mu$, and it is an exponential function of the covariates $x'\beta: \mu = exp(x'\beta)$. The variance depends on the mean: $\sigma^2 = \mu(1 + \alpha\mu)$ The marginal effect ME_j of x_j is the derivative $ME_j = d\mu/dx_j = exp(x'\beta)\beta_j$ and it has the same sign as the coefficient β_j. Here β_j is the proportional change due to a change in $x_j: \beta_j = (d\mu/\mu)/dx_j$ When x_j is in logarithms β_j is the elasticity. When x_j is a dummy indicator its marginal effect is $ME_j = \Delta\mu/\Delta x_j = (exp(\beta_j) - 1)exp(x'\beta)$.

[19] Marginal effects for all equations are available from the authors on request.

[20] Tests accept the restriction that logarithms of project budget and the number of firms can be replaced by the logarithm of project budget per firm.

[21] In results not shown we find that commercialization delay has no effect on patents, proving that this variable affects only the later stages of commercialization and thus expected final value, as in Section III.

inter-firm cohesion, we include a dummy indicator of complementarity of partner R&D. Partner R&D complementary is significant at the .01-level.

To conclude (3.1), we note that the logarithm of additional money invested by the firm has no significant effect on patents. Additional money invested is significant in the commercialization equations of Tables 6 and 7.

Table 6. Dependent variable: log (cumulative revenue from the RJV).

	Tobit		IV Tobit[a]	
Variable or statistic	**(6.1)**	**(6.2)**	**(6.3)**	**(6.4)**
Log (project budget per firm)	0.355	0.517	0.525	0.611
	(0.934)	(1.039)	(0.954)	(1.124)
Years since project began	0.209	0.127	0.182	0.118
	(0.241)	(0.261)	(0.255)	(0.272)
RJV new direction for the industry (1 if yes, 0 if no)	−0.176	0.724	−0.168	0.710
	(1.789)	(1.886)	(1.643)	(1.798)
Private firm (1 if yes, 0 if no)	2.737*	2.624*	2.687*	2.632*
	(1.169)	(1.231)	(1.245)	(1.325)
Founder of RJV (1 if yes, 0 if no)	1.391	2.331	1.377	2.305
	(1.532)	(1.635)	(1.437)	(1.656)
New intellectual property from RJV not protected (1 if yes, 0 if no)	−1.813	−1.387	−1.846	−1.376
	(1.440)	(1.514)	(1.409)	(1.505)
RJV enhances value of earlier R&D (1 if yes, 0 if no)	1.329	2.179	1.253	2.183
	(1.393)	(1.524)	(1.502)	(1.659)
Partner R&D complementary (1 if yes, 0 if no)	0.102	−0.236	0.122	−0.178
	(1.430)	(1.524)	(1.611)	(1.713)
Commercialization delay	−1.407**	−1.544**	−1.425**	−1.551**
	(0.305)	(0.321)	(0.331)	(0.355)
Log (additional money invested by the firm)	0.714**	0.685**	0.705**	0.674**
	(0.187)	(0.203)	(0.221)	(0.234)
Log (additional money invested by other firms)		−0.092*		−0.096
		(0.041)		(0.059)
Number of observations	309	286	309	286
Left-censored observations	252	236	252	236
Sigma	6.680	6.596		
Log pseudo-likelihood	−260.933	−227.678		
F-statistic	9.49	9.05		
P-value for *F*	.0000	.0000		
Wald chi^2			39.15	36.59
Test for exogeneity				
Chi^2 (2)			0.38	0.26
Probability > chi^2 (2)			.825	.879

Notes: RJV, research joint venture. All equations include dummy variables for technical area of the project. Estimates use standard errors clustered by RJV project.
[a]IV Tobit method is the two-step efficient estimator developed by Newey (1987). Excluded instruments are the logarithms of project budget per firm and additional money invested by the firm, from the closest respondent whose project is in a different industry and which does not share ownership with the project in question.
*Variable is significant at the 5% level.
**Variable is significant at the 1% level.

Table 7. Dependent variable: RJV expected to yield revenue. In the next five years (1 if yes, 0 if no).

