HOW MUCH YOU KNOW VERSUS HOW WELL I KNOW YOU: SELECTING A SUPPLIER FOR A TECHNICALLY INNOVATIVE COMPONENT

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How do firms select a supplier for an innovative component? Three literatures speak to this question. Transaction cost economics focuses on the value of internalization, the literature on inter-firm relationships on the value of past relationships, and the firm capabilities literature on the value of superior capabilities. Choosing a supplier means choosing a bundle of these characteristics—internal vs. external, amount of prior transactions, and capabilities—but no study has integrated all three characteristics, making it impossible to understand the trade-offs involved either theoretically or managerially. I propose and test a model integrating all three factors, allowing us to understand the trade-offs involved. I find that when uncertainty is low, the decision is made primarily on the basis of differences in technical capabilities. As uncertainty increases, prior relationships and a supplier being internal take on greater positive significance relative to the importance of technical capabilities. At extreme levels of uncertainty, the value of internal supply relationships becomes very high and past relationships lose their significance. While adherents of each literature have criticized the others for what they omit, this model moves beyond this mutual recrimination by incorporating the key concerns of each literature, setting the stage for future research that draws upon the strength of each. The model provides guidance for any situation where a firm must chose a partner under uncertainty. Lastly, it addresses the strategic question of how companies should organize in the long run to access the capabilities needed for competitive success. Copyright © 2004 John Wiley & Sons, Ltd.

INTRODUCTION

How do firms select a supplier for an innovative component? This question is critical because firms often seek to improve a product by incorporating innovative components, i.e., components that do not yet exist in their desired form. For example, a laptop computer manufacturer can

attempt to improve its computer by incorporating a larger, higher-resolution display than currently exists. However, it cannot buy the innovative display 'off the shelf.' Developing a new display will require a period of intense interaction between buyer and supplier. Thus, selecting the right supplier—possibly an internal supplier—is an important strategic decision.

Three literatures speak to the issue of supplier choice. Transaction cost economics (Williamson, 1975) focuses on the effect of some characteristic of the transaction, e.g., uncertainty, on the associated governance costs. It then asks how one aspect of the buyer–supplier relationship, internal vs. external, magnifies or diminishes that effect. A significant strand of the literature on inter-firm

relationships (e.g., Gulati, 1995; Uzzi, 1996) asks the same question, but looks at a different aspect of the buyer–supplier relationship: prior transactions. The literature on firm capabilities (Barney, 1991; Winter, 1987) points to the value of a supplier's technical capabilities.

Choosing a supplier means choosing a bundle of these characteristics: internal vs. external, amount of prior transactions, and technical capabilities. Of course, the supplier with the greatest technical capabilities may not be the supplier with which the buyer has the strongest relationship, but no study has integrated all three characteristics into a single model. This makes it impossible to understand the trade-offs involved from either a theoretical or managerial viewpoint. Transaction cost economics and the literature on inter-firm relationships inform us about the strength of the buyer–supplier relationship, but not how it is balanced against technical capabilities. The reverse is true of the firm capabilities literature. Also, neither transaction cost economics nor the inter-firm relationship literature can help us understand when a long-term relationship outweighs a hierarchical relationship with a supplier.

This paper proposes and tests a model that integrates all three factors in a single framework. This allows me to make three primary contributions.

First, the model provides a more complete, nuanced, and accurate understanding of how firms resolve the inevitable trade-offs between internalization, past relationships, and capabilities in a way that no one of the literatures can do in isolation. Doing so helps resolve some of the intransigent tensions between these three literatures.

From the viewpoint of transaction cost economics, much of the literature on firm capabilities suffers from a lack of attention to the potential for opportunism (Foss, 1996; Mahoney, 2001; Williamson, 1999). The firm capabilities literature argues that transaction cost economics ignores or underemphasizes differences in firm capabilities, such as their technical capabilities (Winter, 1988). The literature on inter-firm relationships has argued that transaction cost economics overlooks the fact that past transactions between the buyer and supplier may generate processes that alter the calculus for future transactions (Gulati, 1995; Ring and Van de Ven, 1994). Since a buyer will have a different history of interaction with each potential supplier, the expected costs of dealing with each supplier will differ.

Each of these concerns has some validity. The model I develop makes it possible to move beyond simply pointing out what each literature fails to consider. Rather, it incorporates the key concerns of each literature, recognizing that the relative importance of each will vary according to the situation under consideration. This responds to Denzin's (1989) call to bring diverse theories to bear on a phenomenon.

The paper's second contribution is to provide managers with a richer framework than previously existed to guide their selection of suppliers. The model helps answer a question managers must answer on a regular basis: not 'Should I make or buy this component?' but 'From whom, inside or outside of my firm, should I buy this?' It also applies to any situation in which a firm must choose a partner under uncertainty. With little or no modification, it can inform the choice of a joint venture partner or a partner for entry into a new geographic market.

The third contribution is to address an important strategic issue in a way that the underlying literatures cannot: how should companies organize in the long-run to access the capabilities needed for competitive success. For example, a notebook computer manufacturer needs to have ongoing access to the capabilities necessary to develop new flat-panel displays. It can develop these internally, develop long-term ties with capable suppliers, assume it will be able to access them on the open market, or combine these strategies. Each approach carries its own combination of costs and risks. Our ability to understand which strategy carries the best balance of cost and risk is limited by the fact that no single literature speaks to all of the issues underlying each of these strategies. By combining the insights of the underlying literatures, the integrated model and associated empirical results provide guidance on the optimal strategy.

The next section reviews theories related to technical capabilities and buyer–supplier relationships and uses these concepts to construct an integrated model of supplier choice. I then test hypotheses derived from the model using information on the procurement of innovative flat-panel displays by notebook computer manufacturers in Japan and the United States. I test the hypotheses using a large-scale empirical study, supplemented by multiple interviews. After presenting and interpreting the results, I show that the integrated model is

a significantly more robust predictor of supplier choice than any of the underlying theoretical lens applied individually. I then discuss the robustness and potential limitations of the study. A discussion of the paper's contributions concludes.

THEORY AND MODEL

Differences in both the technical capabilities of suppliers and in their relationships with the buyer affect the calculus of supplier selection. However, determining their relative importance requires combining them into a single model.

To do so, I take as a starting point the reduced-form model of the governance decision widely used in transaction cost economics (Williamson, 1996 : 106–109). Transaction cost economics is not more fundamental to my arguments than the capabilities and inter-firm relationship literatures, but offers a formal model to use as a foundation for building an integrated model of supplier selection.

As a baseline, consider Figure 1, in which a buyer can procure an innovative component from an internal (I) or external (E1) supplier. The horizontal axis represents the degree of technological

uncertainty posed by the desired innovation.[1] Lines I and E1 map the total costs the buyer incurs by choosing that supplier at a given level of technological uncertainty. Total costs include the costs of producing the component, adjusted for quality and the likelihood of successful development, governing the relationship to avoid potential opportunism, and communicating during the development process.

Following the practice of transaction cost economics, I assume firms organize their transactions to minimize total costs. Therefore, on the left side of the graph, when uncertainty is low and the external supplier offers lower total costs, the buyer will choose the external supplier. On the right side of the graph, uncertainty is high and the internal supplier offers lower total costs and is preferred. Next I discuss factors that influence the position of the cost lines.

Uncertainty

The cost lines slope upwards because greater uncertainty increases the costs of governance and communication over the development cycle for an innovative component. In the context of technological innovation, uncertainty will be high when the desired innovation requires large advances beyond the current technological frontier. Using Galbraith's (1977) definition of uncertainty, there is a large difference between the amount of information required to develop the innovation and the amount of information already possessed. In Williamson's (1975) terms, because much information is missing, it will be difficult for a decision-maker to specify a complete decision tree.

