Codifiability, Relationship-Specific Information Technology Investment, and Optimal Contracting

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ABSTRACT: The past few years have seen an explosion in the number of e-marketplaces, including a variety of electronic exchanges in the B2B arena, but many of these have also collapsed (e.g., Chemdex/Ventro). The question addressed in this paper is what are the underlying factors that affect which transactions are likely to be supportable by B2B exchanges. In particular, we identify and study three factors: supplier management, idiosyncratic investments in information systems, and codifiability (i.e., digitalizability) of product and order-fulfillment specifications underlying transactions. We show that transaction codifiability plays a fundamental role in influencing the nature of sustainable contracting and IT investments in e-markets. Hypotheses are derived from an analytical model of codifiability in e-marketplaces;

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these hypotheses are supported by several case studies by the authors and others on the key success factors underlying B2B exchanges.

KEY WORDS AND PHRASES: B2B exchanges, codifiability, electronic marketplaces, relationship-specific investments, supplier management.

Motivation

THE RECENT EVOLUTION AND BUMPY HISTORY OF business-to-business (B2B) exchanges suggest several puzzles about the nature of transactions that are likely to be supported by B2B exchanges [4, 17, 35]. It appears that information technology (IT) has had a fundamental impact on the nature of B2B procurement and contracting relationships. First, by improving information sharing and collaborative planning through the creation of B2B electronic marketplaces, IT has increased the opportunities for interfirm procurement and the visibility of supply chains. Second, to facilitate such interfirm contracting, IT has been a key driving force for relationship-specific investments necessary to support such collaborative planning.[1] To elaborate, we begin with a discussion of several examples.

Covisint began as a consortium-based, reverse aggregator, serving the interests of large automotive companies (the buyers). It has now hit hard times. This is due partly to supplier resistance to joining the exchange, including their concerns with the pricing or business model of the exchange [5, 18, 20]. What are the suppliers' top fears? First, the magnitude of up-front relationship-specific IT investments: hardware platform, software for design-collaboration (e.g., NexPrise, MartixOne), and portal and procurement (e.g., SAP, Oracle, CommerceOne). Those investments are obligatory for having a relationship to participate on Covisint but do not guarantee sales, either at the contract market or at the spot market. Moreover, these IT investments are increasing due to the constant changes by the exchange host in the platform; for example, Covisint has switched design-collaboration software from NexPrise to MatrixOne. The consequence is that the auction preparation cost of participating in Covisint is much higher than using the previous standard quote approach. Second, suppliers are facing many ill-defined original equipment manufacturer's (OEM) requirements. Third, OEMs seem to use the auction-discovered price as a basis for further contract negotiations, thus squeezing supplier margins. Finally, the price-only focus of the exchange ignores many other value-adding attributes of products and product logistics, treating all products as if they were low-value commodities. The result is that Covisint is far from the success story originally imagined [5, 18, 20].

B2B exchanges in the semiconductor industry trade near-commodity chips (such as semiconductor memory chips DRAM—dynamic random access memory, e.g., DRAMexchange)[2] as well as more specialized chips [6]. The exchanges in this industry typically are neutral aggregators and function as private networks or consortia. The industry has been notorious for suffering from continuous cycling in capacity utilization, leading to huge swings in profitability. Rather than honoring long-term contracts, suppliers and buyers take turns eating each other's lunch. The resulting high level of price volatility and variations in allocated supply to buyers have hurt suppliers and buyers alike, as both face mounting difficulties in their production planning, scheduling, staffing, and pricing. In response to the 40-year history of such volatility, the industry has begun to restructure procurement practices based on information and contracting innovations provided by B2B exchanges, such as the proposed DRAM futures trading in the Singapore Exchange.[3] The current industry trend of "structured sourcing" is the primary example of this, with its aims to achieve the goals of hedging price, assuring supply and saving cost.[4]

Finally, the electronics industry has already benefited from the mixed use of contracting and spot sourcing. Consider Converge [21], a public exchange for electronic components, computer products, and networking equipment.[5] Converge provides a secondary market/source, for buying and selling as well as price discovery, for leading high-tech manufacturers and distributors. The success of Converge derives from its high degree of market liquidity, which is the result of its effective aggregation of the supply and demand from thousands of suppliers and buyers.

The above examples suggest the following fundamental factors underlying the sustainability of B2B electronic marketplaces. First, in the Covisint example, relationship-specific IT investment for the supplier to participate in consortium-based B2B exchanges is a central factor. Second, motivating the establishment of the DRAMexchange example are forecasts of significant savings in advanced planning, scheduling, and staffing based on contracting innovations derived from the exchange. Futures and options contracts have been designed for this industry (and several other capital-intensive industries) as efficient risk management tools to reduce price volatility, assure supply, and save cost. Third, in the Converge example, companies are combining both contract sourcing and spot sourcing to accomplish similar benefits. The Converge example also illustrates a piece of folk wisdom on the importance of liquidity for success of B2B exchanges.

To capture the above fundamental driving factors for the success of B2B exchanges, this paper provides a framework for understanding and predicting which transactions will be mediated via such exchanges and why. The key element of our synthesis is the codifiability of transactions. We define codifiability as the ability to precisely characterize in electronic format the nature of the product/service contracted for, including delivery requirements and any other contractual/fulfillment requirements that may pertain to a specific transaction, in a manner understandable to relevant parties. For example, the above case of Covisint suppliers' complaints about ill-defined OEM requirements is directly related to this notion. We draw this definition of codifiability from Levi [22], who uses the notion of codifiability in an interfirm setting in contrast to previous usage (e.g., [38]), which analyzed effects of codifiability only within a firm.

This paper develops a theoretical framework integrating the notion of codifiability with competitive contracting and IT investments. The model developed adopts the following perspective. A buyer faces a decision as to how to source an intermediate product from one or more suppliers.[6] The buyer can do so either by setting up longer-term contracts via private or industry consortium-based exchanges, or through (spot) purchase via public exchanges. The trade-off between the costs and risks of each transaction mode is intended to reflect the consequences of codifiability of transactions and the volatility of demand. We find that imperfect codifiability, modeled as increasing adaptation costs by buyers and contract cost advantages for suppliers, tends to push the buyer toward long-term contracting and may result in lower overall demand and in some suppliers being driven out of the market. Equilibrium conditions determining the optimal contract mix and surviving suppliers depend on all of these factors, and give rise to a set of hypotheses about expected sourcing practices and survival rates of exchanges. These hypotheses are supported by several case studies, derived from Day et al. [5], Laseter et al. [20], and Levi [22] on key success factors for B2B exchanges.