	Probit		IV Probit[a]	
Variable or statistic	**(7.1)**	**(7.2)**	**(7.3)**	**(7.4)**
Log (project budget per firm)	0.094	0.146	0.052	0.091
	(0.131)	(0.127)	(0.143)	(0.161)
Years since project began	−0.203**	−0.201**	−0.199**	−0.196**
	(0.039)	(0.042)	(0.039)	(0.040)
RJV new direction for the industry (1 if yes, 0 if no)	0.135	0.142	0.136	0.147
	(0.224)	(0.233)	(0.241)	(0.251)
Private firm (1 if yes, 0 if no)	0.597**	0.458*	0.599**	0.464**
	(0.188)	(0.200)	(0.177)	(0.186)
Founder of RJV (1 if yes, 0 if no)	0.228	0.284	0.225	0.258
	(0.185)	(0.202)	(0.201)	(0.221)
New intellectual property from RJV not protected (1 if yes, 0 if no)	−0.301	−0.322	−0.303	−0.322
	(0.195)	(0.211)	(0.188)	(0.201)
RJV enhances value of earlier R&D (1 if yes, 0 if no)	0.364*	0.389*	0.364	0.388
	(0.183)	(0.198)	(0.197)	(0.208)
Partner R&D complementary (1 if yes, 0 if no)	−0.165	−0.072	−0.167	−0.072
	(0.196)	(0.207)	(0.240)	(0.250)
Commercialization delay	−0.104**	−0.106**	−0.101**	−0.103**
	(0.033)	(0.033)	(0.038)	(0.039)
Log (additional money invested by the firm)	0.176**	0.168**	0.178**	0.171**
	(0.026)	(0.027)	(0.029)	(0.030)
Log (additional money invested by other firms)		−0.014*		−0.013
		(0.007)		(0.008)
Number of observations	327	302	327	302
Log likelihood	−162.109	−148.682		
Wald chi^2	130.81	124.65	89.41	80.51
P-value for chi^2	.0000	.0000	.0000	.0000
Test for exogeneity				
Chi^2 (2)			0.77	1.52
Probability > chi^2 (2)			.680	.467

Notes: RJV, research joint venture. All equations include dummy variables for technical area of the project. Estimates use standard errors clustered by RJV project.
[a]IV Probit method is the two-step efficient estimator developed by Newey (1987). Excluded instruments are the logarithms of project budget per firm and additional money invested by the firm, from the closest firm-project participant whose project in a different industry and does not share ownership with the project in question.
*Variable is significant at the 5% level.
**Variable is significant at the 1% level.

In column (3.1) of Table 3 adds the logarithm of additional money invested by other firms in the RJV to (3.1). The other results stay about the same and additional money invested by other firms is insignificant.

A.2. Generalized method of moments and construction of the instruments

Table 3 concludes with (3.3) and (3.4). These are IVs results that use generalized method of moments (GMM) to handle endogeneity of project budget per firm and additional money invested by the firm. Endogeneity could arise for project budget if larger projects are awarded to firms that invent more, instead of firms inventing more because of a larger budget. Also, more inventive projects encourage firms to invest more, rather than the reverse, causing additional money invested to be endogenous. For both, endogeneity could lead to correlations with the equation errors. Project budget per firm is the more important, since additional money is not significant in (3.1) and (3.2).

The GMM procedure assumes an exponential function of the covariates. It minimizes a quadratic form based on the product of the IVs with the equation errors.[22]

Before we undertake GMM, we require instruments for identification. As noted, the instruments refer to the logarithm of project budget per firm and the logarithm of additional money invested by the firm. Later, we need another instrument for the indicator, expected commercialization over the next five years. As previously, we call the instruments that we derive 'closest neighbor' instruments because they minimize the distance between values of the variables for one observation, a firm-project participant, and the values for another. They are subject to the restriction that the other observation is from an RJV project that does not share ownership and is from a different industry. Put differently, we search for an unrelated 'twin' of a given observation.[23] The resulting variables are similar and highly correlated with the original variables, but satisfy the exclusion restriction, that they do not belong in the final or second-stage equations. This makes them instruments (Angrist and Pischke 2015). We use these 'closest neighbor' instruments in all the GMM results.

