Complementary Assets and the Choice of Organizational Governance: Empirical Evidence From a Large Sample of U.S. Technology-Based Firms

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***Abstract*—Despite the considerable volume of research on technology commercialization, the role of complementary assets in driving technology commercialization remains controversial. In this paper, we provide a balanced perspective that integrates notions from transaction costs, firm capabilities, and industrial organization studies. In particular, we analyze the offsetting effects of the nature, ownership, and strength of downstream complementary assets on the *gains from trade* and *transaction costs* from alternative technology commercialization strategies. These strategies include competition in the product market, licensing, forming a technological joint venture, and selling the company to, or merging it with, holders of complementary assets. We test our hypotheses using a unique dataset encompassing commercialization transactions occurring between 1996 and 2002, among 545 technology-based firms. Our results suggest that innovators operating in industries requiring cospecialized complementary assets or possessing weak downstream capabilities, which are both associated with relatively higher sunk costs of entry in the product markets, are more likely to merge with incumbents rather than compete in the product market. Findings also suggest that innovating firms operating in industries requiring cospecialized complementary assets or possessing weak downstream capabilities, which are also associated with higher transaction costs, are more likely to adopt more integrated cooperative commercialization solutions.**

***Index Terms*—Appropriability, cospecialized complementary assets, downstream complementary capabilities, organizational governance choice, technology commercialization.**

I. Introduction

A KEY objective of technology strategy research is to identify the optimal organizational governance mode that highly innovative firms should employ in order to commercialize their technologies. Prior research has focused on an innovative firm's decision to either compete in the product market or cooperate with incumbents by licensing or selling the company to owners of complementary assets [1]–[5]. Results suggest that this choice is mainly determined by factors such as the strength of intellectual property rights (IPR), the nature and possession of complementary assets required to commercialize innovations, and the barriers to entry.

While the role of IPR has been extensively studied by economic and management scholars, the role played by the nature, ownership, and strength of complementary assets required to commercialize a technology remains controversial; unsurprisingly, the empirical findings are scant and mixed. The pioneering work of Teece suggests that complementary assets, when hard to acquire, should lead the innovating firm to partner with holders of complementary assets in most circumstances.[1] Along these lines, Gans and Stern [6, p. 340] suggest that:

> "As Teece [5] has emphasized, the control over costly-to-build complementary assets is a key wedge between the capabilities of the start-up and more established firms in an industry, and the inability to acquire these resources cost effectively has an important impact on the returns earned by a startup innovator. Specifically, when specialized complementary assets are required, the sunk costs of product market entry become substantial [. . .]. Under a product market competition strategy, the costs associated with duplicating specialized complementary assets held by established firms are entirely borne by the technology entrepreneur. However, under a cooperation strategy, the gains from trade will include the avoidance of costly duplication of investments, and these gains will be shared between the partners in the collaboration."[2]

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[1]According to Teece, the *ex-ante* effect of complementary assets on the vertical boundaries of the firm is ambiguous, in principle. In particular, using the well-known decision tree of Teece's article [5, p. 296], when the complementary assets required to commercialize an innovation are specialized/cospecialized with the innovation, innovating firms should vertically integrate in the product market only if the appropriability regime is weak, the complementary assets are critical, the innovating firm is in a sound cash position, and the firm is better positioned than its incumbents and imitators for the acquisition of complementary assets. All these conditions are rarely met, especially by small entrepreneurial companies [5].

[2]In a similar vein, Arora *et al.*, in their pioneering contribution to the markets for the technology literature, suggest: "A commonplace about technology licensing, particularly from the perspective of small firms, is that the technology owner does not receive the full return from the technology [. . .]. In many instances, this leads entrepreneurs adopt a strategy where they try to acquire the complementary capabilities themselves to avoid having to share rents. There are some potential pitfalls in such a strategy. The obvious one is that small firms also have limited bargaining power when it comes to acquiring capital required to build or acquire the complementary assets they need to exploit the technology themselves. Further, to the extent that many of the complementary assets are themselves not readily accessible through a market mechanism, and to the extent that the entrepreneurial startup may not be very efficient at building those assets in-house, in-house exploitation is probably a much riskier and possibly less efficient strategy" [1, p. 241].

The key idea in the summary passage quoted previously is that when complementary assets are hard to acquire, such as when they are specialized with technologies that have yet to be commercialized, we should witness an expansion of technology exchanges due to increased incentives for technology suppliers and buyers (holders of the required complementary assets) to partner and share the value created by the exchange, thus avoiding the wasteful duplication of investments in complementary assets. Such game theory perspective is consistent with research explaining technology commercialization using a firm capability perspective [7]–[10].

Empirical support for this view is mixed. Even the empirical results of Gans *et al.* [3] related to the impact of a survey-based measure of complementary assets on the decision to compete rather than to cooperate (through licensing or selling the company) for a sample of U.S. startups are inconclusive. This is not surprising, since this perspective neglects the effect of complementary assets on transaction costs. In particular, a high degree of specialization (or cospecialization) between the innovation and the required complementary assets has offsetting effects on the incentives to cooperate: on one hand, specialization increases the sunk costs of entry in the product market, thus increasing the gains from exploiting the incumbents' complementary assets; on the other hand, it may increase the threat of opportunism and holdup associated with cooperative agreements, which are important drivers of the transaction costs associated with technology transfer agreements [11].[3] Similarly, while an innovating firm with weak downstream complementary capabilities may gain from leveraging its partner's complementary assets, it will also face a higher threat of having its new technology imitated, as imitation is associated with the negotiations necessary to transfer technology across firm boundaries. After all, ownership of downstream capabilities increases the appropriability of innovation rents by reducing the imitation threat, thus reducing the transaction costs associated with efforts required to safeguard the innovating firm from the threat of knowledge spillovers.

In summary, the nature, ownership, and strength of complementary assets *contemporaneously* increase the gains from trade and the transaction costs of technology transfer agreements. Therefore, the net effect of complementary assets on the relative returns to competitive and cooperative strategies is, *ex-ante*, ambiguous. The main contribution of this paper is to disentangle each of these effects and highlight conditions under which one of the two offsetting effects is likely to dominate. This is accomplished by comparing the payoffs from competitive commercialization strategies to the payoffs from cooperative strategies that are characterized by their varied effectiveness when it comes to mitigating the transaction costs associated with technology transfer. These cooperative strategies include licensing, forming a technological joint venture (TJV), and merging with incumbents.[4]

Following this logic, we hypothesize that the positive effect of complementary assets on the gains from trade should dominate when comparing competitive commercialization strategies to cooperative strategies that minimize the threat of opportunism and knowledge spillovers, such as mergers. Our results suggest that innovating firms operating in industries requiring cospecialized complementary assets or possessing weak downstream capabilities, which are both associated with relatively higher sunk costs of entry in the product markets, are more likely to merge with incumbents rather than compete in the product market.

Conversely, transaction cost economics explains the estimated effect of complementary assets on the payoffs from alternative cooperative strategies. Indeed, we find that innovating firms operating in industries requiring cospecialized complementary assets or possessing weak downstream capabilities (which are both associated with higher transaction costs) are more likely to adopt strategies that minimize transaction costs, such as mergers.

Our contribution is a step toward a deeper understanding of the role of complementary assets in technology strategy. We provide a balanced perspective that highlights the role of game theory, transaction costs, and firm capabilities in technology commercialization. By doing so, we also contribute to the recent strategy literature that places increasing emphasis on the role of firm capabilities in firms' boundary choices [10], [12]–[17]. This literature is often motivated by the desire to explain inconclusive empirical results. Scholars focusing on both strategy and technology commercialization have emphasized the need for empirical research to integrate different paradigms and employ "mixed methods" [18]–[21]. Consistent with this trend, our empirical analysis is conducted at both the technological and organizational levels.