This uncertainty increases communications costs. The technology is likely to be in a state of flux (Teece, 1977: 249) and performance and design requirements are often unknown *ex ante* (Monteverde and Teece, 1982). This condition requires ongoing communication as the development process reveals unforeseen difficulties and information on the innovation's actual potential. This communication will be difficult because information at or beyond the technological frontier is especially likely to be uncodified and difficult to transfer between
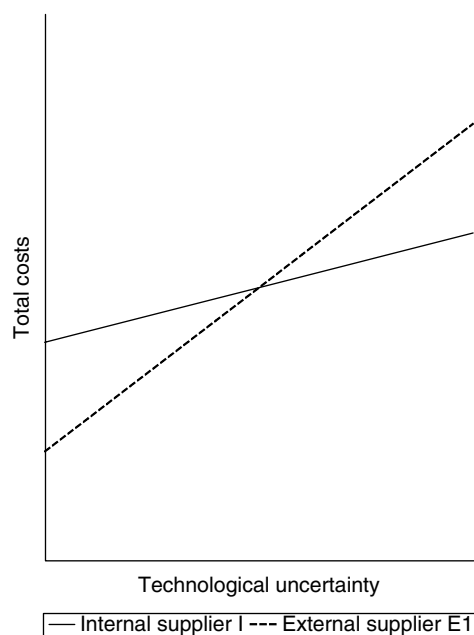

Figure 1.   A model of supplier selection

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[1] In many applications of this model, the horizontal axis represents asset specificity. I address the issue of asset specificity below.

individuals or groups (Hansen, 1999; Nelson and Winter, 1982).

Uncertainty also makes governance more difficult. The buyer and supplier are more likely to disagree about the appropriate technological approach (Argyres, 1995) and to have difficulty formulating R&D goals (Armour and Teece, 1980). Once development is underway, the probability of encountering a contingency that renders the initial technical approach inappropriate is high (Masten, 1984). In response, the buyer and supplier can either draft a contract covering a wide range of contingencies, which is costly and will never be complete, or engage in costly renegotiation each time an unanticipated contingency develops. In the event of failure, it is difficult for the contracting parties (Arrow, 1971; Davidson and McFetridge, 1984) or the courts (Masten, 1984) to determine fault. Studies in industries including aerospace (Masten, 1984), telecommunications (Globerman, 1980), and electric components (Anderson and Schmittlein, 1984) have found evidence that uncertainty increases governance costs.[2]

Technical capabilities

Potential suppliers may differ in their technical capabilities and, thus, in their ability to produce a component according to the desired specifications and schedule. Firms develop capabilities by carrying out related activities repeatedly (Nelson and Winter, 1982; Nonaka and Takeuchi, 1995). Differences in past activities thus lead to heterogeneous capabilities.

Of course, firms can and do add capabilities. However, doing so is time-consuming, costly, and often risky, leading Teece and co-authors to state that it is 'rarely an attractive proposition to try and develop a collection of novel skills rapidly'

(Teece *et al.*, 1994: 17). Firms should thus evaluate potential suppliers on the basis of their current capabilities (Henderson and Cockburn, 1994; Kamien and Schwartz, 1982). If a firm chooses a supplier other than the most technically capable, either development will proceed with inferior capabilities, or investments of time and resources will be needed to improve the capabilities of the chosen supplier.

To incorporate technical capabilities into the supplier selection model, I observe that as technical uncertainty approaches zero, communication and governance costs decline and make up an increasingly smaller portion of the total cost. Production costs, a function of the supplier's technical capabilities, become the main driver of differences in total costs. Therefore, technical capabilities enter the model via the y-intercept of each supplier's cost line.

Figure 2 introduces a second external supplier, E2, identical to the original external supplier, E1, except for having greater technical capabilities and, consequently, a lower y-intercept. Since they are identical by construction in all other respects, E2 always offers lower total costs than, and will be preferable to, E1. To capitalize on E2's greater technical capabilities, the buyer delays moving to the internal supplier until technical uncertainty is higher than previously.[3] This leads to my first hypothesis.

Hypothesis 1: The greater a supplier's technical capabilities, the more likely a buyer is to select that supplier.

While this hypothesis is highly plausible, it is important not only as a baseline, but also because it addresses an important point of tension between the capabilities literature and transaction cost economics. Adherents of the firm capabilities literature have criticized transaction cost analysis for ignoring or underemphasizing such differences in firms' capabilities (Barney, 1999; Winter, 1988).

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[2] Like the above cited studies, I focus on uncertainty, rather than frequency and asset specificity, the other two dimensions of transactions normally considered by transaction costs analysis (Williamson, 1985: 79). Because I focus on the same buyers, suppliers, and technology, frequency does not vary across transactions. Asset specificity may co-vary with uncertainty, since the more uncertainties there are to be resolved, the more partner-specific solutions will be involved. However, interviews indicate that beyond the specificity present in any innovative display, increasing uncertainty impedes communication and the ability to contract for technical contingencies much more than it increases asset specificity. Therefore, I focus on the primary impact of uncertainty.

[3] In this and all of the illustrative figures, there is nothing deterministic about the relative positions of the various suppliers. In Figure 2, it would be equally possible for the internal supplier to have technical capabilities superior to those of either external supplier. In that case, it would always offer the lowest total costs and the buyer would never choose an external supplier. I have chosen situations that are most useful in illustrating the principles in question.
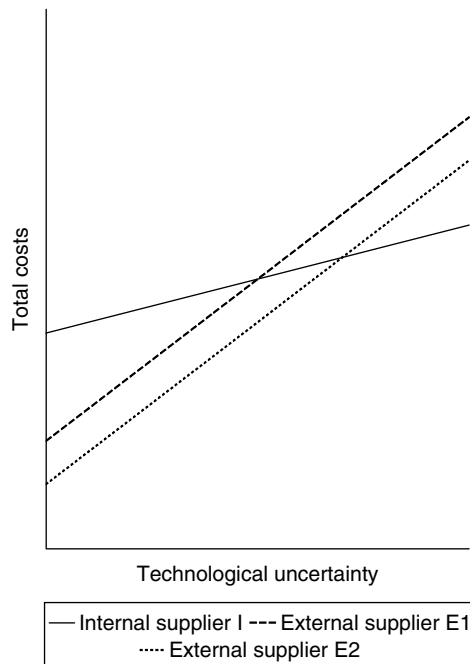
Figure 2. The impact of differing technical capabilities

Theoretically, transaction cost economics encompasses any factor, including technical capabilities, that affects either governance or production costs, but the critique is valid in terms of empirical research. A few early empirical studies controlled for differences in production experience and production costs between buyer and supplier (e.g., Walker and Weber, 1984). However, as transaction cost economics moved forward, empirical work largely set aside differences between firms to focus on cost comparisons between different modes of organizing a given transaction (Williamson, 1999). In a rare exception, Argyres' (1996) case study found that both governance issues and capabilities affected the decision to make or buy a component.

The transaction cost literature has recently rediscovered the importance of capabilities, with Williamson identifying firm capabilities as the obvious next element to be incorporated into the calculus of transaction cost economics (Williamson, 1999). To do so, he suggests complementing the transaction cost framework with the thread of the firm competence literature that focuses on the role of routines (e.g., Nelson and Winter, 1982), as I do here. At the same time, Foss (1996) and Mahoney (2001) have argued the converse, that the origin and impact of differential firm capabilities cannot be understood without

taking opportunism into account per the transaction cost economics literature. However, to date, little empirical work has answered this call.

The impact of the buyer–supplier relationship

A buyer must also consider the costs of managing the relationship over the development process. Unlike existing goods, innovations cannot be obtained by a one-off, anonymous transaction and require time to develop. During that time, the buyer and supplier—possibly divisions of the same firm—must interact to develop mutually acceptable specifications (Monteverde and Teece, 1982) and to design the final product to incorporate the innovative component. This interaction poses challenges of communication and governance.