The instruments are computed as follows. We have names of firms and their parents on each project.[24] From this we construct the variable LINKED. This equals 1 if a pair of projects shares *any* firm and thus *any* common ownership, and 0 otherwise; and if any project pair is in the same industry. For each firm-project participant *i* and its three variables: the logarithm of project budget per firm, the logarithm of additional money invested by the firm, and the dummy for expected commercialization over the next five years, we arrange all other firm-participants *j* in a long vector that includes, for *every other* firm-project participant: LINKED and the three variables: the logarithm of project budget per firm, the logarithm of additional money invested by the firm, and the dummy for expected commercialization over the next five years. If LINKED equals 1, we set the values of the three variables for these other observations to missing and remove them from the analysis. For all other firm-project participants *j* LINKED equals 0 and there is no common ownership or industry. We compute the distance between values of the three variables for firm-project participant *i* and the remaining other firm-project

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[22] In this example, there are two excluded instruments and two endogenous variables. Hence the system is just identified and there are no over identifying restrictions. The instruments z_i satisfy the moment conditions $E[z\{y_1 - exp(y_2'\alpha + x_1'\beta)\}] = 0$. See Cameron and Trivedi (2010, Section 17.5.2 and references cited there).

[23] Methods applied to these 'twins' are distinct from methods for biological twins, for example in Ashenfelter and Krueger (1994) and Ashenfelter and Rouse (1996). We do not use difference-in-differences to eliminate common unmeasured traits such as ability because we eliminate in advance the common unmeasured traits.

[24] We thank Jianing Yang for unifying the firm names under a common parent firm.

participants j.[25] We select the outside observation k for which distance is at the minimum. This 'closest neighbor' observation provides instruments for the endogenous variables.

A.3. GMM estimates of the patent grant equation

GMM results are in (3.3) and (3.4) of Table 3. These results are reassuringly like the single equation findings in (3.1) and (3.2), suggesting that simultaneity bias is not an issue. However, founder of the RJV and complementarity of partner R&D become insignificant, partly because standard errors of the coefficients increase.

B. Evidence on patent applications

Table 4 reports findings for patent applications. Results are like those in Table 3 with two exceptions. Compared to patent grants, the coefficient of founder of the RJV nearly doubles. Because applications often become grants in the future, rewards to founders shift to the future. Another difference is that patent applications are a flow: they are not cumulative like patent grants. This explains why, the variable, years since the project began is insignificant. This concludes the discussion of patents from the RJVs.

C. Evidence on additional money invested

Additional money invested by the firm lies in between patents and commercialization. Table 5 reports findings where the logarithm of additional money invested is the dependent variable. In 43% of all cases, additional money is at a corner of 0, leading us to use Tobit analysis for the estimation.[26]

Starting with (5.1), key determinants of the logarithm of additional money invested by the firm are: RJV is a new direction for the industry, founder of the RJV, and partner R&D is complementary. In order, these increase additional money invested because of greater technological opportunity, because of greater early stage investments by founders, and because a more successful prior research stage if partner R&D is a complement to a given firm's R&D. The results show that selection of projects for novelty and complementarity encourages firm investment. Conversely, failure to protect new intellectual property from the RJV discourages follow-up investment. Commercialization delay is insignificant, indicating that additional money precedes commercialization. Last, future commercialization increases additional money invested, showing the simultaneity of follow-on investment with commercialization.

In column (5.2) of Table 5 adds the logarithm of additional money invested by other firms in the RJV to (5.1). As in Tables 3 and 4, this partner firm variable is insignificant. That is consistent with partial collaboration, where development inputs of former partners move independently of

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[25] Let the three variables of interest be $x1, x2, x3$. Then the Euclidean distance between any two observations i, j is $Dist(i,j) = \sqrt{(x1_i - x1_j)^2 + (x2_i - x2_j)^2 + (x3_i - x3_j)^2}$. The program that computes the IVs minimizes this distance and finds the closest neighbor observation and the values of its variables.