While previous empirical studies on technology commercialization have typically focused on a single industry and either small firms or large public firms [22]–[24], we provide a systematic cross-industry analysis that includes information on a large and heterogeneous sample of the commercialization strategies of public and private U.S. companies operating in a broad range of manufacturing industries. In particular, we believe that while narrow industry studies may be well suited to examine issues of interfirm organizational relationships and the role of firm capabilities, the ability of these studies to empirically analyze concepts such as the nature of complementary assets required

[3]Teece himself highlights the risks of strategic partnering in his seminal 1986 article [5, p. 294]: "It is most important to recognize, however, that strategic (contractual) partnering, which is currently very fashionable, is exposed to certain hazards, particularly for the innovator, when the innovator is trying to use contracts to access specialized capabilities. First, it may be difficult to induce suppliers to make costly irreversible commitments which depend for their success on the success of the innovation. To expect suppliers, manufacturers, and distributors to do so is to invite them to take risks along with the innovator. The problem which this poses for the innovator is similar to the problems associated with attracting venture capital. The innovator must persuade its prospective partner that the risk is a good one. The situation is one open to opportunistic abuses on both sides. The innovator has incentives to overstate the value of the innovation, while the supplier has incentives to 'run with the technology' should the innovation be a success." Note, however, that not all such risks are integrated in Teece's theoretical framework, as summarized by the well-known flowchart summarizing the drivers of the integration versus contract decision for an innovating firm [5, p. 296].

[4]For the remainder of this paper, we shall, for brevity, refer to a "merger" to indicate both the acquisition of a focal firm by another firm or a merger between the two entities.

for commercialization is limited, primarily due to the fact that there is relatively low cross-industry variation in the measures of complementary assets. From this point of view, utilizing novel measures of complementary assets is essential for our contribution. These novel measures include: 1) a survey-based measure of the nature of complementary assets, such as the extent to which upstream and downstream activities required for technology commercialization are cospecialized (mutually dependent); and 2) a second measure based on a firm's stock of trademarks, which allows us to systematically measure a firm's marketing capability and its brand capital across industries.

We study the population of technology-based firms that hold a portfolio of at least 15 patents obtained between 1998 and 2002. These firms have been defined as serial innovators; in other words, they are technology-based firms that were able to sustain innovation beyond the first great idea upon which they were founded [25]–[27]. The information collected about these firms is unique in that it includes patent information aggregated up to the ultimate parent and linked to multiple data sources: 1) news on product launches from the Gale-Promt database; 2) news on licensing, TJVs, and mergers and acquisitions (M&A) from the Thomson Reuters Securities Data Company (SDC) Platinum database; 3) the USPTO trademarks database and patent-to-industry concordance file, providing information on a firm's marketing capability; and 4) the Carnegie Mellon Survey (CMS) on industrial R&D, providing our key measure of cospecialized complementary assets [28].

II. Theory and Hypothesis Development

A. *Organizational Governance Decisions*

Companies can commercialize their new technologies through vertical integration in the product market by, for example, building or leveraging internal downstream complementary assets, or by cooperating with industry incumbents, whereby the technology may or may not be transferred to partners [1], [6]. The literature on markets for technology has typically focused on understanding contract-based alliances, particularly those whereby the rights to use a technology are transferred to owners of downstream complementary assets via a licensing agreement [1], [2]. Gans *et al.* [3] go a step further by analyzing the decision to compete or cooperate with incumbents, with cooperation consisting of licensing *or* the sale of the company holding the new technology. From the perspective of a technology startup, this paper suggests that selling a company to holders of complementary assets is an important alternative to licensing.

The role of M&A as a strategy to acquire technology has been highlighted by studies focused on the demand side of the markets or comparing the R&D make or buy decision [29], [30]. For example, large pharmaceutical firms facing productivity declines often use acquisitions to fill gaps along their research pipeline within a specific therapeutic category or research program [31].

We focus on a firm's decision to compete in the product market or engage in cooperative commercialization strategies whose main objectives are to access downstream complementary assets. Cooperative strategies imply transfers of technology across the focal firm boundaries. In our context, and consistent with the market for technology literature [3], [32], we refer to such technology strategy choices as cooperative commercialization strategies. We defined these as interfirm linkages whereby the innovating firm and holders of complementary assets jointly commit resources to commercialize new technologies. In addition to licensing, which is the classic contract-based mechanism, we also include TJVs and M&A. These are important mechanisms to appropriate returns from innovation; they imply the transfer of technology ownership rights across firm boundaries through equity-based, rather than contractual, mechanisms [33].Consistent with Kale and Puranam [33], we rank such cooperative strategies based on the required degree of organizational integration between cooperating partners, where the smallest integration is contract-based (licensing), the greatest is full equity-based integration (sale of the company or merger), and the middle ground is joint equity ownership (TJVs). The key rationale for our ranking is that the different degrees of organizational integration imply different degrees of transaction costs [24].

We only analyze a limited set of commercialization options. Licensing is only one type among various forms of governance structures, which also include TJVs, equity partnerships, and nonequity partnerships. Each governance structure significantly differs from the others with respect to control, commitment, flexibility, knowledge transfer, and transaction costs. Our choice of technology commercialization options reflects the need to compare alternative organizational forms with at least one common objective—unilateral transfer of existing new technologies from the focal supplier to holders of downstream complementary assets. These options should also present sharp differences with respect to the appropriability hazards of technology transfer. Licensing represents the archetype of a contract-based exchange alliance in which there is a well-identified unilateral transfer of technology [32]. TJVs represent the archetype of an equity-based alliance with an intermediate degree of integration between partners [34]–[36]. Establishment of a TJV typically provides specific information about the objective of the venture at the time of the announcement, thus allowing us to select deals incorporating the unilateral transfer of the focal firm's technologies. We exclude commercialization choices that do not constitute alternatives for the exploitation of existing technologies by innovators seeking to access downstream complementary assets.[5]

[5]In particular, we do not consider strategic alliances not classified as licensing or TJVs that are used as exploration mechanisms to create new technology or acquire new capabilities rather than exploit existing technology [20], [56]. We also exclude alliances that may be used to source complementary assets from partners (such as in the case of manufacturing or marketing agreements), but that do not imply the transfer of rights to use or own the supplier's technology [62]. Such arrangements are not clearly characterized by the appropriability hazards permeating technology transfers [49]. Moreover, the object of these types of alliances "usually does not exist at the time the contracts are inked" [62]. In these cases, it is thus a challenge to identify whether the deals imply the commercialization of the focal firm's technologies. We also exclude cross-licensing agreements and minority equity investments from our analysis. The former do not represent a cooperative commercialization mode used to access downstream complementary assets. Finally, we do not consider other minority

B. Comparing the Payoffs From Competitive and Cooperative Commercialization Strategies

We analyze the drivers of the classic decision of a technology-based firm to compete in the product market with an industry incumbent, as opposed to forming a cooperative strategy, based on licensing, TJVs, or mergers, that entails the transfer of the rights to develop and commercialize the technology to the incumbent firm. As formalized in the bargaining model of Gans *et al.* [3], the choice to engage in a commercialization strategy is determined jointly by the supplier and the buyer. Within this framework, a cooperative solution is reached as long as the joint gains from trade between partners outweigh the transaction costs of reaching a cooperative solution. Key drivers of gains from trade include 1) the additional profits that could be gained by reducing competition in the product market; and 2) the savings from avoiding duplicative commercialization investments, such as those associated with required complementary assets. In what follows, we highlight the impact of the nature, ownership, and strength of complementary assets on the gains from trade and transaction costs of cooperation in general, and then with reference to each specific cooperative commercialization solution.

1) Cospecialization Between Innovation and Downstream Complementary Assets: Successful commercialization of an innovation requires proper manufacturing, marketing, and a variety of other complementary assets [5]. If an innovation is part of a manufactured good, the remaining components would be considered complementary assets, as would: the capability to manufacture the good, the ability to create a strong brand associated with that product, and the capacity to form a distribution network for selling and servicing the finished good. These complementary assets are often cospecialized to the innovation, which suggests that a bilateral dependence exists between the invention and the downstream activities [5]. Cospecialization typically originates from the relationship-specific investments required from both the innovator and the commercialization entities. When the innovation is commercialized outside of firm boundaries in a context of high cospecialization, the transaction costs are high [5]. These transaction costs include, but are not limited to, the innovator's exposure to the threat of holdup or opportunistic behavior by the firm controlling the complementary assets [11].