A large literature has examined the impact of past relationships on the success with which a buyer and supplier can manage these challenges. Sustained relationships have been found to increase suppliers' innovativeness (Helper, 1991a) and involvement in product development (Wasti and Liker, 1999), as well as leading to faster, lower-cost procurement (Dyer 1996a). This literature has been critical of transaction cost economics' practice of treating each transaction between a buyer and supplier as discrete (Doz and Prahalad, 1991; Ring and Van de Ven, 1994). Nooteboom (1992) summarized these concerns when he wrote that 'An embedding of a transaction in an ongoing process of exchange is required to make transaction cost economics coherent.'

Past interactions improve communication between buyer and supplier in several ways. First, because the buyer and supplier have first-hand knowledge of each other's capabilities, they can more effectively partition tasks so that the most capable party is assigned each task (Fichman and Levinthal, 1991). Second, relationship-specific communication and coordination routines develop over time (Mitchell and Singh, 1996). Third, a buyer and supplier will, over the course of multiple interactions, develop a common language for discussing technical and design issues (Buckley and Casson, 1976).

Past interactions also reduce the cost of governance by building trust, by which I mean the expectation that one's exchange partner will not act opportunistically for one or more social, psychological, or economic reasons. Although the future behavior of a partner is unobservable, first-hand

knowledge of a partner's past behavior provides some information (Granovetter, 1985). Crocker and Reynolds (1993) found that the U.S. Air Force took fewer steps to protect itself from opportunistic behavior by an engine supplier if that supplier had refrained from opportunistic behavior in the past.

Trust also develops between individuals engaged in repeated transactions (Uzzi, 1996). This trust can become institutionalized, leading to trust between the organizations that endures despite changes in the individuals involved (Zaheer, McEvily, and Perrone, 1998).

Dyer's (1994, 1996b) studies of supplier networks in the Japanese automotive industry show that these relationship-specific communication and governance efficiencies can be very valuable. If the supplier relationship were to end, this value would be lost, which serves as a brake on opportunism for both parties (Williamson, 1983). So long as the benefit of opportunism does not exceed the value of the relationship, neither party is likely to risk the long-term value of the relationship for short-term gain, either by blatant acts of opportunism such as breach of contract or more subtle actions such as below-peak performance (Klein, 1980; Pisano, 1989). If the buyer and supplier believe that unexpected contingencies will be resolved with neither party taking opportunistic advantage, development of the innovative component can occur under the aegis of an agreement short of an elaborate contract, reducing *ex ante* contracting costs and the need for costly formal control mechanisms (Powell, 1990).

Each of these communication and governance efficiencies increases as a buyer and supplier work together over time. Helper (1991a) and Sako and Helper (1998) found that trust between buyer and suppliers increased the longer they had worked together. Mutual knowledge, inter-firm routines, and a common language develop in the course of repeated interaction of people from the partner firms (Ring and Van de Ven, 1994), increasing the value of the relationship and serving as a stronger brake on opportunism.

Thus, a buyer and supplier should be better able to address challenges of communication and governance the more they have transacted in the past. Empirically, Parkhe (1993) found that a prior history of cooperation between two firms reduced their expectations of opportunism, while Heide and Miner (1992) found that buyer–supplier cooperation increased with higher frequency of contact in the existing relationship.

Despite these advantages, past transactions with a supplier do not necessarily make that supplier the most attractive choice. The value of past transactions depends on the technological uncertainty posed by the desired innovation, a fact that can be represented graphically. In Figure 3, supplier E2 still has superior technical capabilities, but E1 is now posited to have transacted with the buyer significantly more than E2 has. Because the buyer and E1 have better mechanisms for managing the governance and communications challenges that accompany higher uncertainty, E1's costs increase more slowly with increasing uncertainty than do E2's. The slope of line E1 is flatter than that of E2.

At low levels of uncertainty, there are few communication or governance costs and the total cost consists primarily of production costs. Since differences in technical capabilities determine differences in total cost, the difference in technical capabilities overwhelms differences in past transactions. The buyer will choose supplier E2, which offers the lowest total cost.

As uncertainty increases, communication and governance costs comprise an increasing proportion
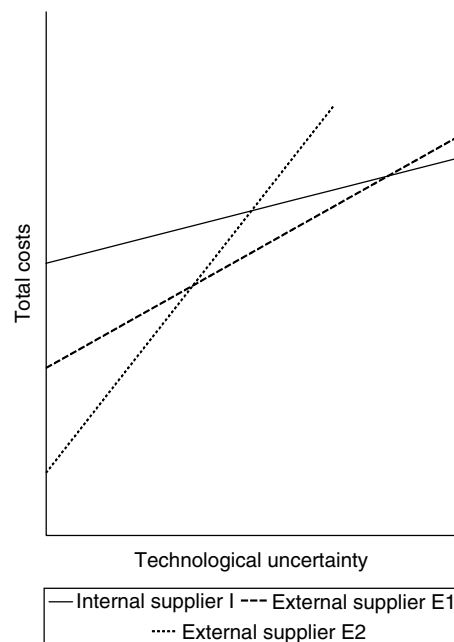

Figure 3.   The impact of differing technical capabilities and buyer–supplier relationships

of the total cost. The advantages of prior transactions outweigh differences in technical capabilities and E1 offers the lowest total costs. In this range of uncertainty, the buyer will prefer a technically mediocre, long-term supplier to a technically superior supplier with whom it has not dealt extensively.[4]

Furthermore, the benefits of long-term relationships may come at the cost of diminished incentives. Parties in long-term relationships may give second chances more frequently, expect due process before termination, and are more willing to negotiate unexpected cost increases. For example, Uzzi (1997: 43) quotes a contractor as saying 'With people you trust, you know that if you have a problem with a fabric they're just not going to say, "I won't pay" or "take it back". If they did then we would have to pay for the loss.'

Therefore, I make no prediction for their main effect of prior transactions. Their benefits are small under low uncertainty and may even be outweighed by the impact of diminished incentives. However, the benefits should become more important as the uncertainty of the desired innovation increases, increasing the positive impact of past transactions on the probability of a supplier being chosen. Consistent with this prediction, Podolny (1994) found evidence of this increasingly positive effect in investment banker's choice of co-managers for debt offerings. In contrast, Wasti and Liker's study of the U.S. and Japanese automotive industries found the effect of experience on the degree of supplier involvement in product design was positive, but did not increase with uncertainty (Wasti and Liker, 1999).

Hypothesis 2: The more uncertain the desired innovation, the more positive will be the effect of prior transactions between a buyer and supplier on the likelihood of a buyer choosing that supplier.

Internal suppliers offer many of the same advantages as long-term suppliers, although for different reasons. Transaction cost economics argues that when the buyer and supplier belong to the same firm, challenges in governance are mitigated.

Within the firm, governance costs are lowered by distinctive governance mechanisms (Mahoney 1992: 567–569) including managerial fiat, a greater legal burden on employees as opposed to contractors to disclose information (Masten, 1988), and judicial forbearance (Williamson, 1991).

Belonging to the same firm can also reduce communication costs. Frequent, intense communication within the firm leads to the development of communication routines and a common language for describing technical issues (Nelson and Winter, 1982). Of course, intense and repeated interaction could occur between firms. However, Sosa *et al.* (2002) found that, within geographically distributed product development teams, individuals belonging to the same organization communicated more than did individuals from different organizations. This echoes Allen's (1977) finding that more technical communication occurred over the R&D process when individuals belonged to the same organization. Kogut and Zander (1996: 502) argue that individuals' identification with the firm generates 'social knowledge that supports coordination and communication,' while Williamson (1985) argues that organizational integrity, due to a sense of shared destiny, leads to better information disclosure.

This reasoning suggests that, on average, a firm can better manage the interactions that occur over the innovation process with an internal supplier than an external one. Returning to Figure 3, an internal supplier's cost line will have a flatter slope than that of an external supplier. As uncertainty increases, the advantages of working with an internal supplier become increasingly important. At the highest levels of uncertainty, the extreme right in Figure 3, the internal supplier offers the lowest total cost and will be the preferred supplier.