[26] The mean of a left-censored Tobit variable is: $E(y|x) = x'\beta + \sigma[\varphi(x'\beta)/\Phi(x'\beta)]$ For a derivation, see Wooldridge (2010, Chapter 17, Section 17.2).

one another. See Equation (A8) of the Appendix, setting the product market competition parameter $\theta = 0$.

It is possible that antitrust policy could explain why partial collaboration prevails and firms commercialize separately. But for our U.S.-based RJVs, set in the 1990s, the NCRA and NCRPA acts had provided safe harbors from antitrust (see Section I). Moreover, we are not aware of any U.S. antitrust cases involving RJVs since the 1990s. So, antitrust does not seem to explain why firms fail to commercialize jointly.

Table 5 concludes with IV Tobit results. Here we must deal with a limitation of IV Tobit. It does not allow for endogenous binary variables like future commercialization.[27] To make progress, we instrument the logarithm of project budget per firm, but we replace RJV is expected to yield revenue in the next five years with a proxy variable, its closest neighbor value for a firm-project participant that does not share ownership with the project and is in a different technical area. In columns (5.3) and (5.4) of Table 5 contain the IV results. The single equation Tobit results go through and the proxy performs very like the original dummy variable for future commercialization. The chi-square test for exogeneity of the logarithm of project budget per firm accepts exogeneity.

D. Evidence on commercialization of new products

Commercialization of new products follows patents and additional money invested since the former enable and protect returns from commercialization. Table 6 contains findings for the logarithm of revenues to date from the RJV, while Table 7 contains findings for an indicator of the likelihood of revenues from the RJV over the next five years. We start with Table 6.

Less than 20% of firm-project participants report positive revenues to date. Since revenue of most respondents is at a corner we apply Tobit analysis in Table 6. The dependent variable is the logarithm of revenues to date, plus 0.001 to allow the taking of logarithms. In columns (6.1) and (6.2) of Table 6 contain single equation estimates. In columns (6.3) and (6.4) of Table 6 report IV Tobit estimates, which take account of potential endogeneity of project budget per firm and additional money invested by the firm.[28] Instruments are the 'closest neighbor' instruments that Section VI.A.2 describes. For the first time, the equations include an indicator for private firm (1 if yes, 0 if no). Private firm is not significant in Tables 3–5. Also included is an indicator for RJV enhances value of earlier R&D (1 if yes, 0 if no). While positive, this is not significant in Table 6.

One difference from the patent findings is that for commercialization, project budget per firm is insignificant, while additional money invested by the firm is significant. This is the reverse of the patent findings. A plausible interpretation is that patents rely on funding from project budget, while new products require additional investments by firms.

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[27] See Wooldridge (2010, Chapter 17, Section 17.5.2) for an analysis. In brief, the problem is that the distribution of the second-stage Tobit variable is unknown when the first stage variable is binary and endogenous. Here we use the two-stage IV Tobit estimator developed by Newey (1987).

[28] We again use the two-stage IV Tobit estimator developed by Newey (1987).

Previously, Table 5 showed that additional money invested incorporates information about earlier stages of the project. Together, the results are consistent with the assumptions of Section III, which presume that firms rely on internal funding after research ends, but require that additional investment depends on prior success of projects.

Consistent with this interpretation, having positive revenues from new products is not associated with being founder of the RJV or with failure to protect new intellectual property from the RJV. It is revealing that complementarity of partner R&D, which was positive and often significant for patents, is never significant for commercialization in Table 6. This agrees with our assumption that complementarity is essential for research but not for commercialization. Partial collaboration, which ceases with research, implies that complementarity of R&D does not matter for commercialization. This is what we find in Table 6 and later in Table 7.

In (6.1) and elsewhere, private firms commercialize early. For privately held firms, early commercialization may be required for additional funding from outside investors.[29]

In (6.1), commercialization delay reduces revenues from new products, suggesting that past delays in execution do in fact decrease commercialization. The discussion of (6.1) concludes with the logarithm of additional money invested. It is positive and significant, consistent with the view that additional money is earmarked for development and commercialization.