The notion of cospecialized complementary assets is fundamentally grounded on the contracting approach of Coase and Williamson [20]. However, the concept has also been used by economic and strategy scholars in a different way. In the game theoretic model introduced by Gans *et al.* [3], building downstream complementary assets that are cospecialized with the technologies to be commercialized entails a sunk cost of entry in the product market. This investment cost could be avoided if the inventing firm partners with industry incumbents who are better positioned with respect to the ownership or acquisition of complementary assets. The potential saving amounts to a "gain from trade" relative to the vertical integration case; the gain can be split by the technology supplier and buyer through negotiation, according to the parties' relative bargaining powers [3].

This game-theoretic bargaining perspective, which has dominated the recent literature on markets for technology, neglects the effect of complementary assets on transaction costs. This perspective has focused instead on the implication that cooperative solutions such as licensing or M&A between entrepreneurial innovators and industry incumbents avoid the duplication of sunk complementary assets and provide an incentive for the cooperative commercialization of new technologies.

Based on the integration of transaction costs and capability arguments within a game-theoretic framework, the previous discussion suggests that cospecialization has *ex-ante* offsetting effects on the returns from cooperative strategies when compared to returns from competition in the product market.[6] However, we argue that such ambiguity does not equally characterize all forms of cooperative commercialization strategies. Indeed, when technologies are commercialized in partnership with holders of complementary assets, the alternative governance choices' varying degrees of organizational integration imply varying degrees of transaction costs. In particular, since the sale of the company to (or merger with) incumbents implies that there exists a combination of value chains between the technology supplier and buyer, the transaction hazards arising from the cospecialization between R&D and downstream activities are reduced or become negligible. Therefore, cospecialization is expected to result in a greater payoff when firms engage in cooperation through the sale of the company relative to when firms engage in competitive strategies. This effect cannot be explained using a transaction cost perspective, since it is entirely driven by the impact of cospecialization on the gains from trade between technology suppliers and buyers. Indeed, an increase in cospecialization leads to an increase in the cost of acquiring complementary assets for the innovator, thus increasing the gains by combining the innovator and incumbent through a company sale or merger, without affecting the potential threat of holdup that can occur when two mutually dependent activities are performed by separate entities.

Hypothesis 1 (Ceteris paribus): Firms are more likely to commercialize new technologies that are cospecialized with the required complementary assets by selling the company to, or merging with, incumbents than to compete in the product market.

investments by holders of complementary assets in the equity of the technology holder, such as corporate venture capital investments, since we believe that they do not constitute a viable commercialization alternative to licensing, TJVs, or the sale of the company. In particular, corporate venture capital investments typically represent a way through which buyers gain a window on future rather than existing technologies that need to be commercialized [31], [68]. This is an attractive option, especially from the point of view of potential technology buyers [66]. Its analysis, however, is beyond the scope of our analysis.

[6]This could be formally analyzed using the model for technology commercialization of Gans *et al.* [3]. Since both the cost to acquire the complementary assets (K) required to compete downstream and the transaction costs (c) associated with the alternative strategy of cooperation with incumbents are increasing in the cospecialization between the technology and complementary assets, the net effect on the incentives to cooperate for the startup—characterized by equation (A4) of their article—is ambiguous.

A comparison of the payoffs from alternative cooperation strategies, including licensing agreements, TJVs, and mergers, allows us to identify the effect of cospecialized complementary assets on transactions costs. The potential gains from trade associated with cooperation with any given potential partner do not vary across cooperative commercialization strategies. Therefore, holding constant the partner's complementary assets, the choice of the governance structure of the partnership will only depend on the degree of transaction costs associated with the alternatives. In particular, new technologies requiring a relatively higher cospecialization between R&D and downstream activities are more likely to be commercialized using governance structures characterized by higher degrees of organizational integration with partners. This is due to the fact that cospecialization requires stronger coordination and relationship-specific investments between partners, which increases the appropriability hazards associated with less integrated organizational forms such as licensing or a TJV, thus reducing the attractiveness of these options when compared to a merger.[7]

Hypothesis 2: Ceteris paribus: Firms are more likely to commercialize new technologies that are cospecialized with the required complementary assets in partnership with incumbents by utilizing relatively more integrated organizational forms, such as selling the company to, or merging with, incumbents, rather than forming a TJV or licensing agreement.

2) Ownership and Strength of Downstream Complementary Capabilities: Complementary assets affect the payoffs to alternative commercialization strategies through yet another distinct channel. Specialized or cospecialized complementary assets tend to be unique and hard to acquire in the markets, develop from the interaction of people from different parts of a firm's organization, and are built over long periods of time [32], [37]. As such, they constitute firm-level downstream complementary capabilities that are valuable, rare, and difficult to imitate, and which provide a source of sustainable competitive advantage [37], [38]. Systematic empirical evidence to date suggests that owning the complementary manufacturing, marketing, and service capabilities required to commercialize an innovation is one of the most effective means of appropriating returns from an innovation across a wide range of manufacturing industries [28].

Since strong downstream complementary capabilities protect the innovator from being imitated by direct competitors in the product market, they reduce the potential gains from any form of cooperation. Indeed, a lower threat of imitation translates into higher expected market power for the innovating firm when competing autonomously, thus reducing the gains from preserving the market power of incumbents when partnering. Innovators with strong, downstream, complementary capabilities also need to incur lower sunk investments to compete in the product market; thus, the gains they might receive from cooperating with incumbents are further reduced.

The reduced incentives to cooperate induced by strong downstream complementary capabilities may be offset by a reduced threat of knowledge expropriation during negotiations associated with cooperative solutions [37]–[39]. Cooperation between a technology buyer and supplier requires disclosure of critical knowledge that may or may not be protected by IPR. When knowledge leakages occur, the risk of expropriation increases [5]. Under these conditions, mechanisms of appropriability, such as a firm's ownership of downstream complementary capabilities, have increased value. The transaction costs involved in drafting contracts that minimize the risks of knowledge spillovers decrease when the innovating firm has strong downstream complementary capabilities, since such a firm is less concerned about the misappropriation of valuable knowledge.

As for the case of cospecialization, the previous discussion suggests that the effect of downstream complementary capability on the incentives to cooperate with incumbents will be, *ex-ante*, ambiguous. However, comparing the decision to compete to the decision to engage in specific forms of cooperation highlights conditions under which such ambiguity can be clarified. In particular, we argue that since a merger with incumbents implies a combination of value chains of the technology supplier and buyer, the threat of expropriation arising from knowledge spillovers during a deal's negotiations is reduced or negligible. As such, firms that have strong downstream complementary capabilities are expected to see smaller payoffs from cooperation through a merger than if they engaged in product market competition. This effect can be explained only by going beyond transaction cost economics, since the effect is driven by a decrease in the gains from trade. Indeed, stronger downstream complementary capabilities increase the appropriability of innovation rents when competing and decrease the cost of acquiring downstream complementary assets for the innovator. Both of these effects tend to *decrease* the gains from trade that could be obtained by combining the innovator and incumbent within a new firm through a company sale or merger.

Hypothesis 3: Firms with strong downstream complementary capabilities are less likely to commercialize new technologies by selling the company to, or merging with, incumbents, than by competing in the product market.

Finally, we argue that ownership of downstream capabilities increases the payoffs from less integrated strategies among the alternative cooperative solutions. This result is entirely driven by transaction cost considerations. As previously discussed, the transaction costs associated with less integrated organizational forms, such as licensing and TJVs, decrease as the innovating firm's downstream complementary capabilities increase. This is not the case for the integrated solutions, such as M&A.[8] We, therefore, formulate the following hypothesis.

[7]The impact of cospecialization on the attractiveness of licensing relative to a TJV depend on the assumptions about how transaction costs related to these two organizational forms respond to cospecialization. In some cases, increasing cospecialization may increase licensing transaction costs at a faster pace than a TJV. In other cases, transaction costs may rise fast enough to decrease the organizational advantage for both modes, favoring mergers among the cooperative solutions.