Firms must weigh this advantage against the lower incentives and greater bureaucratic costs that occur in within-firm transactions (Helper, 1991b; Williamson, 1985: 140–153). Graphically, lower incentives and greater bureaucratic costs raise the *y*-intercept of the internal supplier's cost line above that of an external supplier with equal technical capabilities.

These two dynamics determine the likelihood of an internal supplier being chosen. Absent uncertainty, bureaucracy and diminished incentives increase costs. At high levels of uncertainty, however, the communication and governance advantages of working with an internal supplier offset

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[4] Note that I am not arguing that technical capabilities might not also take on greater importance with increasing uncertainty. Rather I argue that since communication and governance costs comprise an increasing portion of the total cost, the *relative* value of relationships becomes greater as uncertainty increases.

these costs. Therefore, it is not possible to determine the net effect of common firm membership independent of the level of technical uncertainty. However, the greater the uncertainty, the greater should be the net value of a buyer and supplier belonging to the same firm.

Hypothesis 3: The more uncertain the desired innovation, the more likely that a firm will select an internal supplier.

As Figure 3 illustrates, the model implies that the value of long-term supply relationships will be greatest under moderate uncertainty.[5] At low uncertainty, the advantages of prior relationships are irrelevant. Under extremely high uncertainty, the far right of Figure 3, the advantages of working with internal suppliers are at their highest. The larger the advantage offered by internal supply, the less impact past experience with any external supplier will have on the choice of supplier. Statistically, this would correspond to an inverted-U shape for the effect of prior experience.

This observation is only possible via an integrated model. Transaction costs economics initially focused on the contrast between interactions within and between firms. The literature on interfirm networks (Ahuja, 2000; Dyer, 1997, 1998; Ring and Van de Ven, 1992) subsequently drew heavily on the logic of transaction cost economics and the knowledge-based view of the firm to understand changes, primarily positive, that occur in communication and governance as firms interact over time (Gulati, 1995). These streams of literature have rarely intersected, leaving it unclear to what degree hierarchy can provide equivalent or superior benefits to long-term inter-firm relationships.

One consequence of this gap has been difficulty in understanding the conditions under which firms should build networks of long-term relationships to access the capabilities they need and when they are best served by building these capabilities internally. This model suggests that long-term relationships are most beneficial in an environment of medium uncertainty, where they provide a firm with efficient access to capabilities without the cost of developing them internally. For a series

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[5] Recall that the specific configuration of values for each variable represented in Figure 3 illustrates the principals in question. The principals discussed in this paragraph apply to any configuration of values, but the identity of the optimal supplier depends on the specific values.

of relatively low-uncertainty innovations, relationships provide little benefit. Indeed, if they prevent the firm from making selections based on technical criteria, they may even be counter-productive. Assuming there are capable suppliers available, there is also less value in developing internal capabilities in such an environment, since the firm can acquire the needed capabilities from suppliers, regardless of their past relationship or lack thereof. When innovations are expected to have very high uncertainty, acquiring capabilities from any external supplier, even a long-term supplier, is costly. A firm will be better served if it has developed the required capabilities internally.

I do not formally hypothesize this relationship for two reasons. First, it is unclear if any observations in my data approach this high a level of uncertainty. Second, as discussed in the methods section, the statistical model appropriate to model supplier choice is not conducive to testing such a relationship. However, I find evidence from both my statistical results and interviews that is congruent with this implication of the model.

DATA AND METHOD

Empirical setting

I test these hypotheses by studying notebook computer manufacturers' sourcing decisions for innovative flat-panel displays from 1992 to 1998. This setting offers several advantages.

First, displays are a key component in notebook computers because they are a large part of the user experience. To distinguish their product, notebook computer manufacturers continually strive to incorporate more advanced displays into their notebook models. Therefore, notebook computer manufacturers take great care in their selection of suppliers for innovative displays.

Second, notebook manufacturers chose suppliers under varying degrees of uncertainty. Because of competitive pressures, computer firms cannot wait for an innovative display to exist before beginning to design the computer into which it will be integrated. The race to introduce a notebook with a 13-inch display was underway when the largest

available notebook display was 12 inches. However, the technical challenges to be overcome varied in number and complexity across innovations.[6] This makes it possible to identify low-uncertainty and high-uncertainty innovations.

Third, the engineering effort to develop an innovative display and integrate it into a new notebook computer model requires the type of management-intensive buyer−supplier relationship this model addresses. This process can easily take over 9 months and requires continuous communication between notebook maker and display supplier, partially because many relevant parameters are highly subjective.[7] As a result, even though the initial specifications from the notebook manufacturer are usually very demanding, the manufacturer and supplier will negotiate compromises during development on a wide spectrum of specifications including driving method, driving voltage, input signal, the dimension of the module, and connector shapes.

Fourth, it is easy to identify discrete innovations. Since the early days of the industry, the key features through which to differentiate laptops were size and resolution, both of which I study. Each has advanced in discrete steps, e.g., the jump from 12.1-inch to 13.3-inch displays or from XGA resolution to the higher SXGA resolution in 12.1-inch displays. This provides a series of identifiable innovations for which I can model buyers' decisions.

Lastly, all of the decisions took place in the same period 1992−98, and involve the same buyers, suppliers, and basic technology. This eliminates many potentially confounding factors.

Data

My primary data source was the COMTRAK database compiled by Stanford Resources, one of the industry's leading consulting firms. For each model produced by a notebook manufacturer, COMTRAK provides the size and resolution of the display, as well as the firm that supplied it. Stanford Resources compiled the information in COMTRAK from interviews with display suppliers and notebook manufacturers from 1992 to 1998. Stanford Resources had a strong incentive to compile these data accurately; COMTRAK subscribers paid $1250 per quarterly issue and were well-informed participants in the industry. The COMTRAK data allowed me to compile a complete inventory of a notebook manufacturer's relationships with display suppliers and to identify the supplier for a manufacturer's first introduction of a given size−resolution combination. I augmented these data with the trade press and issues of *Laptop Handbook and Buyer's Guide*. Valuable information on the industry's development came from Murtha, Lenway, and Hart (2001).

The data include 116 introductions of innovative displays, meaning that a manufacturer incorporated a new size−resolution combination, by 13 manufacturers. For each innovation a manufacturer incorporated, I generated an observation for each potential supplier, including measures of the supplier's technical capabilities and the characteristics of the manufacturer−supplier relationship at that time, a vector of control variables, and an indicator of whether the manufacturer selected that supplier for its initial introduction of that innovation. Table 1 summarizes my conceptual variables and the empirical data used to test them. Table 2 presents descriptive statistics and correlations.

I supplemented the quantitative data with interviews at three notebook computer manufacturers in the United States and Japan. At the two firms that also produced displays, I interviewed individuals in both the notebook computer and display divisions. Interviews were semi-structured, lasting between 45 minutes and 2 hours, with participants including procurement managers, engineers, and others. To assure maximum clarity during the interviews in Japan, I began with a pre-translated set of questions in Japanese. Depending on the language ability of the respondent, responses and further questions took place in Japanese, English, or a combination. I also interviewed principals at three major consulting firms in the industry (two in the United States, one in Japan), relevant officials at Japan's Ministry of International

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[6] Producing larger displays requires new handling equipment and processes. For example, it is necessary to apply processes such as vapor deposition or photolithography uniformly over an ever-increasing surface area. Equipment has to be faster and have greater throughput. Resolution increases require putting more circuitry on the same-size display, demanding reduced line-widths, tighter tolerances, and more driver chips with more challenging packaging.

[7] For example, although it is possible to specify and measure absolute brightness, designers can determine consumer acceptance of a given brightness only in the context of other parameters, including color matching, brightness uniformity, and brightness leakage.