In column (6.2) of Table 6 adds the logarithm of additional money invested by other firms in the RJV to (6.1). It is negative and significant at the .05-level for cumulative revenue from the RJV. As we have seen, separate commercialization does not rule out the product market competition suggested by this result. This has another implication. The Appendix points out that product market competition could contribute to the failure of the RJVs in this sample to break even.

Table 6 concludes with the IV Tobit results shown in (6.3) and (6.4). The findings are very like the single equation results. Chi-square tests for exogeneity of project budget per firm and additional money invested accept the hypothesis that these variables are exogenous.

Table 7 reports Probit estimates of the probability of future revenues. The dependent variable equals 1 if the RJV is expected to yield revenues from new products over the next five years, and 0 if not. The percent of the sample that views future revenues as likely rises from 18% having positive revenues to date in Table 6 to 43% in Table 7.

Findings are closely similar to those of Table 6. An exception is the variable, years since project began. It is negative and significant: revenues from older projects are increasingly in the past. As in Table 6, private firms are more likely to commercialize. Additional money invested significantly (.01-level) raises the odds of future commercialization while project budget per firm has no effect. Complementarity of partner R&D is not significant, consistent with the view that collaboration ends with early stage research. Additional money invested by other firms in the RJV is negative and marginally significant, suggesting a degree of product market competition between former partners, even though firms commercialize separately. Commercialization delay diminishes future revenues, as it did cumulative revenues.

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[29] We thank Jennifer C. Adams for this insight.

In columns (7.3) and (7.4) of Table 7 report IV Probit estimates.[30] These are close to the single equation results and chi-square tests for exogeneity accept the hypothesis that project budget per firm and additional money invested are exogenous.

The empirical work concludes with Table 8. It reports extensions of the commercialization equations. The first three equations extend (6.4), Table 6, while the last three extend (7.4), Table 7. For simplicity, the table omits variables already in earlier tables and instead focuses on the new indicators for most important partner is a customer, supplier, or competitor. Only the indicator, having a customer for a partner is significant. It increases cumulative revenues and revenues expected in the next five years, while supplier and competitor have no effect. Vertical RJVs are more likely to commercialize, but only if the firm is an upstream manufacturer or supplier to a downstream customer or user.

Table 8. Extensions of the commercialization equations.

	IV Tobit[a]			IV Probit[b]		
Variable	**(8.1)**	**(8.2)**	**(8.3)**	**(8.4)**	**(8.5)**	**(8.6)**
Most important partner is a customer (1 if yes, 0 if no)	3.443*	3.391*	3.356*	0.657**	0.639**	0.644**
	(1.471)	(1.474)	(1.475)	(0.220)	(0.220)	(0.220)
Most important partner is a supplier (1 if yes, 0 if no)	−1.523	−1.506	−1.556	−0.092	−0.088	−0.099
	(1.902)	(1.905)	(1.903)	(0.242)	(0.243)	(0.243)
Most important partner is a competitor (1 if yes, 0 if no)	−2.378	−2.406	−2.305	0.237	0.220	0.234
	(3.475)	(3.493)	(3.493)	(0.422)	(0.422)	(0.422)
Log (stock of additional money invested by other firms, previous RJVs)		−0.116			−0.041	
		(0.228)			(0.030)	
Log (stock of additional money invested by other firms, same location, previous RJVs)			−0.172			−0.037
			(0.272)			(0.034)

Notes: RJV, research joint venture. All equations include dummy variables for technical area of the project. Estimates use standard errors clustered by RJV project.
[a]IV Tobit equations add the variables shown above to (6.4) of Table 6.
[b]IV Probit equations add the variables shown above to (7.4) of Table 7.
*Variable is significant at the 5% level.
**Variable is significant at the 1% level.

In addition, for Table 8 we construct logarithms of additional money invested by partners on all past ATP projects and by partners on past ATP projects sharing the same three digit zip code as the present project. These variables are not significant. This implies that spillovers between projects are not important. This completes the discussion of commercialization as well as the empirical work.