[8]Note that downstream complementary capabilities are only one mechanism to appropriate innovation rents [28]. In particular, firms can appropriate innovation rents through strong IPR [1]–[3], [5]. The literature has shown that a comparison across different alliance forms, contract based solutions such as licensing are preferred to hybrids such as JVs [35], [36]. We extend this analysis by examining the role of downstream complementary capabilities and by broadening the spectrum of external commercialization options to include mergers. Although we do not focus on the role of IPR, we will control for their effect in the empirical analysis.

Hypothesis 4: Firms with strong downstream complementary capabilities are more likely to commercialize new technologies in partnership with incumbents by utilizing relatively less integrated organizational forms, such as licensing or a TJV, rather than selling the company to, or merging with, incumbents.

III. Data and Measures

The analysis in this paper relies on six datasets covering firm patents and trademarks, merger and acquisition activity, licensing and TJVs, new product introductions, and survey data on the nature of complementary assets. In this section, we describe the origins of each of these datasets.

Because our intent is to examine a large, cross-industry set of firms possessing new technologies that need to be commercialized, the firms we studied were chosen for their public record of sustained, successful technological innovation. Patent information was used to establish the firms' inventiveness. We refer to this database as the Chi Research-Small Business Administration (SBA) patent database [25]–[27]. The criterion for inclusion in this database is that a firm had 15 or more USPTO patents issued between 1998 and 2002. In identifying these companies, all establishments and subsidiaries were unified to the ultimate parent company; their patents counted toward the parent firm's patent count. Company structures were unified using sources such as the company's website, Who Owns Whom, Mergent, and CorpTech, in order to discern whether the company is a subsidiary and if it owns any other companies. To be included, an organization had to be independent, for-profit, not bankrupt, not a TJV, and not foreign owned during the first half of 2003 when the data were collected. The population of independent U.S. firms with more than 15 patents issued between 1998 and 2003 encompassed 1270 firms. Of these, 516 (40%) were small firms with less than 500 employees and 15 were of unknown size [26]. Thus, all U.S. SMEs with a strong patent record are included. In this study, we further restricted the analysis to the 1048 firms with primary activity in the manufacturing sector. The final set of sample firms was further reduced to 549 firms, due to our analysis being conditional on firms having at least one of the technology commercialization strategies considered.

For small firms, being granted 15 new patents in a four-year window is an exceptional achievement. A lower threshold would expand the set of firms examined, bringing in both more small firms and also less technologically intensive large firms. However, limiting the number of firms in the study to those with 15 patents in a four-year window was necessary to ensure accurate firm identification. In particular, the assignee information text on each patent must be connected with an extant company. Although this connection is trivial in many cases (a large number of IBM's patents are indeed assigned to "IBM"), a great deal of work is ultimately required to account for mistakes, variations, and ever-changing corporate structures in order to produce a database that accurately represents corporate patent ownership. Furthermore, the high volatility among SMEs, which are acquired or disappear regularly, means that a great deal of work must be done to ensure that the patenting entities are currently in business and independent. Ignoring this point would compromise the integrity of the results [40].

Once we identify the patents of our focal firms, we assign the patents to product industries using each patent's primary technological class and the patent-industry concordance developed and maintained by the United States Patent and Trademarks Office (USPTO).[9] The USPTO concordance links each patent class to one or more of 57 industries, or sectors, using a two- to four-digit SIC, that are expected to produce the product designed by the patent or use the new patented processes in the manufacture of their products. This concordance allows us to assign patents to the SIC industry representing the main activity of the transaction and to provide measures that proxy for technology characteristics at the transaction level.

It was considerably easier to obtain the rest of the data, which was supplied at the firm level. Information on licensing, TJVs, and M&A from the years spanning 1996 through 2002 was obtained from the SDC Platinum database available from Thomson Reuters. This database covers approximately 672 000 global M&As and alliances from 1985 to the present. The information supplied by this database was collected from news sources, SEC filings and the filings of SEC's international counterparts, tender offers, annual reports, trade publications, wires, and proprietary surveys of investment banks, law firms, and other advisors.

Data on whether our sample firms introduced new products into the market during the study period are collected from Promt (Predicasts Overview of Markets and Technology), a database from Gale that classifies information from nearly 1000 business and trade journals, industry newsletters, newspapers, market research studies, news releases, and investment and brokerage firm reports. Promt classifies articles into several categories of events, including new product introductions. It also reports detailed information on the SIC code of the product. The use of literature-based indicators of innovation has been pioneered by Pavitt *et al.* [41], and further employed by Acs and Audretsch [42] and Kleinknecht and Reijnen [43]. The Promt database has been extensively used in the literature [44]–[46].

To measure the strength of a firm's downstream complementary capabilities, we obtained trademarks from the USPTO CASSIS Trademarks BIB database. Employment data were obtained from companies' websites, Who Owns Whom, Mergent, Dun & Bradstreet, Corptech, and SEC filings. The firms' primary activities were identified based on a variety of criteria, including their activity descriptions, reported SIC (standard industry classification) codes, and the technological classes of their patents.

Our study is unusual for the breadth of its coverage. Most studies of commercialization are undertaken on a much more

[9] An excerpt of this report is available at http://www.uspto.gov/go/taf/brochure.htm. P. Harrison from the USPTO (Paul.Harrison@uspto.gov) provided us with the decision rules used for the concordance: "1) Determine if patents in a USPCS subclass are product, apparatus and/or process. 2) If product, determine type of establishment that would be engaged in producing that type of product. 3) If apparatus, determine type of establishment that would be engaged in producing that type of apparatus. 4) If process, determine whether process more closely related to the product of that process or apparatus used in the process then classify accordingly. 5) If unable to determine, then place in all possible SIC categories."

TABLE I
DESCRIPTIVE STATISTICS FOR INDEPENDENT VARIABLES

	Mean	Standard Deviation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1 Cospecialized comp. assets (industry of transaction)	-0.841	0.347	1																				
2 Downstream compl. capab. (firm in industry of transaction)	-5.996	1.907	0.00	1.00																			
3 Patents (firm in industry of transaction)	1.024	1.659	*-0.12*	*0.09*	1.00																		
4 Forward citations (firm in industry of transaction)	1.769	2.632	*-0.12*	*0.06*	*0.98*	1.00																	
5 Backword citations (firm in industry of transaction)	0.956	1.274	*-0.09*	*0.08*	*0.80*	*0.87*	1.00																
6 Science linkages (firm in industry of transaction)	0.278	0.581	*-0.11*	*0.08*	*0.55*	*0.58*	*0.62*	1.00															
7 Employees (firm)	2.647	1.564	*-0.04*	*0.32*	*0.36*	*0.33*	*0.30*	*0.18*	1.00														
8 Age (firm)	3.812	0.957	0.02	*0.29*	*0.17*	*0.14*	*0.18*	*0.10*	*0.60*	1.00													
9 Public (firm)	0.889	0.314	*-0.04*	*0.05*	*0.19*	*0.20*	*0.18*	*0.11*	*0.30*	*0.05*	1.00												
10 Primary activity is in Electronics (firm)	0.248	0.432	*-0.05*	*-0.20*	*0.07*	*0.06*	*-0.08*	*-0.08*	*-0.26*	*-0.34*	*0.07*	1.00											
11 Primary activity is in Chemical-Pharmaceuticals (firm)	0.173	0.379	-0.02	*0.10*	*0.08*	*0.08*	*0.19*	*0.39*	*0.08*	*0.18*	*0.09*	*-0.26*	1.00										
12 Primary activity is Chemical-Pharmaceuticals (transaction)	0.154	0.361	-0.03	*0.04*	0.03	0.02	*0.10*	*0.34*	*0.06*	*0.16*	*0.05*	*-0.24*	*0.65*	1.00									
13 Primary activity is Electronics (transaction)	0.325	0.468	*-0.05*	*-0.19*	*0.11*	*0.11*	-0.03	*-0.10*	*-0.16*	*-0.24*	*0.06*	*0.59*	*-0.30*	*-0.30*	1.00								
14 Prior JV with partner	0.006	0.078	*-0.05*	*0.05*	0.03	*0.04*	0.03	*0.05*	0.01	*-0.05*	0.01	-0.03	0.01	-0.03	0.02	1.00							
15 Prior licensing with partner	0.009	0.097	*-0.06*	0.03	*0.08*	*0.09*	*0.10*	*0.10*	*0.09*	*0.07*	0.02	*-0.06*	*0.06*	0.04	*-0.05*	-0.01	1.00						
16 Partner's stock of trademarks	0.124	0.603	*-0.08*	0.03	*0.10*	*0.12*	*0.15*	*0.12*	0.03	-0.01	0.03	*-0.05*	*0.05*	0.03	*-0.04*	*0.21*	*0.28*	1.00					
17 Partner's age	6.937	24.274	*-0.10*	*0.07*	*0.14*	*0.17*	*0.20*	*0.18*	0.01	-0.02	0.03	*-0.08*	*0.12*	*0.07*	*-0.08*	*0.21*	*0.28*	*0.63*	1.00				
18 Partner is public	0.092	0.290	*-0.13*	*0.08*	*0.15*	*0.19*	*0.22*	*0.22*	0.02	*-0.05*	0.02	*-0.05*	*0.11*	*0.04*	*-0.06*	*0.23*	*0.26*	*0.52*	*0.63*	1.00			
19 Partner is foreign (non US)	0.065	0.247	*-0.10*	*0.07*	*0.15*	*0.19*	*0.19*	*0.18*	0.02	0.01	0.03	*-0.04*	*0.09*	*0.05*	*-0.05*	*0.09*	*0.17*	*0.24*	*0.54*	*0.49*	1.00		
20 Partner's primary activity is in Pharmaceuticals	0.019	0.135	*-0.07*	*0.04*	0.01	0.03	*0.05*	*0.29*	*-0.09*	*-0.09*	0.00	*-0.08*	*0.25*	*0.18*	*-0.10*	*0.09*	*0.06*	*0.15*	*0.24*	*0.34*	*0.17*	1.00	
21 Partner's primary activity is in Electronics	0.027	0.161	*-0.08*	0.03	*0.12*	*0.16*	*0.13*	*0.06*	0.01	-0.02	*0.05*	*0.04*	*-0.04*	*-0.04*	*0.09*	*0.12*	*0.14*	*0.28*	*0.34*	*0.39*	*0.34*	-0.02	1.00