Literature Review

WHEREAS EXCHANGES MAY TAKE DIFFERENT FORMS, buyers who join an exchange perceive it as another way to manage their procurement and suppliers. We therefore examine how supplier management has been researched in multiple disciplines: economics, strategic management, and operations management. We briefly review each below.

The first stream of work related to ours is the economics literature. Economics approached the problem from two main perspectives. The first is principal-agent theory and game theory, with the buyer typically modeled as the principal and the supplier as an agent. This work concentrates on outlining the nature of contracts between the buyer(s) and supplier(s). It addresses how the principal can provide appropriate incentives to an agent, so that the agent can act in the principal's interest. In the present context, a buyer (the principal) has to structure incentives for suppliers to make interfirm relationship strengthening investments. In this paper, we model the effects of IT-specific investments by requiring these to be in place as a prelude to long-term contracting. The second approach, transactions cost economics (TCE), predicts that at equilibrium we should see different types of relationships and contracts between buyers and suppliers based on the total cost of transaction, including governance costs. Thus, predicted forms of relationship are conditional on transaction-related factors, such as frequency, monetary volume, variability, and complexity, and of course on relationship-specific investments. Depending on the level of those factors, interfirm relationships range between vertical integration, through partnerships and sole sourcing, to spot markets. The emphasis is on equilibrium analysis and not on strategy formation underlying equilibrium outcomes. It is the latter with which this paper is concerned. This economics framework has been previously applied in interorganizational information systems (IOS); for example, Clemons and Kleindorfer [2] developed a Nash bargaining model to analyze IT (IOS) investment and Bakos and Nault [1] applied the Hart-Moore [11] framework to ownership and investment in electronic networks. Han et al. [10] further advanced the analysis to the supply-chain procurement context, in the case of vendor-managed inventory.

It should be pointed out that codifiability has been discussed indirectly in TCE, under the heading of incomplete contracts, where the incompleteness in question concerns the ability of contracting agents to specify in advance all possible contingencies that might arise and might influence payoffs from a transaction. Williamson, however, did not mean just the simple uncertainty involved when multiple events may occur but included in it the incompleteness due to inherent inability to specify possible contingencies. However, as Slater and Spencer [28] point out, the exact concept of uncertainty is not well defined in TCE, and both Coase [3] and Williamson [31] concentrated on its effects rather than the phenomenon itself. As Levi [22] argues, codifiability captures a substantial part of this intuitive insight of Williamson. The framework below models codifiability's effects formally and analyzes the interaction of codifiability with other market factors that codetermine contracting intensity. As Williamson describes, one expects that as codifiability (i.e., ability to define and contract over contingencies) decreases, so will the intensity of long-term contractual arrangements increase over spot market transactions. Williamson and others (e.g., [16]) analyze other factors that interact with long-term contracting, including idiosyncratic investments. For example, Joskow [16] finds empirically for coal-based fuel-supply contracts to the electric power industry that the magnitude of relationship-specific investments is positively associated with the use of long-term contracts rather than spot transactions, as Williamson hypothesized. In the model below, we formally model idiosyncratic IT investments as the investments required to enable contracting and capture Joskow's above-mentioned result by associating such investments with the need to reduce uncodifiability. Besides extending previous results on contracting to include options-based contracts, the present model is also quite general in capturing competitive effects among suppliers.

The second stream of literature related to ours is the strategic management literature (e.g., [8, 13]). This approach postulates that buyers make a strategic choice with regard to what types of relationships they establish with their suppliers in order to gain competitive advantage, while maintaining control of sources of profit in the supply chain. However, much like principal-agent theory, this approach assumes an overarching, general strategy that may be differentiated at most between spot-markets and sole sourcing.

The third stream of literature related to ours is the operations management literature. This literature focuses on the operational variables that are important for understanding relationships with suppliers. Helper and MacDuffie [12] concentrated on product standardization and complexity as drivers of supplier management strategy and recently B2B e-commerce strategy. Complexity, also identified by Williamson [32, 33], and standardization are indeed important factors in supplier management. For example, Novak and Eppinger [26] found product complexity and vertical integration to be positively related, echoing the earlier findings of Walker and Weber [30] that transactions tend to be internalized rather than outsourced when they are complicated. Note that both standardization and complexity are directly related to codifiability and transferability of transactions. Ceteris paribus, the more complex a product is, the less codifiable it is, and the more difficult it is for an external supplier to produce the product to the desired specifications.

An important precursor for this work is a paper by Donohue [7] that describes multimode production. For example, in the printing and fashion industry, retailers may order early ("contract production") or late ("short-term reorders"). Contract production leads to smoother production and lower-cost procurement, resulting in lower inventories and better scheduling and staffing of production facilities compared to short-term reorder production (spot production). As a result, the marginal (or unit variable) cost of contract production is, in many industries, considerably less than production in response to last-minute, rush orders (e.g., [14]). This is routinely recognized in these industries through advance-order discounts and other two-tier pricing approaches. The model below captures this effect through differentiating contract and spot production costs.