VII. Summary, discussion, and conclusion

In this paper, we analyzed a unique data set that reveals the structure of RJVs. Because the ATP data cover a wide range of performance measures of RJVs observed at different stages, and because we observe RJVs being shaped by the organization, structure, and behavior of multiple partners on the same RJV, we gain insights into how RJVs work. We have also linked the empirical analysis to simple models of RJVs that offer implications for data. One of the

[30] IV Probit is two-stage IV Probit. It is due to Newey (1987).

implications supported by the ATP data is that RJV partners cease to collaborate after the research period. This avoids the splitting of rewards for development and commercialization when partners are competitors. This result holds unless complementarities among firms in development are exceptionally strong. Another implication is that problems of project execution produce feed-back and feed-forward that reduce incentives for firms to invest. Still another is that additional investments by firms support development rather than invention. Our results are consistent with these implications.

At the time when the ATP projects are last measured (in 2004) revenues fall short of costs. If we impose 0%, 10%, or 20% rates of return over cost, required future revenues are implausibly large compared to cumulative revenues to date. Social returns over and above private returns are possible, but they would have to rescue the projects from a weak performance on commercialization.

The regression findings are these. First, founders of RJVs invest more and are rewarded for their efforts. Patent grants and applications, and to a lesser extent revenue, from the RJV are higher for founders, and founders are more likely to invest additional money. Second, lack of intellectual property protection reduces patenting from the project and commercialization delays reduce revenue from the project and additional money invested. This agrees with reduced investment incentives. Third, larger projects yield more patent grants and applications and larger cumulative revenues to date. Fourth, RJVs which are new to the industry yield significantly more patents and increase additional investment, all because of greater technological opportunity.

Several results from our analysis have implications beyond the immediate RJVs that we study. One implication is that additional money invested by firms subsequent to the RJV seems to be partly aimed at development of future projects rather than revenue from the current project. These are ‘roundabout’ projects that are not concerned with immediate commercialization. The compelling point in favor of this is the fact that firms are willing to put up their own money, suggesting that real gains are to be had. But unfortunately, that makes commercialization, an objective of the program, largely unobservable.

Another implication is that additional money invested by partners has no effect on patenting, revenue from new products, or additional money invested. This is consistent with the hypothesis that RJVs end with the research stage because that approach avoids the splitting of rewards from value creation. However, additional money invested by partners does have a weakly negative effect on commercialization, suggesting some amount of product market competition.

It is important to mention that if all firms are the same, entry to win a subsidized RJV will generate a cost of entry equal to the aggregate subsidy under the program. This reinforces the view that knowledge spillovers from new industrial technologies are most likely to justify R&D subsidies.

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Appendix. Collaboration in RJVs

We illustrate the choice between full and partial collaboration using an example where final value of a project takes a Cobb-Douglas form. This example could be generalized, but its simplicity and elegance recommend it. We focus on the third and final period of the model discussed in Section III because it determines incentives to invest earlier, in the first and second periods.[31] Each firm pursues a Cournot-Nash strategy and treats the other firm's inputs as given in choosing how much of their own input to invest.

A.1. Full collaboration

Under full collaboration the firms work together during the final period. The expected value function EV_i^F for firm *i* is:

$$\mathrm{EV}_i^F(T) = \max_{d_i}\left\{\frac{1}{2}EB_F \cdot T \cdot d_i^{\mu} \cdot d_j^{\nu} - d_i\right\} \; i = 1, 2.\% \tag{A1}$$

The first term on the right is expected benefit from the project. Because of equal sharing it is multiplied by one-half. EB_F is expected productivity under full collaboration. It is subject to risk, for example, of intellectual property not being protected. The term *T* is technology created during the second period. Since we work backward from the third period we take *T* as given. The exponent of the firm's development input is positive: $\mu > 0$. The sign of exponent ν of its partner's development input d_j depends on whether d_j is a strategic complement or substitute (Bulow, Geanakoplos, and Klemperer 1985). When d_j is a strategic complement, $\nu > 0$ and the firms cooperate in developing the product. If d_j is a strategic substitute $\nu < 0$. Under Bertrand price competition, the other firm invests d_j to lower its marginal cost and takes market share from i. This reduces value for firm *i*.[32]