Note: Correlations in italics are significant ($p < 0{:}05$). Total number of observations = 2952. Number of unique firms = 549. Year dummy variables are not included in the table.

restricted set of firms within one industry, usually in either the biotechnology or the information technology industry. As argued previously, the broad set of firms is critical for our objective, since one of the main variables of interest (the nature of complementary assets) is expected to vary significantly across industries.

Information about the cospecialization between innovation and downstream activities such as manufacturing and marketing comes from the 1994 CMS on industrial R&D [28], which contains cross-sectional data on a representative sample of R&D laboratories that conducted R&D in manufacturing industries as part of a manufacturing firm. Responses were aggregated at the—three-to-four-digit SIC level and linked to the corresponding primary activity of the transaction. Although the timing of the survey precedes our sample period, existing evidence suggests that the importance of complementary assets or patent protection in profiting from innovation changes slowly over time, at least at the industry-level [28], [39].[10]

After merging datasets, selecting the technology deals of the focal firms, and excluding observations with missing values, we obtain a final sample of 2952 transactions related to the 1996–2002 period. Of the transactions, 86% represent vertical integration events and 14% represents partnering events. Of transactions registered as partnering events, 34% are classified as licensing deals, 58% are TJVs, and 8% represent mergers. The final sample comprises 549 firms, or about 44% of the population, all of which operate in the manufacturing sector and underwent at least one type of transaction during the sample period.[11] The average number of transactions per firm is 5.4. The median number of transactions per firm is 3, while the standard deviation is 6.7.[12] The following section describes in detail the variables used in the analysis, while descriptive statistics and correlations for the independent variables are presented in Table I.

A. Dependent Variable: Technology Commercialization Strategy

To test our hypotheses, we use an unordered discrete choice variable, *Technology Commercialization Strategy*, which corresponds to cases of vertical integration, licensing, TJV, and merger. A transaction represents an instance of vertical integration in the product market when the Promt database classified a press release as one signifying the launch of a new product. Transactions on cooperative commercialization strategies are similarly based on news announcements and gathered through the Thomson Reuters SDC Platinum database.[13]

[10]For example, survey evidence on the change in the relative importance of patents in appropriating the returns from innovation between the mid 1980s and the mid 1990s, a period that witnessed a pro-patent legal and policy shift, suggests that the effectiveness of patent protection has increased only "modestly" over time [28].

[11]For robust inference, we cluster standard errors by firm due to the potential autocorrelation of errors across observations related to the same firm across multiple transactions during the study period.

[12]Included in the top ten list of firms with the largest numbers of transactions we find P&G, Motorola, 3M, HP, Texas Instruments, Parker-Hannifin, Honeywell, Sun Microsystems, and Caterpillar.

[13]A transaction is coded as a *technology licensing* deal if the agreement was classified as such by the SDC database and if the focal firms represent the seller. SDC does not code whether participants buy or sell technology, although this information can be identified through the deal synopsis. A transaction is coded as a *technological JV* if two conditions are met: 1) the deal is defined as a JV by the SDC. These are cooperative business activities formed by the participants with one or more separate organizations for strategic purposes creating an independent business entity and allocating ownership, operational responsibilities, and financial risks and rewards to each member while preserving their identity and autonomy. The new entity might be newly formed or it might be a combination of its members' pre-existing units and/or divisions. 2) The objective of the JV is to exploit technologies owned by our focal firms. In many cases, this objective is identified from the SDC synopsis. For both licensing and JVs, we complemented our search using online archival news if the synopsis did not state whether the focal firm was the licensor or whether the objective of the JV was to exploit the focal firm's technologies. An event is classified as a *sale of companyor merger* when the majority interest in the technology supplier is acquired by another company or the technology supplier merged with another firm, as reported by the SDC database. From the Thomson Reuters database, we selected transactions where the focal firms represented the target of an M&A transaction classified by SDC as: "Merger" ("A combination of business takes place or 100% of a company is acquired"); "Acquisition of Assets" ("All assets of a company, subsidiary, division, or branch are acquired"); or "Acquisition of Majority Interest" ("Acquirer must have held less than 50%, and be seeking to acquire 50% or more, but less than 100% of the target company's stock").

Each transaction defines a *primary activity*. The Promt database classifies articles by assigning a four-digit SIC code for the new product announcement. Similarly, in the case of licensing and TJVs, the SDC assigns a four-digit SIC industry code to the primary activity of the agreement. For the case of company sale or merger, we follow the convention and use the primary four-digit SIC code of the target firm (the focal technology supplier) as the primary activity of the transaction.

B. Main Independent Variables

1) Cospecialized Complementary Assets: It is difficult to measure the degree of cospecialization between innovation and downstream complementary assets required for technology commercialization. As Teece [32] suggests, cospecialization is associated with the interaction and learning over time of people from different parts of a firm's organization. This interaction and learning is especially relevant for the case of R&D, which typically requires organizationally embedded interpersonal and interfunctional activities [48]. Moreover, the potential bilateral dependence between R&D and downstream activities typically requires proximate, tight, and frequent communication links [32]. Therefore, the CMS on industrial R&D provides a measure for the frequency of face-to-face interactions between personnel from R&D and production, and R&D and marketing, based on a four-point Likert scale.[14]

In order to build our measure, we first construct a variable, which takes the value of 1 if R&D personnel interact daily (e.g., above the median in the CMS survey) with manufacturing or marketing personnel at the R&D lab level. We then compute the four-digit SIC average of the dummy and match it to the primary activity of the transaction. Our measure thus reflects how hard it is to separate the upstream and downstream activities required for technology commercialization in the primary industry of the transaction.

A virtue of this measure is that it reflects the mutual dependence between the focal technologies and the complementary assets required for their final commercialization in the product markets.[15] However, it is suboptimal to use industry rather than technology-level data for a transaction-specific concept like cospecialization. To the extent that this variable captures unobserved industry-level effects that are not captured by our industry fixed effects, the interpretation of the results could be muddled. Our experiments that use more disaggregated industry fixed effects as controls suggest that our qualitative conclusions remain unchanged.