Finally, the stream of work most relevant to ours is the recent options-based thinking in B2B exchanges for capital-intensive industries. Wu, Kleindorfer, and Zhang [37] (WKZ) appears to be the first study in this stream. They describe the basic problem and solve it for a single supplier and a single buyer, with extensions to multiple buyers being then outlined as straightforward. Their main results are the buyer's and supplier's optimal strategies for a non-state-contingent demand function. This basic framework has been followed and extended by many others. Spinler et al. [29] generalized the WKZ model to the case of state-contingent demand. They show most of the WKZ results go through, suggesting the wide applicability of the fundamental structure of WKZ. Golovachkina and Bradley [9] and Deng and Yano [6] further study whether the WKZ options-based contracts can be used as a decentralized mechanism to coordinate the entire supply chain; their numerical studies suggest that this might not be the case with a single supplier, but options-based contracts can improve supply-chain efficiency significantly. They identify conditions when options-based contracts can coordinate the entire supply chain near first-best. Martínez-de-Albéniz and Simchi-Levi [23] and Wu and Kleindorfer [36] (WK) model the impact of competition among suppliers, generalizing the WKZ framework to the case of multiple suppliers. Although both studies achieve consistent results, suggesting further robustness of the WKZ basic structure, there are significant differences in model assumptions; for instance, Martínez-de-Albéniz and Simchi-Levi [23] assume immediate scalable capacity, whereas Wu and Kleindorfer [36] assume capacity is fixed in the short term. This short-term nonadjustability of capacity is essential in B2B exchanges for capital-intensive industries that we are interested in here. The results derived in this stream of research are general precursors to the current paper. For a more complete review of this literature, see Kleindorfer and Wu [19].

The closest work to ours is that of WK. They provide the main foundations of von Stackelberg's equilibrium analysis for multiple suppliers in a contract market. The essential results in WK are the following. First, it is shown that greedy contracting is optimal for the buyer; that is, contracting follows a merit order based on a specific index of the full options value of the contract. Second, the necessary and sufficient conditions for equilibrium are characterized. Third, the two-part tariff structure of equilibrium contracts is efficient, whereas a pure forward contract is not.

This paper takes a special case of the multiple-buyers/multiple-suppliers framework in WK, in which all suppliers have identical costs and capacities. We generalize this case to allow a number of important additional features related to codifiability and to the role of interorganizational information systems in enabling electronic markets and supply chains to function efficiently. These features include differences in sourcing cost if done under contract rather than from the spot market, differences in purchase cost based on incomplete customization for the buyers if they buy in the spot market, and the cost of setting up and maintaining the requisite IT platforms to undertake trading/procurement in an efficient manner. We refer to this generalized WK model as the LKW model. What we will show below is that the basic WK results can be generalized in the presence of codifiability and relationship-specific IT investment, but with significant new insights. This paper capstones previous work in that without the presence of the noted contracting-spot transactions cost differences, efficient options trading depends on access conditions or on risk aversion of suppliers. For example, when suppliers enjoy perfect access to the spot market, previous work (e.g., [36] and the above-reviewed supply-chain contracting literature) suggests that the options market is of limited value—in fact, it disappears. These might be realistic in some settings, but given the prevalence of contracted sourcing in nearly every B2B market, there must be something else going on here. After numerous interviews with industry specialists involved in both contracting and spot sourcing, together with anecdotal evidence as presented below, we have concluded that the key issues driving contracting as a foundation for procurement are the codifiability and informational issues we identify and model in this paper.

Model, Solutions, and Managerial Implications

In this section, we describe the basic framework, assumptions, and notation, followed by our key results and managerial insights.

Model Preliminaries

There are J identical suppliers and a single buyer who utilize an exchange for contract and spot procurement of some intermediate good. Table 1 provides a list of notation. The set of all suppliers who are available to participate both in the contract and the spot market is Ξ, but there may be many suppliers who are outside of this set and who only participate in the spot market. Let K be the supplier's total fixed available capacity. The buyer and suppliers sign option contracts in advance (period 1), and then "on the day" (period 2), after the spot market price is revealed, they decide how much to exercise/deliver from the contract and how much to purchase/sell on the spot market. Suppliers compete in a one-shot Bertrand-Nash [24] game by offering contracts $[s, g, L]$ to the buyer, where s is the reservation cost per unit of capacity, g is the execution cost per unit of output, and $L \leq K$ is the suppliers' capacity bid to the contract market.

Table 1. Notation

Symbol	Definition
$\Xi = \{1, ..., J\}$	The set of J identical suppliers.
$M \subseteq \Xi$	Equilibrium set.
p	Short-term equilibrium price of set M.
b_c	Suppliers' short-run marginal cost under contract production.
b_s	Suppliers' short-run marginal cost under spot production.
K	Supplier's total available capacity.
$s = (s_1, ..., s_n)$	Reservation cost per unit of capacity.
$g = (g_1, ..., g_n)$	Execution cost per unit of output.
$L = (L_1, ..., L_n)$	Supplier's capacity bid to the contract market.
$Q = (Q_1, ..., Q_n)$	Buyer's contract quantity with each supplier at period 1.
$q = (q_1, ..., q_n)$	Buyer's exercised quantity from the contract at period 2.
x	Buyer's spot purchase quantity at period 2.
$U(z)$	Buyer's willingness-to-pay function.
$V(D_2, q, x, \phi)$	Buyer's utility function.
p_s	Exogenous spot market price.
$F(v, 0)$	Cumulative distribution function of the spot price P_s.
μ	Mean of the spot market price.
$D_2(P_s)$	Buyer's total demand at period 2.
$D_s(P_s) = (U')^{-1}(P_s)$	The single source demand where there exists only the spot market with no contract options.
$D(v, a) = D_s(G^{-1}(v, a))$	Buyer's overall demand function.
$D^{-1}(v, a)$	The inverse function of $D(v,a)$ for fixed a.
I	Supplier's relationship-specific IT investment for contracting.
a	Buyer's adaptation cost per unit of good purchased from the spot market.
$F(v, a)$	Cumulative distribution function of full spot price $P_s + a$.
$m(P_s, a)$	Spot market liquidity.
$\underline{s} = E\{m\{P_s, a\}(P_s - b_s)^+\}$	Supplier's opportunity cost on the spot market.
$G(v, a)$	The "effective price function."
$G^{-1}(v, a)$	The inverse function of $G(v,a)$ for any fixed a.
$X(M)\sum_{i \in M} L_i$	Total bid capacity of all suppliers in set M.
$\chi(z)$	The indicator function.
$\Pi(s, g, L, P_s, a)$	Supplier's profit function.

Suppliers must make relationship-specific investments, denoted as I, in information systems and other systems, in order to participate in the contract market. These investments may be thought of as prequalification investments that are required to improve transaction codifiability and critical for the contract market. The buyer may also make purchases in the spot market. In this case, there may be additional risks and costs for the buyer arising from the last-minute nature of spot procurement. We capture these buyer-related costs in the per-unit adaptation cost, a.