To solve for the inputs, take the derivative of (A1) with respect to d_i, to obtain the first-order condition. If a firm is at a corner $d_i = 0$ and the project ends. Note that weak property protection can lead to this result. Instead assume an interior solution where the other firm's input is held constant, as shown by superscript 0 in d_j^0:

$$\frac{\mu}{2}EB_F \cdot T \cdot d_i^{\mu-1} \cdot \left(d_j^0\right)^{\nu} - 1 = 0, \qquad i,j = 1, 2.\% \tag{A2}$$

d_i

$$d_i = \left(\frac{\mu}{2}EB_F \cdot T\right)^{\frac{1}{1-\mu}} \cdot \left(d_j^0\right)^{\frac{\nu}{1-\mu}}, \qquad i,j = 1, 2.\% \tag{A3}$$

Development inputs rise or fall together if $\nu > 0$ because one firm's input increases the other's marginal product. But if $\nu < 0$ the inputs move in opposite directions since one firm's input

[31] We have worked this example back to the initial period. The resulting value function reflects the findings for full and partial collaboration in the final period, making this the crucial period for the analysis.
[32] A less extreme case occurs when product market competition is not enough to reverse the sign and $\mu > \nu > 0$.

decreases the other's marginal product. Set $d_j^0 = d_j$ representing equilibrium and solve (A3). The result is:

$$d_1 = d_2 = \left(\frac{\mu}{2} \cdot EB_F \cdot T\right)^{\frac{1}{1-\mu-\nu}}. \quad \text{(A4)}$$

Substitute (A4) into (A1) and simplify. This yields the maximum value function for full collaboration:

$$\begin{aligned}\mathrm{EV}_i^F = EV^F &= \frac{1}{2} EB_F \cdot T \cdot \left(\frac{\mu}{2} EB_F \cdot T\right)^{\frac{\mu+\nu}{1-\mu-\nu}} - \left(\frac{\mu}{2} EB_F \cdot T\right)^{\frac{1}{1-\mu-\nu}}, \\ &= \frac{1}{\mu}\left(\frac{\mu}{2} EB_F \cdot T\right)^{\frac{1-\mu-\nu}{1-\mu-\nu}} \cdot \left(\frac{\mu}{2} EB_F \cdot T\right)^{\frac{\mu+\nu}{1-\mu-\nu}} - \left(\frac{\mu}{2} EB_F \cdot T\right)^{\frac{1}{1-\mu-\nu}}, \\ &= \left(\frac{1-\mu}{\mu}\right) \cdot \left(\frac{\mu}{2} EB_F \cdot T\right)^{\frac{1}{1-\mu-\nu}} \equiv C_F \cdot T^{\frac{1}{1-\mu-\nu}}.\end{aligned} \quad \text{(A5)}$$

Cooperation increases value because $\nu > 0$ and $1 - \mu - \nu < 1 - \mu$, whereas Bertrand product market competition decreases value since $\nu < 0$ and $1 - \mu - \nu > 1 - \mu$.

A.2. Partial collaboration

Under partial collaboration each firm undertakes development separately, but rivalry in the product markets is possible, using the technology T created during the research phase of the RJV. Final period value is:

$$\mathrm{EV}_i^P = \max_{d_i}\left\{\mathrm{EB}_P \cdot T \cdot d_i^{\varphi} d_j^{-\theta} - d_i\right\}. \quad \text{(A6)}$$

EB_P is expected productivity of final value under partial collaboration and T is technology produced in the second period. Diminishing returns implies $0 < \varphi < 1$. The term $\theta \geq 0$ captures rivalry. The only option under partial collaboration is Bertrand price competition. Differentiate (A6) with respect to d_i. If the firm is at a corner then $d_i = 0$ and the project ends, an outcome that price competition contributes to. Instead assume an interior solution and set the derivative equal to 0 yielding the first-order condition:

$$\varphi \cdot \mathrm{EB}_P \cdot T \cdot d_i^{\varphi-1}\left(d_j^0\right)^{-\theta} - 1 = 0, \qquad i, j = 1,2. \quad \text{(A7)}$$

Solving (A7) for d_i we reach:

$$d_i = (\varphi \cdot \mathrm{EB}_P \cdot T)^{\frac{1}{1-\varphi}}\left(d_j^0\right)^{\frac{-\theta}{1-\varphi}}, \qquad i, j = 1,2. \quad \text{(A7)}$$