Table 1.　Conceptual variables and empirical data

Conceptual variable	Empirical data	Variable name
Independent variables		
Technical capability of supplier	Number of U.S. display-related patents in previous 5 years	PATENTS
Nature of the buyer–supplier relationship	Number of years in which buyer and supplier have transacted	YEARS
	Are the buyer and supplier part of the same company? (0/1)	INTERNAL SUPPLIER
Technical uncertainty of innovation	Technical advance required as perceived by industry	PERCEIVED UNCERTAINTY
	Technical advance required as determined by need for new processes (0/1)	NEW PROCESS REQUIRED
Control variables	To what degree do the buyer and supplier compete in the notebook market?	COMPETITOR
	Common nationality (0/1)	SAME NATIONALITY
Dependent variable		
	Is this the supplier selected for the given innovation? (0/1)	CHOICE

Table 2.　Descriptive statistics and correlations

		Mean	S. D.	Min.	Max.	1	2	3	4	5	6	7	8
1	CHOICE	0.03	0.17	0.00	1.00	1.00							
2	PERCEIVED UNCERTAINTY	2.82	1.24	1.00	5.00	0.00	1.00						
3	NEW PROCESS REQUIRED	0.25	0.43	0.00	1.00	0.00	0.78*	1.00					
4	COMPETITOR	9.04	7.42	0.00	34.40	−0.07*	0.12*	0.12*	1.00				
5	SAME NATIONALITY	0.40	0.49	0.00	1.00	−0.04	0.02	0.00	−0.04	1.00			
6	PATENTS	181.52	200.8	0.00	926	0.22*	0.12*	0.06*	0.22*	−0.11*	1.00		
7	YEARS	0.25	0.74	0.00	5.00	0.30*	0.09*	0.05	−0.06*	−0.04	0.35*	1.00	
8	INTERNAL SUPPLIER	0.04	0.20	0.00	1.00	0.17*	0.01	0.01	−0.24*	0.24*	0.07*	0.24*	1.00

* Significant at 0.10 level

Trade and Industry,[8] and other long-time industry participants. The combination of qualitative and quantitative methods allows me to 'capture a more complete, *holistic*, and contextual portrayal' of the phenomenon (Jick, 1979: 603, emphasis in original).

Dependent variable

In the set of observations related to a manufacturer's introduction of a given innovation, this indicator variable was set to 0 for all suppliers except the one the manufacturer chose. For that supplier,

it was set to 1. Note that while a buyer may eventually use a number of suppliers for a given type of display, I focus on the single supplier used in a manufacturer's *initial* introduction of a notebook with a given display type.

Independent variables and measures

Technical capabilities

Patents are widely used to measure technical capability (Hall, Jaffe, and Trajtenberg, 2000). I measure a supplier's technical capability by the number of display-related U.S. patents it applied for in the previous 5 years (PATENTS). This figure is updated annually. I defined display-related patents

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[8] Now the Ministry of Economy, Trade and Industry.

as those containing the terms 'liquid crystal display' or 'LCD' or classified in International Patent Classification section G02F 1/–, G09G 3/–, G09F 9/3-, or G09F 13/–. I selected these patent classifications according to Spencer (1997) and confirmed that they were the classifications common to all patents selected for inclusion in the 'Liquid Crystal Display' section of *Industry and Technology Patents Profiles: Electronic Displays and Display Applications*, published by Derwent Information/Thompson Scientific, a leading publisher of patent information. An industry informant confirmed the appropriateness of this measure for the display industry: Although decision-makers rarely if ever actually count the number of display-related patents each potential supplier holds at a given time, the number of patents held by a supplier correlates closely with its technical capabilities and with other firms' beliefs about those capabilities.

The manufacturer–supplier relationship

I measure two aspects of the relationship between the manufacturer and each of its potential suppliers: the extent of past transactions and whether they belong to the same company.

I measure past transactions by the number of previous years in which the manufacturer had purchased at least one notebook computer display from the supplier (YEARS). If a manufacturer and supplier had relationships prior to their entry into my data, my measures of their relationships will be truncated. To control for this possibility, I do not model decisions made in the first 3 years of a manufacturer's presence in the data. Sixty-eight of the original 116 innovations remained in the sample.

The indicator variable, INTERNAL SUPPLIER, is set to 1 if the supplier is part of the same company as the computer manufacturer. I include the interaction of INTERNAL SUPPLIER and YEARS, since the value of previous transactions may differ for internal and external suppliers.

I measure technical uncertainty in two ways. The first, PERCEIVED UNCERTAINTY, rates industry perceptions of the advance beyond existing technology that each innovation required. It ranges from 1 to 5. A researcher in a leading consulting company, an 18-year industry veteran with experience as both a product engineer and product marketing manager, provided this rating for each innovation I observed in my data. Since this measure was constructed after the fact, it may be biased by knowledge of which innovations ultimately proved the most difficult. However, it will correlate closely with *a priori* perceptions of uncertainty unless there were innovations that proved surprisingly difficult or simple, which my informants indicate did not occur.

The second measure of technical uncertainty, the dichotomous variable NEW PROCESS REQUIRED, measures whether suppliers could produce the display by refining existing techniques or if new techniques were necessary. A resolution increase was highly uncertain (NEW PROCESS REQUIRED = 1) if it required new process technology or breakthroughs in metallurgy, rather than executing existing materials and processes better. A size increase was highly uncertain if it required the assembly of an entirely new fabrication line, as opposed to being possible through improvements in an existing fabrication line. It was clear before development began when the limits of current materials or production lines had been reached. A senior industry participant who worked in the display division of a firm that made both displays and notebooks suggested this measure. For each innovation I observed, he identified whether it required a new process or not.

The two measures are consistent, but not identical. All of the innovations rated 5 on the PERCEIVED UNCERTAINTY scale required new processes. Every innovation that required a new process was rated either 4 or 5 on the PERCEIVED UNCERTAINTY scale. There were 20 innovations of above-average perceived uncertainty that did *not* require new processes.

Controls

Some notebook manufacturers and potential suppliers had inter-organizational relationships in other fields. For example, Acer and Texas Instruments had a joint venture to manufacture memory chips starting in 1989. These relationships might generate trust and communications ability between the firms. To control for the effect of these relationships, I use the Quadratic Assignment Procedure (QAP) from network analysis, as described in the Appendix. This procedure controls for

the unobserved heterogeneity in buyer–supplier dyads, including unobserved relationships.[9]

Working with a supplier from another country creates several challenges, including language differences (Arrow, 1971) and, possibly, lower trust (Zucker, 1986). These effects may have diminished given the pervasive globalization of the electronics industry, but I include an indicator variable, SAME NATIONALITY, set to one if the supplier is of the same nationality as the manufacturer, to control for possible effects.

Firms occasionally procure displays from suppliers with which they compete in the notebook computer market, despite the possibility of information leakage and opportunistic behavior in the display market to influence competition in the notebook market. Industry informants suggest that the high minimum efficient scale and significant cycles of supply–demand imbalance in the display industry drive this behavior. Downstream competitors rely on cross-selling of displays to even out these imbalances. Reputation effects mean that a blatantly opportunistic supplier would be unable to sell to downstream competitors in the future, a powerful incentive to avoid opportunistic behavior. Since the impact of a potential supplier being a competitor in the notebook market is unclear, I include a variable (COMPETITOR) measuring the intensity of competition between the buyer and supplier in the notebook computer market. If the supplier does not produce notebook computers, this variable is set to 0. Otherwise, it is set to the sum of the manufacturer and supplier's worldwide market share in the notebook computer industry.[10]

METHOD: THE DISCRETE CHOICE MODEL

For each innovation, I wish to model the effect of each potential supplier's characteristics on the probability of the buyer choosing that supplier rather than any other potential supplier. I therefore apply McFadden's discrete choice model (Domencich and McFadden, 1975; McFadden, 1973).

Let the potential suppliers be indexed by s and the computer manufacturers making the choice by m. The vector of variables associated with supplier s at the time a supplier was being chosen for innovation i is x_{si} and the vector of coefficients to be estimated is β. The utility a manufacturer obtains by choosing supplier s is

$$U_{si} = \beta' x_{si} + \varepsilon_{si} \qquad (1)$$

where ε_{si} is an unobserved random term that is an identically and independently distributed extreme value, independent of β and x_{si} (Amemiya, 1981).