Similarly, there may be a cost difference, on the suppliers' side, between production for the contract and spot market. Let b_c be the suppliers' short-run marginal cost of providing a unit under contract production, and let b_s be the suppliers' short-run marginal cost of providing a unit under spot market production. We assume that $b_c \leq$

b_s so that variable cost under contract is no higher than variable cost under spot production. The difference $b_s - b_c$ reflects the cost of last-minute production, which may vary as codifiability varies, as well as the lower costs in maintenance, staffing, and production smoothing arising from advanced planning possible under longer-term contract production.

Solutions

The problem confronting the buyer is to choose an optimal portfolio of contracts from those available from the n identical, competing suppliers. The buyer's utility is defined as

$$V\left(D_2, q, x, \phi\right) = U\left(D_2\right) - \sum_{i=1}^{n} s_i Q_i - \sum_{i=1}^{n} g_i q_i - \left(P_s + a\right) x, \quad (1)$$

where $\phi = (P_s + a, Q)$ is the spot price and the vector of contract capacities, q is the vector of purchases under contract from suppliers, x is the amount purchased in the spot market, and D_2 is the total consumption of the buyer, so that $D_2 = x + \sum_{i=1}^{n} q_i$.

Define the "effective price function" $G(v, a) = E\{\min(P_s + a, v)\}$, that is, the expected price paid for the good on the day, which is the minimum of the price of purchasing that unit under contract (at price v) and purchasing it from the spot market (at price $P_s + a$).

We model spot market liquidity via $m(P_s, a)$, which is the probability that any supplier can find a last-minute buyer on the spot market when the realized spot price is P_s and the adaptation cost is a. As the number of participants in the spot market (the depth of the market) decreases or as codifiability decreases (reflected in increasing a), one would expect this access probability function $m(P_s, a)$ to also decrease, reflecting the fact that fewer participants or decreased codifiability would make it more difficult to find an appropriate spot market supplier with whom the buyer can communicate precise requirements.[7]

We refer the reader to Table 1 for notation. Most important, we note the bid price, defined as $p_i = s_i + G(g_i, a)$, and overall demand $D(v, a)$. Assuming k as the last unit provider in the contract market, the theorem asserts that k will be determined as the maximum bid price p_k, which can support the buyer's demand for capacity of the first k suppliers, ranked in order of their bid price (these suppliers make up the set $M_2 = \{i \in \Xi \mid p_i \leq p_k\}$). Any supplier bidding greater than p_k will be in the set $M_4 = \{i \in \Xi \mid p_i > p_k\}$, whereas any supplier who bids exactly the same price as p_k is in the tied set $M_3 = \{i \in \Xi \mid p_i = p_k\}$. Any supplier bidding less than p_k is in the set $M_1 = \{i \in \Xi \mid p_i < p_k\}$. The following theorem is a direct generalization of the theorem 1 of WK, but modified to incorporate the buyer's adaptation cost a. The proofs are analogous to those of WK and are omitted here. Intuitively, the logic of WK [36] goes through because the only change here is in effective price function $G(g_i, a) = E\{\min(P_s + a, g_i)\}$, but the presence of adaptation costs does not affect the buyer's ranking of the suppliers, a key structure obtained in WK.

Theorem 1 (buyer's optimal contract portfolio): Let (s, g, L) be any vector of suppliers' bids. Without loss of generality, assume that suppliers' bids are ranked in order of the index $p_i = s_i + G(g_i, a)$*, so that* $p_1 \le p_2 \le \ldots \le p_J$*. If* $G(U'(0),a) \le p_1$*, then the buyer's solution will be to set* $Q_i(s, g, L, a) = 0$*,* $\forall i$*, that is, no contracting is optimal. Otherwise, contracting occurs in order of the given index* p_i *that is optimal for the buyers, that is, the optimal portfolio of contracts has the form:* $\forall i \in M_1$*,* $Q_i(s, g, L, a) = L_i$*;* $\forall i \in M_4$*,* $Q_i(s, g, L, a) = 0$*; and for* $i \in M_3$

$$Q_i\left(s,g,L,a\right) = \left(L_i \,/ \sum_{l \in M_3} L_l\right)\left[D\left(p_i,a\right) - \sum_{j \in M_1} L_j\right],$$

where k is any supplier with the largest value of the index p_i *satisfying*

$$p_k < G\left(U'\left(\sum_{i \in M_1} L_i\right), a\right).$$

The structure of the optimal portfolio captured in Theorem 1 is relatively simple. It calls for the buyer to rank all offers in terms of a single index $p_i = s_i + G(g_i, a)$, which is the effective price of the bid by supplier i, and then to pull off as much capacity as allowed by supplier i, proceeding in rank order of the contract index until the marginal willingness to pay (WTP) is exceeded by the contract index.

Now we consider the supplier's problem.[8] The supplier's profit is given by

$$\Pi\left(s,g,L,P_s,a\right) = sQ + \left(g - b_c\right)q + \left(P_s - b_s\right)^{+} m\left(P_s,a\right)\left(K - q\right) - I\chi\left(L\right),$$

where $q = Q\chi(P_s + a - g)$ and $\chi(z)$ is the indicator function (which takes the value of 1 when $z > 0$ and 0 when $z \le 0$). Expected profit is therefore given by

$$\begin{aligned} E\Pi\left(s,g,L,a\right) &= sQ + \left(g - b_c\right)\left(1 - F\left(g,a\right)\right)Q \\ &+ \left(K - Q\right)\int_{b_c}^{\infty}\left(P_s - b_s\right)m\left(P_s,a\right)dF\left(P_s,a\right) \\ &+ Q\chi\left(g - b_c\right)\int_{b_c}^{g}\left(P_s - b_s\right)m\left(P_s,a\right)dF\left(P_s,a\right) - I\chi\left(L\right). \end{aligned} \tag{2}$$

Each supplier's problem is to choose (s, g, L) so as to maximize its expected profit $E\Pi(s, g, L, a)$ from both the contract market and the spot market, subject to the constraint that $Q(s, g, L, a) \le L \le K$, assuming other suppliers' prices are fixed.