2) Downstream Complementary Capabilities: We measure the firm's downstream complementary capabilities in the primary activity of the transaction using the number of trademarks owned by the firm that were still active as of December 2002, as indicated in the USPTO CASSIS Trademarks BIB database. According to the USPTO, a trademark "identifies and distinguishes the source of the goods or services of one party from those of others." Trademarks can be thought of as an important measure of an organization's marketing capability [46].[16] Indeed, firms would not be able to sustain a trademark without holding a distinctive identity in the markets for their products [46], [50].

Marketing capabilities are complementary to technological capabilities, in the sense that the marginal payoff of technology is greater if the firm also has greater marketing capabilities [49]. Prior research has also identified marketing capabilities to be important specialized assets for commercialization, in the sense that the capabilities are not readily accessed through the market [51]. Finally, trademarks enhance a firm's appropriability by protecting its investments in marketing and other intangibles such as brand and reputation [46]. In turn, brand-capital is characterized by asset-specificity, since it is difficult to redeploy in alternative uses or by alternative users [52].

Our measure first counts new trademark registrations per year and then cumulates them to obtain a measure of the stock of downstream complementary capabilities. To match trademarks to the SIC code representing the primary activity of the transaction, we develop a concordance between the classification of goods and services under the Trademark Act and the SIC classification.[17] We divide the trademark stock by the corresponding stock of new registered trademarks obtained by the population of U.S. firms with more than 15 patents during the sample period in the primary SIC of the focal transaction. This normalization better captures the notion of capability. Our final measure of *Downstream Complementary Capabilities*, more than others, reflects multiple levels of analysis, as it measures a firm-level downstream complementary capability in the primary activity

We also excluded transactions classified as bankruptcy acquisitions. As previously discussed, we exclude spinoffs or the divestiture of a business division if such transactions do not result in the loss of majority control of the focal parent company. As such, companies that are a target of acquisitions during the study period loose independence and do not appear in the sample thereafter as participating in other licensing or JV transactions. We consider these deals as representing the sale of technology, since our sample is based on innovators who have obtained at least 15 patents during the study period. From this point of view, we are adopting a slightly more conservative threshold than previous studies to define technology-based M&A [24], [47]. These transactions meet our central selection criteria because they reflect technology exploitative commercialization strategies which imply the transfer of ownership of new technology.

[14]Respondents were asked: "How frequently do your R&D personnel talk face-to-face with personnel from the 'Production,' 'Marketing or Sales,' and 'Other R&D units' functions?"

[15]In the CMS survey, R&D lab managers answered questions with reference to the "focus industry" of their lab, defined as the principal industry for which the unit was conducting its R&D. Such "focus industry" was then assigned a four-digit SIC code, which we then match to the SIC code of the transaction (product launch, alliance, or merger). The response on the linkages across activities in the value chain will, therefore, connect multiple levels, e.g., the technology-level (R&D activity) and industry-level (manufacturing and marketing activities).

[16]Arora and Nandkumar [49] use the number of sales executives as a measure of a startup's marketing capability and report a significant correlation between their measure and the number of trademarks owned by the startups in the software security industry.

[17]Goods and services protected by trademarks are classified into 42 international classes, most of which can be linked to the two-digit SIC industry classification level (http://www.uspto.gov/trademarks/notices/international.jsp). For example, the first three classes are "Chemicals," "Paints," and "Cosmetics and cleaning preparations," which can be assigned to SIC 28 (Chemicals and Allied Products). For the trademark classes that can be assigned to multiple two-digit SICs we used a "fractional count" method analogous to the way the USPTO counts patents by SIC codes for their "Patenting Trends in the United States" reports). For example, since the class "Electrical and scientific apparatus," can be assigned to two SIC industries ("Electronic & Other Electric Equipment" and "Instruments and Related Products"), we assigned 50% of trademarks to each of the two corresponding SICs. The concordance is available upon request.

of the focal transaction. This fact is not necessarily a weakness, since it allows us to integrate transaction cost with the influences of firm capability on organizational governance.

C. Control Variables

Patents: We control for the average yearly number of patents granted to the technology supplier in the primary activity of the focal transaction during the five-year window preceding the year of the transaction.

Patents may have offsetting effects on the choice of cooperative commercialization mode. On one hand, firms with more patents have more technologies to commercialize. It has been shown that cooperative agreements involving more technologies tend to be governed through increasingly hierarchical governance forms [35]. On the other hand, patent protection mitigates the appropriability hazards of contractual forms of alliances, thus reducing transaction costs and, therefore, favoring relatively less hierarchical alliances.

Forward patent citations: We control for the value of different patents through forward citations. Forward citations are the citations made to a focal patent by other patents that are issued after the focal patent's grant. We compute the average of the forward citations of the typical patent granted to the technology supplier in the primary activity of the focal transaction during the five-year window preceding the year of the transaction. Previous studies have shown that patents with a greater number of forward citations tend to have a greater likelihood of licensing [53] or a greater probability of being externally sourced [12].

Backward patent citations: As a control for the degree to which technology is more radical, we include the average number of citations to prior patents associated with the patents granted to the focal firm in the primary activity of the transaction during the five-year window preceding the year of the transaction.

Science linkages: Knowledge becomes more costly to transfer when it is less codified and more tacit [54]. Thus, contractual commercialization strategies such as licensing are more likely to be effective when technologies are more easily codified [2]. We include the measure of science linkages available from the Chi Research-SBA patent database [55]. This is computed as the average number of patent references to prior scientific papers of the focal firm's patents related to the primary activity of the transaction during the five-year window preceding the year of the transaction.

Other transaction-level characteristics: We include two broad dummy variables related to the primary activity of the transactions, which correspond to the chemical and electronic sectors (SIC = 28 and SIC = 36). We also include dummies associated with the year of the transaction.

Focal firm controls: Our data allow us to measure the characteristics of the technology supplier firm. In particular, we include overall firm size (determined by the number of employees), whether the company is public, and the age of the firm. We also include two broad industry dummy variables related to the chemical–pharmaceutical–biotechnology group, and one broad industry dummy for the computer-electronics group, measured at the level of the primary industry of the technology supplier. We use broad industry dummies to avoid collinearity with other industry level variables and to facilitate identification. However, results are qualitatively robust to the inclusion of more disaggregated industry dummies.

Partner firm controls: We include a set of variables that are only defined for the cooperative commercialization modes. In particular, as a measure of the partner's downstream complementary capabilities, we include the cumulative number of new trademark registrations owned by the partner that were still active as of December 2002 according to the USPTO CASSIS Trademarks BIB database. We also include a dummy for whether the partner had made a licensing or a TJV agreement with the innovating firm prior to the date of the focal transaction. Finally, we include dummy variables measuring the partner's age, the location of its headquarters, whether it is public, and whether it has primary activity in electronics (SIC = 36) or in pharmaceuticals (SIC = 283).[18]

IV. Estimation and Results

A. Method

To test our hypotheses, we employ the multinomial logit model and, as a robustness test, a test of the independence of irrelevant alternatives (IIA) assumption on which the multinomial logit is based. The multinomial logit models assume that, given a choice (Y) between M alternatives, the probability that firm i will chose alternative $j = m$ (with $j = 1, \ldots, M$) is

$$\Pr(Y_i = m) = \frac{e^{V_{im}}}{\sum_{j=1}^{M} e^{V_{ij}}}. \tag{1}$$

V_{im} represents the payoff to firm i from choice m, as well as the component of payoffs observed by the econometrician. This formulation is obtained assuming that the unobserved component of the payoffs from each choice is independent identically distributed across choices, with Type 1 extreme value distributions, and that the component is observed by the firm but not the econometrician [56]. To test our hypotheses, we define $M = 4$, with $j = 0$, if the transaction is classified as "vertical integration"; $j = 1$ if classified as "licensing"; $j = 2$ if classified as "TJV"; and $j = 3$ if classified as "sale of company or merger."