The probability of manufacturer m choosing supplier s for innovation i is given by

$$P(y_{mi} = s | x_{si}) = \frac{\exp(x_{si}\beta)}{\sum_{j=1}^{s} \exp(x_{ji}\beta)} \qquad (2)$$

Since there were 32 potential suppliers for each of the 68 new model introductions, this yielded $68 * 32 = 2176$ observations. Hausman and McFadden's (1984) test indicates that my sample exhibits independence of irrelevant alternatives, a key assumption of the discrete choice model.

To test my hypotheses, I must evaluate the statistical significance and relative magnitude of covariates for low-uncertainty vs. high-uncertainty innovations. There are several statistical approaches to making such a comparison.

One approach is to estimate a single regression for all innovations (Aiken and West, 1991). A dummy variable is set to 1 for one type of innovation, e.g., systemic, and interacted with the relevant covariates. Considering only one variable, x, and letting the dummy variable, H, be set to 1 for high-uncertainty innovations, the equation would be of the form

$$Y_i = \beta_0 + \beta_1 x_i + \beta_2 (H_i x_i) + e_i \qquad (3)$$

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[9] An extensive literature review identified some of these relationships. However, many relevant relationships, such as purchases of other components from a supplier, never appear in the press and the nature of these relationships varied enormously. There is no theoretical basis for rating these relationships on a continuous basis and a dichotomous variable is not appropriate. Fortunately, QAP controls for their effect, although it does not allow me to measure their impact.

[10] As is usually the case, I lack information on the price offered by each supplier. However, two factors make this lack less important in this setting than most. First, I focus on the early stages of a display's life cycle, during which sales to early adopters generate very large margins, dwarfing differences in prices offered by suppliers. Over the life of a given model, other display suppliers will come online, and competition will drive everyone's price to a market level (interview with industry informant, confirmed by an unrelated industry informant). Second, my interest is in *comparing* decisions made under low and high uncertainty. There is no reason to suspect that price would have a stronger impact on one than the other.

An estimate of β_2 significantly different than 0 indicates that the impact of x varies between low- and high-uncertainty innovations. The sign of β_2 indicates whether the impact of x is diminished or increased for highly uncertain innovations.

As indicated by the presence of a single error term, e_i, this approach assumes that the error variance of low- and high-uncertainty innovations is the same (Darnell, 1994: 111; Pindyck and Rubinfeld, 1991: 107). If this is not accurate, differences in residual variation will confound any attempt to compare coefficients across groups and differences in the estimated coefficients tell us nothing about the differences in the underlying impact of x on the two groups (Allison, 1999: 190).[11]

Unobserved heterogeneity likely differs between low- and high-uncertainty innovations. Low-uncertainty innovations require less management of the design process, lowering the cost of choosing a hard-to-manage supplier and giving more play to unobserved factors. Managers may also simply pay less careful attention to selection, increasing the variance for low-uncertainty innovations. Although untestable, this logic casts severe doubt on the results that combining low- and high-uncertainty innovations into a single estimation would generate.

Therefore, I estimate high- and low-uncertainty innovations in separate regressions. This avoids the unsupportable assumption of common variance at the cost of complicating comparisons of the effect of covariates across innovation types.

RESULTS

Table 3 presents the results. Model (a) presents the control variables, which I discuss in the later models. Model (b) estimates the full set of coefficients on all innovations. PATENTS is positive and significant, indicating that buyers are more likely to choose a supplier with high technical capabilities.

This result supports Hypotheses 1. Since Hypotheses 2 and 3 are contingent on the uncertainty of the innovation, Models (c) through (f) divide the innovations into low uncertainty and high uncertainty using the two measures of uncertainty. Models (c) and (d) divide the innovations according to PERCEIVED UNCERTAINTY, the degree of perceived uncertainty reported by industry informants. Innovations rated higher than the mean rating (2.82) are classified as high uncertainty. Models (e) and (f) divide the sample according to the value of NEW PROCESS REQUIRED, which measures whether refinements of existing processes were sufficient or whether new processes were required.

Using either measure of uncertainty, PATENTS is positive and significant for both low- and high-uncertainty innovations, supporting Hypothesis 1. A supplier's technical capability is clearly an important consideration when choosing a supplier.

For perceived uncertainty, Models (c) and (d), YEARS is significant only for high uncertainty, consistent with Hypothesis 2. The value of prior transactions is contingent on the level of technical uncertainty. Buyers only value past experience with a supplier when they perceive that the desired innovation will require a substantial advance beyond the technical frontier. This result indicates that I am not merely observing inertia in supplier selection.

Testing Hypothesis 2 further requires calculating the relative effect of technical capabilities and prior experience under low and high uncertainty. Since the coefficients in any logit equation are scaled by an unknown variance, one cannot compare coefficients across samples. However, one can compare ratios of coefficients (Train, 1998: 237). For example, computing the ratio $\beta_{\text{years}}/\beta_{\text{patients}}$ yields a value of 50.71 for low-uncertainty innovations and 272.23 for high-uncertainty innovations. This result means that under low uncertainty buyers value a year of experience as much as 51 patents held by a supplier. In comparison, under high uncertainty, buyers value a year of experience as much as 272 patents. For a high-uncertainty innovation, a buyer will be willing to give up almost five times as much technical capability for an additional year of past transactions as it would be willing to give up for a low-uncertainty innovation. This difference is significant at the 0.049 level, further supporting Hypothesis 2.

Further evidence comes from managers, who cited several benefits in long-term relationships.

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[11] In the linear case, it is possible to test this assumption (Quandt, 1960). However, in a logit model, this assumption is not testable because neither β nor σ^2, the error variance of the underlying latent variable, can be identified. Only β/σ can be identified, requiring an arbitrary assumption about the variance to identify the model (Long, 1997: 47). The likely effect of using a single equation despite differences in variance between the groups is that the slope coefficients will *not* be found to be different (Gujarati, 1988: 527).

Table 3. Results of discrete choice model predicting supplier choice

	(a) Controls	(b) All	(c) Low perceived uncertainty	(d) High perceived uncertainty	(e) Low new process uncertainty	(f) High process uncertainty
COMPETITOR	−0.108** (0.021)	−0.043 (0.029)	−0.028 (0.045)	−0.064^ (0.039)	−0.055 (0.035)	−0.009 (0.058)
SAME NATIONALITY	−0.391 (0.266)	−0.908^ (0.474)	−1.082 (0.740)	−0.883 (0.636)	−0.682 (0.516)	−1.832 (1.235)
PATENTS		0.004** (0.001)	0.005** (0.001)	0.003** (0.001)	0.004** (0.001)	0.003* (0.001)
YEARS		0.555** (0.158)	0.231 (0.241)	0.817** (0.212)	0.592** (0.182)	0.460 (0.341)
INTERNAL SUPPLIER		1.838** (0.708)	1.172 (1.284)	2.156* (0.914)	1.069 (0.893)	3.906** (1.412)
INT. SUPP. * YEARS		−0.031 (0.275)	0.903 (0.563)	−0.539 (0.341)	0.051 (0.347)	−0.093 (0.522)
Decisions observed	68	68	31	37	51	17
Observations	2176	2176	992	1184	1632	544
Log-likelihood	−221.9	−151.01	−68.22	−79.16	−115.42	−33.35
Incremental chi-square over a controls-only model		41.78**	70.4**	78.2**	106.48**	38.74**

Standard errors in parentheses. ^ Significant at 10%; * significant at 5%; ** significant at 1%

Although they mentioned trust, i.e., fewer fears of opportunism, they saw other benefits as more important. The predictability that develops over multiple transactions helps buyers anticipate problems that might arise. As a U.S. manager explained, 'If a company swears it will meet a schedule, but you know they have missed every deadline for the last five years, you can make adjustments.' A Japanese manager agreed, focusing on his greater ability to anticipate and correct technical shortcomings. This ability is especially important because display problems often become evident only after the computer is in the hands of the customer.