From Equation (2), it is straightforward to show that the supplier's optimal bidding strategies are $L^* = K$ and $g^* = b_c$, as captured in Lemma 1 of WK. The reason is that the supplier unnecessarily constrains his bid if setting $L^* < K$ (it would be better to simply increase the supplier's price) and there is no reason to bid an execution price different from b_c, as this will provide inappropriate signals to a buyer in executing the contract on the day.

Given $L^* = K$ and $g^* = b_c$, each supplier's profit function can be written as

$$E\Pi(s, b_c, K, a) = [s - \underline{s}]Q(s, b_c, K, a) + \underline{s}K - I\chi(L),$$

where $\underline{s}$, defined as $\underline{s} \equiv E\{m\{P_s, a\}(P_s - b_s)^+\}$, is the supplier's opportunity cost on the spot market and $z^+ = \max[z, 0]$. Supplier's relationship-specific investment I in information systems, not modeled in WK, now plays a significant role. For any equilibrium to be sustained, the equilibrium price p must satisfy the following individual rationality constraints:[9]

$$(p - c(a))K \geq I,$$

where $c(a) = \underline{s} + G(b_c, a)$ is the lowest bid (the threshold) at which a supplier is willing to participate, given that the supplier can always sell residual output in the spot market.

For any potential equilibrium with n suppliers, we note that $h(v, n) \equiv (v - c(a))[D(v, a) - (n - 1)K]$ is the profit function of the supplier providing the final unit of contract demand, assuming that the other $n - 1$ suppliers participating in the equilibrium are selling all of their capacity in the contract market.[10] The following theorem is a direct generalization of Theorem 2 in WK, taking into consideration codifiability. Intuitively, the logic of WK goes through in establishing the first two conditions of Theorem 2. In WK, the capacity of all suppliers participating in the contract market is fully contracted, leading to a contract capacity nK. Condition 2 is analogous to the corresponding condition in WK and reflects a requirement that no supplier can improve its own lot by unilateral increases in price. Finally, the above-discussed Condition 3 represents the requirement that, at equilibrium, each supplier can earn enough in the contract market to cover the fixed cost of participating in that market.

Theorem 2 (equilibrium conditions): Let (K, p, n) be any short-term equilibrium of n identical suppliers. If c(a) ≥ G(U′(0), a), then no supplier will participate in the contract market. Otherwise, when c(a) < G(U′(0), a), then the necessary and sufficient conditions for an equilibrium p to exist are[11]

Condition 1: $$p = D^{-1}(nK, a);$$

Condition 2: $$\frac{\partial h(v, n)}{\partial v}\bigg|_{v=p} \leq 0;$$

Condition 3: $$p \geq \frac{I}{K} + c(a).$$

Managerial Implications

To determine the maximum number of suppliers, denoted n^*, that can be supported in equilibrium in the contract market, we use the standard Wilson equilibrium [34], under which suppliers continue to enter the contract market until it is unprofitable to do so. From Condition 1 and the downward-sloping property of the inverse function of overall demand, equilibrium price is decreasing in the number of suppliers. Condition 3 sets a lower bound on the equilibrium price. Combining Conditions 1 and 3, we obtain the characterization of the maximum number of suppliers in the contract market equilibrium as

$$D^{-1}\left(\left(n^{*}+1\right)K, a\right) < \frac{I}{K} + c\left(a\right) \leq D^{-1}\left(n^{*}K, a\right), \tag{3}$$

where K is the common capacity for the suppliers, $c(a) = \underline{s} + G(b_c, a) = E\{m\{P_s, a\}(P_s - b_s)^+\} + G(b_c, a)$ is the minimum contract price that can be sustained given access and cost conditions, and I is the magnitude of IT investment required to participate in the contract market.

The implications of codifiability are evident from (3). First, as I increases, participation in the contract market is clearly negatively affected, leading to a decrease in n^* and an increase in contract market price p. Second, an increase in the difference of $b_s - b_c$, that is, either an increase of b_s over b_c, or a decrease of b_c over b_s, would lower the supplier's threshold $c(a)$ in (3) for participation in the contract market, increasing n^* and decreasing equilibrium contract price p. It can be shown, following WK, that the equilibrium contract is efficient in the sense that it achieves first-best profits for the entire supply chain and no participant has any incentive to deviate from the equilibrium contract. Third, let us consider the impact of increases in adaptation cost a. The impact on $\underline{s} = E\{m\{P_s,a\}(P_s - b_s)^+\}$, is negative, as $m\{P_s, a\}$ is decreasing in a. The impact on $G(b_c, a)$ is likely to be positive, as $G(b_c, a) = E\{\min(P_s + a, b_c)\}$, but could be of no effect if the magnitude of a is significant. Note the inverse function of total demand will also decrease as the adaptation cost a increases. The result is, therefore, that either way is possible.

Fourth, we see that an increase in spot market price P_s is likely to result in a positive increase of $\underline{s}$, unless $m\{P_s, a\}$ is very strongly decreasing in P_s, and a positive impact on $G(b_c, a)$, thus a net increase in $c(a)$, leading to a decrease in n^* and an increase in contract market price p. This allows us to obtain the insight that clearly shows the strong interaction of the contract market price and the spot market price. Finally, the LKW framework also provides new insights into the relationship between liquidity (m), codifiability (a, $b_s - b_c$), and relationship-specific IT investment (I). In this regard, an often-cited "mystery" in the dotcom bust was why many dotcoms died despite the fact that they did not lack liquidity (i.e., adequate m). Note that as m increases, $c(a)$ in (3) increases, and therefore so does the contract market price. This counterintuitive fact results from the increased ability of the contract market to support suppliers when the spot market provides a more liquid market under excess supply conditions.

What the above theory suggests is that codifiability, in addition to liquidity, is the key driving factor for the success of e-markets. Low codifiability and low relationship-specific investment cause high extensive use of contract sourcing. We use Figure 1 to summarize these insights derived from the LKW model.