This model allows us to identify factors driving the payoffs from each organizational form relative to the base outcome. The normalized model can be obtained by dividing both the numerator and denominator of (1) by $\exp(V_{im})$. We also substitute in the denominator of (1) $V_{ij} = \boldsymbol{X\beta} + \boldsymbol{Z\gamma}$, with $\boldsymbol{X}$ being a matrix of exogenous variables that are defined for all alternatives and $\boldsymbol{Z}$ being a matrix of partner-level exogenous variables that are only defined for the cooperative commercialization cases. We perform a constrained estimation of the multinomial logit setting $\gamma = 0$ when $j = 0$.[19] We perform the estimation by

[18]For robustness, we also experimented with a dummy variable measuring whether focal firm and partner operate in the same industry (defined at the two-digit SIC level). The control was not significant and results were unchanged. We, therefore, dropped such control variable from the empirical analysis.

[19]We first defined the constraints using Stata "constraint" command. Then, estimated the model using "mlogit," specifying the constraint() option.

choosing different base outcomes and determine the effect of the main variables of interest according to the relative attractiveness of each pair of choices. Finally, we use the logarithms of all right-hand-side continuous variables and the $\log(1 + x)$ transformation, a specification that provides a better fit to the data due to the skewness of some of the dependent variables.

B. Results

1) Cospecialized Complementary Assets: The estimate presented in the first row of Table II (column 1) suggests that, consistent with hypothesis 1, high cospecialization tends to increase the gains from trade of a merger between technology supplier and buyer without affecting transaction costs, thus making the payoffs from competing in the product market less than those of merging. The related coefficient (column 1) is indeed negative and significant at the 1% confidence level. Such gains from trade are due to the high cost of acquiring the required complementary assets for the technology supplier when these are cospecialized.

Consistent with hypothesis 2, the results show that cospecialization between innovation and downstream complementary assets significantly increase the relative returns to more integrated commercialization forms (see columns 4–6 in Table II). These effects are significant at conventional levels.

2) Downstream Complementary Capabilities: The evidence is consistent with our expectations that gains from trade considerations lead innovating firms to prefer downstream competition to a merger with incumbents when firms own the required downstream complementary capabilities. This is reflected by the positive coefficient (significant at the 10% confidence level) presented in the second row of column 1 (see Table II), which supports hypothesis 3.

We find instead that firms with strong downstream complementary capabilities, as indicated by their possession of a greater number of trademarks relative to competing innovators, favor less integrated commercialization strategies. Payoffs from a merger are less for innovating firms with downstream complementary capabilities in the focal industry of the transaction than payoffs from a TJV or licensing, with all the effects significant at conventional levels. Overall, these results provide strong support for hypothesis 4. Since we compare payoffs from cooperative commercialization solutions, the potential gains from trade with the partner will not vary across choices and results are entirely driven by transaction cost considerations. In particular, our results suggest that downstream complementary capabilities, such as marketing capabilities, are more valuable under cooperative solutions characterized by greater contractual hazards.

Notice that high cospecialization between innovation and downstream complementary assets or weak complementary capabilities have significantly higher payoffs from competition than from licensing or forming a TJV (see columns 2 and 3 of Table II). This is not surprising, since licensing and TJVs tend to be characterized by a higher degree of transaction costs than mergers, due to the greater threat of opportunism and imitation associated with these strategies. These costs condition the effect of complementary assets. We interpret these results to suggest that the increase in transaction costs associated with cospecialization or weak downstream complementary capabilities dominates, on average, the increase in the gains from trade derived from partnering with holders of costly complementary assets through a licensing agreement or forming a TJV.

Finally, Table III provides the economic significance of these effects. Indeed, while the absolute level of payoffs is not identified, the normalization of payoffs relative to a base outcome in the multinomial logit model allows us to identify the probability of each choice and the related marginal effects of the dependent variables. The effect of cospecialization on the probability of competition is positive, large, and highly significant. A 1% change in the degree of cospecialization is associated with a 5.4% increase in the probability that the focal company chooses a competitive commercialization strategy rather than a cooperative strategy. A 1% change in the degree of cospecialization is associated with a 1.4% reduction in the probability of licensing and a 1.7% reduction in the probability of forming a JV, effects weakly significant at 10%. A 1% increase in the degree of cospecialization is associated with a 2% increase in the probability that the focal firm chooses to merge, with the effect being highly significant (at 1%). In general, cospecialization tends to increase the probability of commercialization based on vertically integrated modes of commercialization.

The effects of downstream capabilities are not as great. A 1% change in the strength of downstream capabilities is associated with a 0.8% decrease in the probability that the focal company chooses a competitive strategy, weakly significant at the 10% level. The effect on the probability of a merger is small (0.2%), but significant at the 5% level. Conversely, the elasticity of licensing and TJV w.r.t. downstream capabilities are positive (0.5% and 0.3%), although only licensing was found to be significant at conventional levels.

C. Robustness

We focus our robustness analysis on testing the sensitivity of the results to the potential violation of the IIA property of the multinomial logit model. The lack of independence of the error terms across choices would lead to wrong inferences concerning the effect of the examined variables on the relative attractiveness of different alternatives, because such inferences would critically depend on the alternatives under consideration.

Our data do not allow us to identify a model that relaxes the IIA assumption. To estimate a nested logit model would require data that vary across alternatives. Since we use primary data to develop measures of alliances, we do not have measures for counterfactuals such as the characteristics of the alternative that the focal firm did not chose, which a nested logit model requires to identify the parameters. However, we can test the sensitivity of the results to violation of the IIA property by estimating a series of multinomial logit models on a subset of choices. When unobserved components of the various alternatives are uncorrelated, the multinomial logit is equivalent to a nested logit model [5, p. 509]. The basic idea of this test is that, under the IIA assumption, we would expect to observe no systematic change in the coefficients estimated when excluding one of the outcomes from the analysis. This amounts to a Hausman test [57, p. 503]. The results of these tests, presented in Table IV, suggest that our main results are indeed robust.

TABLE II
MULTINOMIAL LOGIT RESULTS

	1 Payoffs from competition relative to merger	2 Payoffs from competition relative to licensing	3 Payoffs from competition relative to TJV	4 Payoffs from TJV relative to licensing	5 Payoffs from merger relative to licensing	6 Payoffs from merger relative to TJV
Main Variables						
Cospecialized complementary assets	-3.137 **	2.224 ***	1.405 ***	1.333 **	4.915 ***	4.166 ***
(of focal activity of transaction)	*1.275*	*0.465*	*0.263*	*0.608*	*1.042*	*0.919*
Downstream complementary capabilities	0.345 *	-0.476 ***	-0.071	-0.498 ***	-0.762 ***	-0.333 **
(of focal firm in the primary activity of transaction)	*0.200*	*0.071*	*0.087*	*0.111*	*0.161*	*0.170*
Controls: Focal firm in the primary activity of transaction						
Patents	1.135	2.757 ***	1.300 ***	2.451 ***	1.821 **	0.786
	0.944	*0.530*	*0.272*	*0.679*	*0.770*	*0.722*
Forward citations	0.037	-2.280 ***	-1.121 ***	-2.027 ***	-2.315 ***	-1.375 ***
	0.659	*0.434*	*0.216*	*0.553*	*0.588*	*0.464*
Backword citations	-2.227 ***	0.878 **	-0.044	1.404 ***	2.751 ***	1.821 ***
	0.612	*0.345*	*0.177*	*0.424*	*0.579*	*0.493*
Science linkages	0.303	-0.593 **	0.041	-0.994 ***	-0.578	-0.104
	1.260	*0.274*	*0.179*	*0.312*	*0.601*	*0.583*
Controls: Focal firm level						
Employees	1.260 ***	0.249	0.121	0.019	-0.903 ***	-1.079 ***
	0.417	*0.189*	*0.102*	*0.232*	*0.347*	*0.296*
Age	0.293	0.805 ***	-0.160	1.351 ***	0.583	-0.390
	0.386	*0.252*	*0.192*	*0.359*	*0.369*	*0.329*
Public	3.096 ***	0.323	0.103	0.649	-2.359 ***	-2.328 ***
	0.768	*0.576*	*0.401*	*0.945*	*0.848*	*0.732*
Primary activity is in Electronics	1.365	-0.314	0.413	-0.837	-1.661 **	-0.953
	1.138	*0.460*	*0.308*	*0.700*	*0.839*	*0.799*
Primary activity is in Chemical-Pharmaceuticals	1.187	-0.811	-0.489	-0.420	-2.091 *	-2.016 *
	0.932	*0.536*	*0.455*	*0.661*	*1.230*	*1.141*
Controls: Transaction level						
Primary activity is Chemical-Pharmaceuticals	0.123	0.059	-0.329	0.272	-1.005	-1.234
	0.970	*0.546*	*0.366*	*0.686*	*1.396*	*1.230*
Primary activity is Electronics	2.507 ***	1.259 ***	0.499 **	1.240 **	-0.726	-1.517 **
	0.856	*0.382*	*0.217*	*0.538*	*0.751*	*0.726*
Time dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Controls: Partner level						
Prior licensing with partner				-1.793 **	-11.737 ***	-11.211 ***
				0.820	*1.146*	*1.214*
Prior joint venture with partner				4.302 ***	-5.683 ***	-10.254 ***
				0.641	*1.250*	*0.835*
Partner's stock of trademarks				0.624 ***	-0.529	-0.669
				0.205	*0.482*	*0.461*
Partner's age				0.012 **	0.019 *	0.013
				0.005	*0.011*	*0.011*
Partner is public				1.734 ***	2.171 **	2.363 **
				0.399	*0.936*	*1.030*
Partner is foreign (non US)				3.041 ***	0.689	-1.409 *
				0.373	*0.874*	*0.863*
Partner's primary activity is in Pharmaceuticals				-0.579	-1.797	0.284
				0.820	*1.876*	*1.543*
Partner's primary activity is in Electronics				-0.313	-1.265	-0.279
				0.542	*1.433*	*1.365*