Managers also valued improved inter-firm communications with long-term suppliers. As one U.S. manager explained:

> It seems like the development of a notebook computer should be a science, but in fact it is the art of getting the right people together. If you aren't familiar with a company, you don't know who the right people are.

Continuing to examine perceived uncertainty, INTERNAL SUPPLIER is not significant for low-uncertainty innovations, but is highly significant and positive for high-uncertainty innovations. Calculating the relative value of a supplier being internal, $\beta_{internal}/\beta_{patients}$, indicates that a supplier being internal is as valuable as 256.7 patents for low-perceived uncertainty innovations and 729.4 patents for innovations with a high-perceived uncertainty. This difference is significant ($p = 0.092$), supporting Hypothesis 3.

Managers' comments are consistent with this result. Negotiations with internal suppliers are eased by the fact that, as one Japanese manager expressed it, 'we all wear the same uniform.' However, each side still views it as a business relationship to be managed. Another Japanese manager felt that he had more open communications with his internal supplier. In particular, he felt he received information about technological advances from his internal supplier earlier than he would from an external supplier, allowing him more time to prepare to take full advantage of the advance. A U.S. manager expressed similar sentiments, drawing attention to discussions about technologies in their embryonic stage that are much more likely to occur with an internal supplier.

A different pattern emerges in Models (e) and (f), which classify an innovation as high uncertainty if it required a new process. The relative value of a year of experience is statistically indistinguishable for low- and high-uncertainty innovations. Computing the ratio $\beta_{years}/\beta_{patients}$ yields 153 for high-uncertainty and 148 for low-uncertainty innovations. These values are statistically indistinguishable ($p = 0.95$), failing to support Hypothesis 2. However, Hypothesis 3 is supported. INTERNAL SUPPLIER is insignificant for low uncertainty, but highly significant and large for high uncertainty. The relative value of working with an internal supplier is 4.5 times greater for an innovation requiring new processes than for one that does not. Although large, this difference is not statistically significant ($p = 0.15$), perhaps reflecting the difficulty of achieving statistical significance for the difference between ratios of coefficients.

Interviews put the apparent failure of Hypothesis 2 in a different light, one consistent with the overall model. An interviewee at a Japanese notebook computer company said that it is very hard to convince an external supplier to undertake the investments required when a new process is necessary. The capital required (up to \$1.5 billion) and very high degree of uncertainty make outside suppliers reluctant to move ahead, even if there is a strong relationship in place. Being part of the same firm is a more credible commitment that the buyer will ultimately purchase the output resulting from this capital investment. YEARS is not significant for innovations requiring new processes because prior experience is not sufficient to overcome the challenges posed.[12] This finding is exactly what the model predicts: under extreme uncertainty, the advantages of working with internal suppliers give them a key advantage over even long-term external suppliers.

In combination, the empirical results provide insights into the conditionally complementary nature of internalization and long-term relationships. At low to moderate levels of uncertainty, internalization and long-term relationships can act as partial substitutes for each other. At high levels

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[12] The positive, significant result for YEARS for innovations not requiring new processes reflects the fact that many innovations not requiring new processes still demanded significant advances beyond the technical horizon. This posed problems of uncertainty, which past experience could help address. The mean value of PERCEIVED UNCERTAINTY for innovations not requiring new processes, Model (e), is 2.27. This is significantly higher ($p = 0.001$) than the mean value for the low perceived uncertainty innovations in Model (c), 1.67. This difference is consistent with that fact that 20 of the innovations *not* requiring new processes were rated as above average in PERCEIVED UNCERTAINTY.

of uncertainty, however, internalization is the superior means of overcoming governance and communication difficulties.

Among the control variables, COMPETITOR is insignificant for innovations of low perceived uncertainty, but significant and negative for highly uncertain innovations, indicating that manufacturers avoid procuring displays from downstream competitors when large technical advances are required. This finding is theoretically consistent. Since it is harder and costlier to protect oneself from opportunistic behavior as uncertainty increases, the possibility of a competitor acting opportunistically is more threatening for high-uncertainty innovations. SAME NATIONALITY, indicating that the buyer and supplier are from the same country, is never significant, which may reflect the impact of globalization in the electronics industry.

EXPLANATORY POWER OF THE MODEL

The model's true worth comes if it can provide better understanding of firm behavior. To explore this, I compare the full model to several alternatives, each reflecting a single lens for viewing the issue of supplier selection:

  (i) random choice of suppliers, as a worst case baseline;
 (ii) only the control variables;
(iii) the control variables plus PATENTS, reflecting the firm capabilities lens;
 (iv) the control variables plus YEARS, reflecting the interfirm relationship lens;
  (v) the control variables plus INTERNAL SUPPLIER, reflecting transaction cost economics' traditional internal vs. external lens.

I first compare the explanatory power of the models by comparing their log-likelihoods (Table 4). Whether looking at all innovations together, low-uncertainty innovations (defined by PERCEIVED UNCERTAINTY) or high-uncertainty innovations, adding PATENTS, YEARS, or INTERNAL SUPPLIER individually improves fit over the control variables. However, the integrated model fits significantly better ($p < 0.001$) than the best of the individual lens. While each theoretical lens offers some explanatory power, integrating them provides even more.

Next, I ask how often a model accurately predicted the supplier that the buyer selected. This test is challenging, as success requires that the buyer actually selected the single supplier that the model predicted had the highest probability of being chosen. As shown in Table 5, the same pattern holds. Any of the individual lenses improve prediction over the control variables. However, the model that consolidates the three lenses is more accurate than any single lens.

By either measure of explanatory power, the combined model is a success. It is a significantly more robust predictor of supplier choice than any individual theoretical lens.

ROBUSTNESS CHECKS AND LIMITATIONS

I argue that internalization provides advantages of communication and governance. But, as Williamson (1985: 151–153) points out, internal operations and investment decisions are especially susceptible to politicization. In particular, there may be an internal procurement bias due to managers seeking employment stability and a desire to protect an internal supplier that might be at a relative disadvantage in the marketplace. If this bias existed in the notebook computer industry, which my interviews suggest it might, we should understand each decision to procure internally as being partially motivated by this bias.

However, my empirical results remain robust even in the presence of this procurement bias. Since my primary interest is in the relative value of internal supply under different levels of uncertainty, a problematic statistical bias occurs only if the political bias towards internal procurement is more pronounced for high-uncertainty innovations. Nothing in theory or my discussions with industry informants suggests that this is the case.

Since I had no *a priori* assumptions of how quickly the value of knowledge depreciates in this industry, I tested my models using display-related patents in the last year and total display-related patents, rather than the last 5 years. Empirical results were robust.

There is an additional issue regarding patents. Lanjouw and Schankerman (1999) and Hall *et al.* (2000) find evidence that weighting patent counts by subsequent citations provides a more accurate measure of firms' technical capabilities than an

Table 4. Explanatory power, comparison of log-likelihoods

	(i) No covariates	(ii) Control variables	(iii) Capabilities lens (Controls + PATENTS)	(iv) Interfirm relations lens (Controls + YEARS)	(v) Transaction costs lens (Controls + INTERNAL SUPPLIER)	(vi) Integrated model (All variables)
All innovations						
Log-likelihood	−235.67	−221.90	−168.66	−174.69	−201.26	−151.01
Compared to model		(i)	(ii) Controls	(ii) Controls	(ii) Controls	(iii) Capabilities
Incremental chi-square (d.f. change)		27.54 (2)	106.48 (1)	94.42 (1)	41.27 (1)	35.30 (3)
Significance of improvement		<0.001	<0.001	<0.001	<0.001	<0.001
Low uncertainty						
Log-likelihood	−107.4	−103.4	−77.8	−85.0	−93.5	−68.2
Compared to model		(i)	(ii) Controls	(ii) Controls	(ii) Controls	(iii) Capabilities
Incremental chi-square (d.f. change)		8.2 (2)	51.0 (1)	36.8 (1)	19.8 (1)	19.2 (3)
Significance of improvement		0.017	<0.001	<0.001	<0.001	<0.001
High uncertainty						
Log-likelihood	−128.2	−118.3	−90.6	−89.6	−107.4	−79.2
Compared to model		(i)	(ii) Controls	(ii) Controls	(ii) Controls	(iii) Capabilities
Incremental chi-square (d.f. change)		19.8 (2)	55.5 (1)	57.4 (1)	21.9 (1)	20.9 (3)
Significance of improvement		<0.001	<0.001	<0.001	<0.001	<0.001

In every case, each model applying one theoretical lens is a statistically significant improvement over a model using just the control variables. However, the integrated model is a statistically significant improvement over the best of the models that use only one lens.