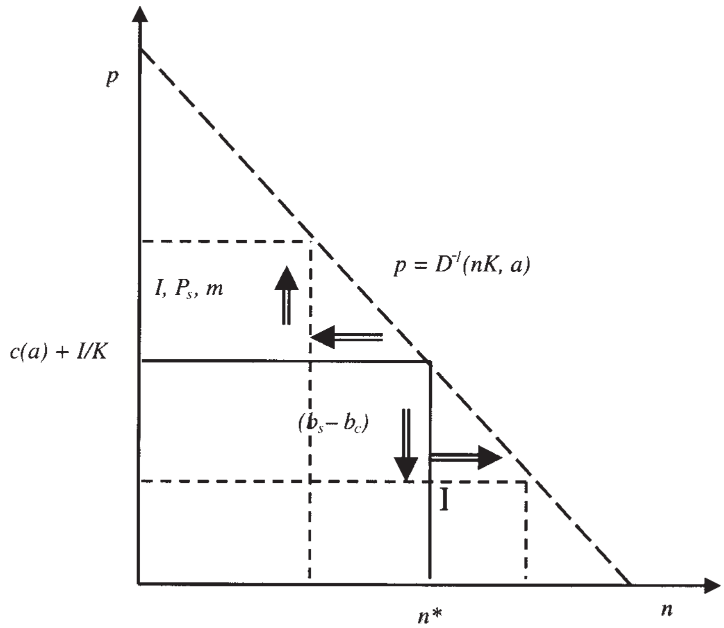

Figure 1. Comparative Statics of Theorem 2. *Notes:* An increase of either I, P_s, or m (as indicated by the upward vertical arrow) would result in fewer suppliers (as indicated by the top horizontal arrow) and a higher equilibrium contract price and vice versa. An increase in (b_s – b_c) (as indicated by the downward vertical arrow) would result in more suppliers (as indicated by the bottom horizontal arrow) and a lower equilibrium contract price and vice versa.

Hypotheses

OUR THEORY SUGGESTS SEVERAL TESTABLE HYPOTHESES for future empirical validation of our framework. Building on Figure 1, we use Figure 2 to illustrate our model predictions and key hypotheses.

H1: The higher the investment (I) required in codifying the systems and procedures for contracting, the fewer the number of suppliers in the contract market.

H2: The higher $b_s - b_c$, the difference in cost between spot and contract production, the greater the number of suppliers in the contract market.

H3: The higher the adaptation costs (a) associated with spot market procurement:

H3a: The fewer the number of suppliers in the contract market;

H3b: The higher the usage of the contract market relative to the spot market.

It is intractable to analytically show H3b, but intuitively we can argue this using Figure 3. Low codifiability results in a high adaptation cost (a), which effectively shifts the contract region upward and shrinks the spot region and, therefore, the relative usage of contract versus spot increases.

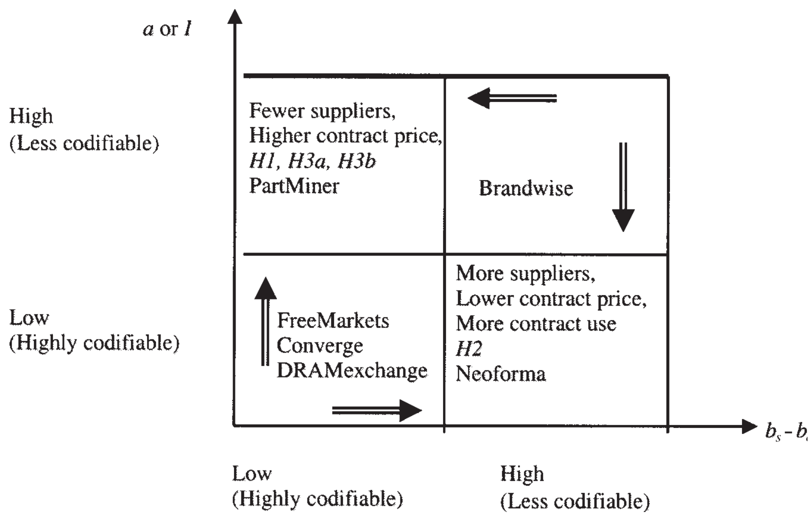

Figure 2. Summary of LKW Model Predictions and Hypotheses. *Notes:* This framework can be used to understand, classify, and predict the evolution of various business models in the context of codifiability. The model predicts an extensive use of contract versus spot in the diagonal northwest and southeast regions, but a mixed use of both in the diagonal of northeast and southwest regions. The arrows indicate possible directions of evolution of business models, depending on the trade-off of various driving factors due to codifiability.

Case Study Evidence

THIS SECTION PROVIDES SOME PRELIMINARY EVIDENCE to support the LKW model. We first recall that Zander and Kogut [38] provided an initial test of the "codifiability hypothesis": they found that the speed, volume, and nature of governance of intra-firm transactions depend in essential ways on the codifiability of these transactions; the less codifiable a transaction, the slower the speed of adoption of interorganizational learning, of imitation by competitors, and the less intense the use of market governance versus negotiated contracts. The following five cases provide support of the above hypotheses in the B2B arena.

Case 1: XChem (Levi [22])

XChem is a leader in the chemical industry and purchases annually about $15 billion worth of products from its suppliers, mostly through its corporate headquarters purchasing department. Levi [22] examined a set of equipment purchases within XChem to determine the extent to which codifiablity of the underlying procurement transactions was associated with a larger supplier base for the transaction. Codifiablity was captured through the XChem's ranking of the difficulty of communicating requirements and specifications for the transaction in question. Some purchases were sourced from a high number of suppliers on a pre-qualified list (more than 5). For those purchases, XChem does