Development inputs of the firms move in opposite directions, because the other firm's input decreases value. Now set $d_j^0 = d_j$, representing equilibrium, and substitute in (A8):

$$d_i = (\varphi \cdot \text{EB}_P \cdot T)^{\frac{1}{1-\varphi}} \left[(\varphi \cdot \text{EB}_P \cdot T)^{\frac{1}{1-\varphi}} d_i^{\frac{-\theta}{1-\varphi}} \right]^{\frac{-\theta}{1-\varphi}}, \qquad i = 1{,}2.$$

Solving for d_i,

$$d_1 = d_2 = (\varphi \cdot \text{EB}_P \cdot T)^{\frac{1-\varphi-\theta}{(1-\varphi)^2-\theta^2}} = (\varphi \cdot \text{EB}_P \cdot T)^{\frac{1}{1-\varphi+\theta}}.\% \tag{A9}$$

Rivalry reduces development inputs since $1 - \varphi < 1 - \varphi + \theta$. Substitute (A9) into (A6) and simplify. This yields the maximum value function for partial collaboration:

$$\begin{aligned} \text{EV}_i^P = \text{EV}^\text{P} &= \text{EB}_P \cdot T \cdot (\varphi \cdot \text{EB}_P \cdot T)^{\frac{\varphi}{1-\varphi+\theta}} \cdot (\varphi \cdot \text{EB}_P \cdot T)^{\frac{-\theta}{1-\varphi+\theta}} \\ &\quad - (\varphi \cdot \text{EB}_P \cdot T)^{\frac{\varphi}{1-\varphi+\theta}}, \\ &= \frac{1}{\varphi} (\varphi \cdot \text{EB}_P \cdot T)^{\frac{1-\varphi+\theta}{1-\varphi+\theta}} \cdot (\varphi \cdot \text{EB}_P \cdot T)^{\frac{\varphi-\theta}{1-\varphi+\theta}} - (\varphi \cdot \text{EB}_P \cdot T)^{\frac{1}{1-\varphi+\theta}}, \% \\ &= \left(\frac{1-\varphi}{\varphi} \right) \cdot (\varphi \cdot \text{EB}_P \cdot T)^{\frac{\varphi}{1-\varphi+\theta}} \equiv C_P \cdot T^{\frac{1}{1-\varphi+\theta}}. \end{aligned} \tag{A10}$$

Rivalry ($\theta \geq 0$) reduces expected value in the final period. If rivalry goes to 0 then Equation (A8) shows that development inputs of the firms are independent of each other.

A.3. Comparison of full and partial collaboration

Equations (A5) and (A10) are final period expected values under full and partial collaboration. Begin by assuming that $\theta = 0$ in (A10) so rivalry is 0 under partial collaboration. If returns to scale are the same $\mu + \nu = \varphi$ and the elasticity of value with respect to technology T is the same. If the research production functions are the same in all respects $\mu + \nu = \varphi$ and $\text{EB}_F = \text{EB}_P$. Partial collaboration then has the edge. Full collaboration yields a lower *private* value because of the splitting of rewards shown by the presence of $\text{EB}_F/2$ in (5). Put differently, the splitting of rewards under full collaboration means that its value function must be more productive than that of partial collaboration for (A5) to exceed (A10). This could happen if losing the other firm's development input under partial collaboration lowers the returns to scale, implying $\mu + \nu > \varphi$. And yet the advantage would go the other way if separate development allows each firm to pursue opportunities where it is more productive. If so (A10) exceeds (A5) and partial collaboration would unlock greater value and provide more of an incentive to invent the technology.

However, these points become moot if product market competition increasingly dominates both cases. In that event, expected value under full collaboration decreases in (A5) as ν becomes more negative and likewise (A10) decreases as $-\theta$ grows more negative. In this situation, partial collaboration would have to exceed a low value under full collaboration to be the better alternative. The solution $d_i = 0$ would become more frequent in these circumstances, pointing to product market rivalry among teams of competitors as the reason for endemic failure of the projects to break even.