Table 5.   Explanatory power, prediction accuracy

	(i) No covariates	(ii) Control variables	(iii) Capabilities lens (Controls + PATENTS)	(iv) Interfirm relations lens (Controls + YEARS)	(v) Transaction costs lens (Controls + INTERNAL SUPPLIER)	(vi) Integrated model (All variables)
All innovations	1.47%	1.47%	22.06%	30.88%	32.35%	41.18%
Low uncertainty	0.00%	3.23%	19.35%	29.03%	32.26%	35.48%
High uncertainty	2.70%	5.41%	29.73%	29.73%	24.32%	43.24%

In every case, each model applying one theoretical lens predicts supplier choice more accurately than the model using just the control variables. However, the integrated model predicts supplier choice better than the best of the models that use only one lens.

unweighted patent counts. I could not use citation weighting since my empirical setting extends to 1998. Many patents applied for in 1997 or 1998 have been published too recently for patents citing them to have been made public. Given my relatively small sample, elaborate estimation techniques to overcome this truncation seem ill advised. Fortunately, these same studies find that even raw patent counts provide useful information (Hall *et al.*, 2000: 6).

As with any single industry study, it would be useful to confirm these findings in another industry. Even within the notebook computer industry, it would ideally be possible to study a larger sample over a longer period. However, the highly detailed data required were available only for the period and sample studied. Because of the difficulty of gathering such data, there have been few longitudinal studies of this nature, making analysis of even this modest data set a useful contribution.

DISCUSSION

I began this paper with a simple question: How do firms choose a supplier for an innovative component? Whether it is new engines for the Boeing 777, hybrid gas/electric engines for automobiles, or new displays for notebook computers, the management of innovation at the component level is critical for competitive success, making a better understanding of the phenomenon a theoretical and managerial imperative.

One can approach the research question from multiple theoretical perspectives. Technical capabilities are important and hard to duplicate, arguing for decisions according to technical criteria. The strength of relationships affects inter-firm communication and governance, suggesting past transactions should be considered. The uncertainty of the

innovation affects the governance and communications costs under different governance structures. This fact suggests that uncertainty should play a role in deciding whether to make or buy a component, but it gives little guidance in selecting among external suppliers.

Both casual examination and formal modeling show that none of these perspectives provides a complete understanding. Transaction cost economics and the literature on inter-firm relationships inform us about the strength of the buyer–supplier relationship, but not how to balance it against technical capabilities. The reverse is true of the firm capabilities literature. Neither transaction cost economics nor the inter-firm relationship literature can help us understand when a long-term relationship outweighs a hierarchical relationship with a supplier.

This paper develops a model that integrates concerns from these literatures. The first contribution of this model is to offer a superior understanding of the inevitable trade-offs involved in choosing a supplier. It argues that the relative importance of the three theoretical concerns—capabilities, past relationships, and being an internal or external supplier—is contingent on the level of uncertainty posed by the desired innovative component. When uncertainty is low, the decision is made primarily on the basis of differences in technical capabilities. As uncertainty increases, prior relationships and a supplier being internal take on greater positive significance relative to the importance of technical capabilities. At extreme levels of uncertainty, the value of internal supply relationships becomes very high and past relationships lose their significance. Empirical testing and qualitative study support the hypotheses that flow from this model and show that the model explains firm behavior more accurately than models based on any one of the underlying literatures is able to do.

Incorporating the key concerns of each literature is not merely an empirical improvement. By recognizing that the relative importance of each will vary according to the situation under consideration, the model sets the stage for future research that draws on the strengths of each of the literatures underlying this model.

The paper's second contribution is to provide managers with a richer framework than previously existed to guide their selection of suppliers. The model helps answer a question managers must answer on a regular basis: not 'Should I make or buy this component?' but 'From whom, inside or outside of my firm, should I buy this?' The model extends beyond the selection of suppliers to any situation in which a firm must choose a partner under uncertainty, including the choice of a joint venture partner or a partner for entry into a new geographic market.

The first two contributions have addressed individual instances of partner selection. In contrast, the third contribution relates to a firm's long-term strategy for accessing the capabilities it needs for competitive success. To obtain ongoing access to vital capabilities, a firm can develop them internally, develop long-term ties with capable suppliers, assume it will be able to access them on the open market, or combine these strategies. Each strategy has strengths and weaknesses, but existing work cannot identify the superior strategy.

The integrated model suggests that there is little value in building internal capabilities or long-term ties if the firm expects to face a series of relatively low-uncertainty innovations. Acquiring capabilities from an external supplier will be relatively low cost. With few governance and communications challenges to overcome, there is little value in long-term relationships and they may even be counter-productive if they prevent the firm from making selections based on technical criteria. A firm anticipating innovations of moderate uncertainty can benefit from long-term relationships with capable suppliers, which provide lower cost access to external capabilities than working with unfamiliar suppliers. However, the value of long-term relationships diminishes as anticipated uncertainty continues to increase. When a firm expects to face innovations of very high uncertainty, acquiring capabilities from any external supplier, even a long-term supplier, is costly. A firm will be better served if it has developed the required capabilities internally.

Supplier selection is a complex, multifaceted problem. This paper significantly advances our understanding of the process, addressing long-standing tensions between relevant literatures, providing guidance for managers, and setting the stage for future research.

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APPENDIX: MRQAP AS A CONTROL FOR POTENTIAL NON-INDEPENDENCE OF OBSERVATIONS

Because I observe multiple decisions involving the same dyads of buyers and potential suppliers, observations may not be independent. If this is the case, coefficient estimates will be consistent, but the standard errors may be inflated. To control for this potential non-independence, I modify a technique used in social network analysis: the multiple regression quadratic assignment procedure (MRQAP) (Krackhardt, 1988). Gulati (1995) applied this method, essentially a specialized bootstrapping technique, for a similar reason.

In its standard application, MRQAP proceeds by first performing a standard multiple regression and retaining the estimated coefficients. It then randomly permutes the rows and columns of the dependent variable matrix in a way that maintains the dependencies along rows and columns, but removes their association with the independent variables. Multiple regression is performed and the coefficients retained. This process is repeated many times.

For each coefficient, the proportion of random permutations that yielded a coefficient as extreme as the one estimated from the original data is computed. Analogous to a *p*-value in normal regression, this represents the probability of such an extreme value occurring by chance, *conditional* on the relationships observed in the data.

I modified this algorithm in two ways. First, I estimated a discrete choice model at each stage, rather than OLS. Second, since I did not have a square matrix of relations, I used an alternative permutation scheme.[13] At each iteration, I permuted the values of the dependent variable for the suppliers according to a random pattern of permutations. This same pattern was used for every decision observed. This procedure preserved dependencies resulting from a supplier's identity.

Based on 1000 permutations, the QAP-estimated *pseudo-p*-values are greater than the originally estimated *p*-values, suggesting that non-independence of observations may have had some effect. However, all non-control variables which were previously significant at the 0.10 level continued to be so under QAP estimation.

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[13] Discussions with William Simpson at the Harvard Business School were very helpful on this point. Any error in application is, of course, mine.