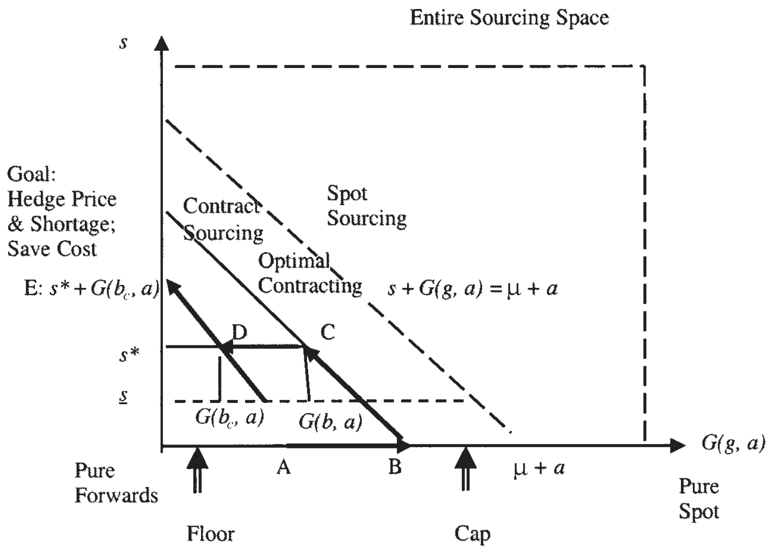

Figure 3. Managerial Implications of the LKW Model. *Notes:* A possible trajectory recommended by the LKW model that enables a continuous Pareto improvement to the optimum (from point A to E) for contract structures for capital-intensive industries. The starting point A depicts the current popular "best of practice" (i.e., fixed or flex IT contract structure used in the semiconductor industry), where $s = 0$, floor price < $G(g, a)$ < cap price. The LKW model suggests that huge gains can be achieved by adopting an options-and-forwards contract structure, properly designed.

not establish long-term contracts but purchases on an as-needed basis from any qualified supplier, typically with a short order lead time. Other commodities are procured by long-term contracts from three or fewer suppliers. Levi [22] shows that there is a pattern in his sample consistent with more codifiable transactions corresponding to a higher supplier base and lower overall investments required to pre-qualify suppliers. This is consistent with H1 and H3 above.[12]

Case 2: FreeMarkets (Day et al. [5])

FreeMarkets also provides on-line auction capabilities, but for buyers and sellers of industrial parts, raw materials, commodities and services in over fifty product categories. Since 2000, FreeMarkets has grown eMarketplace users by 31% to 131. In addition, the company now has over 200 supply verticals and over 150,000 suppliers participating in its online auctions worldwide. Since 1995, over $40 billion of commerce has been facilitated by FreeMarkets. . . . Instead of an open exchange, the company works with its customers to design, arrange, and conduct on-line auctions for well-specified commodities from a pre-screened group of qualified vendors. This strategy is well-suited to the needs of purchasing and sourcing agents, reflecting founder Glenn Meakem's experience at GE's procurement group prior to founding FreeMarkets.

FreeMarkets is a perfect example of the codifiability hypothesis and our model. It is an independent (pure-play) public exchange, leveraged by Internet technology and viable as a stand-alone value-added B2B exchange. It uses a prescreened group of qualified vendors for well-specified commodities. The FreeMarkets type of business model is sustainable in part because it works in a highly codified space with highly codified processes and utilizes a highly codified purchasing method, namely auctions. In Figure 2, FreeMarkets is clearly in the low–low (southwest) quadrant.

Case 3: Electronic Components (Laseter et al. [20])

> PartMiner Inc., founded in 1993 to serve the global electronic-components industry, is representative of the Total Procurement segment. This e-Marketplace provides Internet-based applications to facilitate the product selection and purchasing processes. Like most early startups, PartMiner began with a revenue model that combined subscription fees and a transaction charge. The model soon proved unsustainable for the company, as it has for many other e-Marketplaces in this segment. In June 2000, PartMiner canceled all of its 2,200 subscriptions and relaunched. It now provides free access with no transaction fees, but charges a small fee for the services of a team of professional buyers who search for rare and hard-to-find components. With this free-access model, PartMiner hopes to draw users to the site and profit from the revenue generated from the 2 percent of its users who need assistance obtaining hard-to-find products.

Thus, PartMiner provides an online exchange for less codifiable products, that is, electronic components, which may have significant adaptation costs (i.e., high "a" in the LKW model). Its main value is to serve as a matching platform to lower this adaptation cost. PartMiner uses highly codifiable items to increase the liquidity of the exchange, but, as it found out, highly codifiable items also make competition easier. The basic value proposition here is to have customers pay for the uncodifiable segment of PartMiner offerings. In Figure 2, PartMiner occupies the low–high (northwest) quadrant. As we can see, PartMiner has successfully evolved its business model from the low–low quadrant to the low–high quadrant as a consequence of learning the codifiability aspect of its niche.

Case 4: Appliances (Day et al. [5])

> While the concept of Brandwise.com, a comparison-shopping website for appliances, was appealing it was unable to overcome two killer constraints. Up to 80 percent of sales to consumers of appliances are immediate replacements of broken units, leaving no time or inclination for careful comparison-shopping. Another impediment was the inability of geographically dispersed and incompatible retail systems to communicate inventory status or fulfill orders. The existing system had long adapted to these rigidities and had little incentive to change.

The transactions that Brandwise attempted to support are characterized by high I and high $b_s - b_c$, that is, the high–high quadrant in Figure 2. But they were not successful in generating sufficient up-front investment to cover the costs I of establishing efficient and collaborative communication required in this quadrant. One would expect sustainable exchanges in the high–high quadrant to be rare and to only occur with relatively high-volume, relationship-specific transactions that would support the high costs of setting up and maintaining a private or consortium exchange.

Case 5: Neoforma (Day et al. [5])

> When demand for its open exchange did not materialize quickly, Neoforma began to shift away from the independent B2B exchange strategy toward building marketplaces to support existing relationships. Neoforma's most significant deal came with Novation, the largest hospital group purchasing organization (GPO) in the United States. In return for building a custom marketplace for Novation and its 400 hospital members, Neoforma gave a 45% ownership stake and two Board seats to Novation. Neoforma continues to add new clients as part of this new strategy.

Neoforma evolved successfully from the low–low quadrant (public, open exchange) in Figure 2 to the high–low quadrant (private network) by enhancing value-added services that effectively made contract offerings of medical products, supplies, and equipment available at low transactions costs to members of this private exchange. Initially, they thought of themselves as playing the central role in this market, but they came to realize that uncodifiability of many transactions required that they play rather a supporting role in facilitating contracting services. The Neoforma case illustrates the importance of aligning the structure of an exchange to the nature of the transactions involved. Neoforma recognized a sustainable niche by helping suppliers take advantage of the significant cost differences between b_s and b_c. Buyers profit through the lower price occasioned by the expanded supplier base.