Note: 1) The table presents results obtained by estimating a multinomial logit model subject to the constraints that the coefficients of the partnership-level variables are set to zero in the competition equation. 2) Standard errors robust to heterosckedasticity and clustered by firm (549 clusters) in italics. 3) ***, **,*: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels; 4) $N = 2952$. 5) Estimates of the intercepts are not included.

TABLE III
MARGINAL EFFECTS ON PROBABILITIES+ : MULTINOMIAL LOGIT MODEL

	Probability of competition	*Probability of licensing*	*Probability of joint venture*	*Probability of company sale or merger*
Cospecialized complementary assets	0.054 ***	-0.014 *	-0.017 *	0.020 ***
	0.012	*0.008*	*0.009*	*0.006*
Downstream complementary capabilities	-0.008 *	0.005 ***	-0.003	-0.002 **
	0.002	*0.002*	*0.002*	*0.001*

+: Change in the probabilities for one percentage change in the dependent variable. ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$. Standard errors robust to heteroscedasticity and clustered by firm are shown in italics.

TABLE IV
TESTING THE SENSITIVITY OF THE RESULTS TO THE IIA ASSUMPTION

	1	*2*	*3*
A: Excluding competition			
	Payoffs from TJV relative to licensing	Payoffs from merger relative to licensing	Payoffs from merger relative to TJV
Cospecialized complementary assets	-0.042	21.109 *	21.150 *
	0.459	*12.454*	*12.457*
Downstream complementary capabilities	-0.163 **	-1.868 *	-1.705 *
	0.066	*1.248*	*1.248*
B: Excluding licensing			
	Payoffs from competition relative to merger	Payoffs from competition relative to TJV	Payoffs from merger relative to TJV
Cospecialized complementary assets	-2.979 ***	1.373 ***	4.128 ***
	0.865	*0.222*	*0.935*
Downstream complementary capabilities	0.327 *	-0.074 *	-0.451 **
	0.187	*0.043*	*0.216*
B: Excluding joint ventures			
	Payoffs from competition relative to merger	Payoffs from competition relative to licensing	Payoffs from merger relative to licensing
Cospecialized complementary assets	-2.707 ***	2.279 ***	4.970 ***
	0.828	*0.376*	*0.936*
Downstream complementary capabilities	0.255	-0.500 ***	-0.808 ***
	0.182	*0.069*	*0.196*
B: Excluding mergers			
	Payoffs from competition relative to licensing	Payoffs from competition relative to TJV	Payoffs from TJV relative to licensing
Cospecialized complementary assets	2.222 ***	1.404 ***	1.442 ***
	0.371	*0.220*	*0.467*
Downstream complementary capabilities	-0.474 ***	-0.071 *	-0.498 ***
	0.063	*0.042*	*0.071*

Note: 1) The table reports results related to our variables of interest obtained by estimating multinomial logit models using the benchmark specification presented in Table II on subsamples resulting from exclusion of each alternative. 2) Standard errors robust to heterosckedasticity and clustered by firm in italics. 3) ***, **,*: Significantly different than zero at the 0.01, 0.05, and 0.10 confidence levels.

V. Discussion and Conclusion

When it comes to technology strategy, it is vital to identify the key conditioning factors driving the choice of organizational governance form for technology commercialization. The literature suggests that the commercialization environment (particularly, the strength of appropriability, the nature of complementary assets, and the interplay of these two factors) is one of the key determinants of such decisions [2], [6], [38], [39] [58].

Although the role of IPR in driving these decisions is understood to a certain degree, the role of complementary assets is still controversial. While leading contributions in the markets for technology literature imply that specialized and cospecialized complementary assets should stimulate cooperative commercialization activities, our results suggest that this effect is critically conditioned by which organizational governance mode is chosen to enact the cooperative solution. In particular, selling the innovating company to holders of complementary assets mitigates the potential for holdup and opportunism associated with cospecialization, with the consequence that the payoffs from this strategy relative to competition increase with cospecialization due to the gains from trade that could be realized by avoiding the duplication of hard-to-acquire complementary assets. However, a detailed comparison of the effect of cospecialized complementary assets on the relative payoffs from alternative cooperative strategies reveals that cospecialized complementary assets favor mergers over licensing or TJVs. Indeed, holding constant the downstream capabilities differential between an innovating firm and its potential partners (and thus the potential gains from trade), cooperative strategies minimizing the higher transaction costs associated with cospecialization are preferred.

Our results also suggest that gains from trade considerations lead innovating companies with strong marketing capabilities and brand capital to compete in the product market rather than sell the company to holders of complementary assets. However, the payoffs from less integrated organizational forms (such as licensing or a TJV) are greater than merging when the innovating firm has greater marketing capabilities. We interpret this finding as suggesting that the value of downstream complementary capabilities increases when cooperation is characterized by more significant expropriation threats.

We believe that our approach contributes to a deeper understanding of technology commercialization strategy. We extend the appropriability and markets for technology literature to consider a broader set of technology commercialization choices that are characterized by different degrees of organizational integration. This allows us to analyze the impact of complementary assets within a well-established industrial organization framework [3], incorporating arguments from multiple strategic management perspectives. In particular, our unique dataset of technology-based firms provides evidence of stark differences in the impact of complementary assets on the payoffs from mergers versus vertical integration decisions and alliances.

We also provide empirical evidence for managers that highlights the conditions under which cooperative business commercialization models with different degrees of integration between partners tend to be preferred along the key dimensions of cospecialization, ownership, and the strength of downstream complementary assets such as marketing capabilities and brand capital.

Our study is subject to certain limitations. First, we analyzed the population of firms that had more than 15 U.S. patents between 1998 and 2002. Thus, the results may not be generalizable to startups with limited technical capability [27]. A second limitation is our use of public information to identify product launches and partnerships, which introduces a bias, as deals for small, private firms are less likely to be publicly announced. A third limitation of the study is that the analysis does not capture all the ways that a technology can be commercialized. As noted, we focus on a limited set of alternatives in order to study commercialization strategies used in the transfer of technology across firm boundaries, and that are used to access downstream complementary assets. Moreover, our cross-sectional data, mostly obtained from primary sources, do not allow us to estimate more general econometric models such as the nested logit, which allows us to treat the underlying choices as being nonsimultaneous and the unobserved components across payoffs to be correlated. Similarly, we cannot control for transaction-specific nor firm-specific unobserved heterogeneity. As such, the relationships analyzed in the paper should not be interpreted causally.

Despite these limitations, we believe that our holistic approach to studying technology commercialization is essential to forming a deeper understanding of the role of complementary assets in the innovating firm's search for the optimal organizational governance mode.

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