Managerial Relevance

We now discuss the managerial relevance of the LKW framework. To illustrate, we use Figure 3 to demonstrate how our findings should be useful for IT contracting for capital-intensive industries, such as the semiconductor industry. Current industry "best of practice" is characterized essentially by two contract forms: quantity fixed contracts and quantity flexible contracts. Both contracts specify a price floor (to protect the interest of the supplier) and a price cap (to protect the interest of the buyer). An example of a quantity fixed contract looks like "Buyer reserves exactly 1,000 units of 256 MB DRAM chips next quarter at the price of $3," whereas a quantity flexible contracts reads "Buyer reserves *up to* 1,000 units of 256 MB DRAM chips next quarter at the price of $3." In either case, we see that the supplier bears all the risks, as there is no reservation fee involved and the buyer can cancel its order in case of low demand or lower than contract price in the spot market. As a consequence, these contracts are frequently not enforced in excess-demand or excess-supply conditions.

In contrast, our model effectively shares the risk between the supplier and the buyer by allowing the supplier to collect a reservation fee, and link the contract quantity with execution fee (moving from the current practice at point A to improved performance at B). This benefits both the supplier and the buyer. Once demand is linked with the execution fee, and noting our no-excess-capacity condition (see the Appendix), the buyer will not overbook unused capacity from the supplier. Further, it is in the best interest of the supplier to truthfully reveal its production cost, making the reservation fee the basic profit driver. The buyer is indifferent as long as the price index ($s + G(b, a)$) remains unchanged (moving from the initial options contract at B to the Pareto-improved contract at C). If cost advantages to contracting ($b_c < b_s$) can be captured through better planning and staffing, then these provide additional reasons for moving to more contract-intensive procurement and for further altering the contract (moving from C to D, benefiting both parties).

We note that in the presence of low codifiability, with high adaptation costs, the efficient options contract becomes effectively a pure forward (in which case the buyer is indifferent between the options contracts D and the pure forward E). The path from the initial inefficient contract A to the more efficient contracts D or E clearly benefits buyers and suppliers alike and achieves efficient risk allocation between them, reaching the joint goals (price and shortage hedging and cost saving) of structured sourcing discussed earlier.

Finally, we note the application of the LKW framework to classify, understand, and predict the evolution of B2B exchanges, as captured in Figure 2.

Conclusion and Further Research

THE FRAMEWORK DEVELOPED HERE GENERATED several important results that help to explain the recent evolution of B2B exchanges. Principally, we find that codifiability is a critical factor in explaining how e-exchanges are likely to support various types of transactions. In particular, our results show how optimal procurement contracting depends on several consequences of codifiability. We represented these consequences through three effects: the magnitude of IT investments required to participate in contract markets, the production cost advantages of contract versus spot markets, and the adaptation costs of last-minute procurement for the buyer. These consequences of codifiability had rather intuitive effects in equilibrium, with contract sourcing advantages leading to more intensive use of contracts. But the framework developed shows that the significance of these consequences depends on a number of key features of the market (e.g., the nature and volatility of spot price, the level and price sensitivity of buyer demand, access conditions for suppliers, and the intensity of competition in the contract market). In particular, a direct link between the spot price distribution and the equilibrium contract price was derived, showing how B2B exchanges can provide valuable price discovery for underlying contracting, even when the volume of transactions on the spot market is relatively low. Balancing these effects in a rational economic framework and deriving the characterizing conditions for equilibrium price and purchasing behavior have been the major contributions of this paper. As noted, our conclusions are consistent with recent empirical evidence on survival of B2B exchanges and have important managerial consequences for both efficient contracting and procurement practice.

One of the trends being witnessed in the B2B e-exchanges arena is the move of many transaction marketplaces toward collaboration facilitators. Whereas our analytical research does not examine this per se, the existence and nature of codifiability provides some explanation. What we see is that those exchanges that encountered relatively uncodifiable transactions have found that a pure transactional exchange is not viable. In the face of uncodifiability, many e-exchanges have turned to facilitating the codification process between buyers and suppliers. We emphasize that an item to be transacted may be highly codifiable, whereas the overall transaction may not be, resulting in the failure of the pure transactional e-exchange. This difference suggests an important future research area to map different possible types of uncodifiability and the corresponding and appropriate modes of interaction and market configuration.

Other areas of future research include the examination of the consequences of supplier heterogeneity, and efficient sharing of total exchange fixed costs (so that the fixed costs I, assumed identical across firms in our model, become not only variable but endogenous to the establishment of the exchange). In these extensions, and supporting empirical work, we fully expect that codifiability as it interacts with interfirm relationships will be a central concept in explaining market structures, hierarchies, and modes and methods of transactions between firms. The framework above, building on the important WK framework and combined with the Levi [22] approach of segmented supplier management, promises to be a rich vein of research on contracting and IT strategy in the B2B arena.

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Notes

1. For example, in the chemical industry and others, top players all implemented the same enterprise resource planning (ERP) system, namely SAP R/3, with one primary intent being to lower transactions costs in order fulfillment and contracting. See, for example, Hitt et al. [15].
2. See, for example, www.dramexchange.com.
3. For more information about proposed contract structures and trading rules, see info.sgx.com/SGXWeb_DT.nsf/DOCNAME/DRAM_Futures/; see also Santiago [27].

4. Source: private communication or interview with Jim Feldhan, President, Semico Research Corporation; Dr. Thomas Olafsson, Manager of Supply Chain Operations, Hewlett Packard; Dr. Dailun Shi of IBM.

5. For more information, see the company's Web site at www.converge.com.

6. Extending the framework to multiple buyers is straightforward, as noted in Wu et al. [37]. The generalization is accomplished by allocating equilibrium supply to buyers in order of their willingness to pay, as in standard demand theory.

7. See also Mendelson and Tunca [25] for a formal investigation of the impact of liquidity on B2B exchanges, but in a different setting than modeled here.

8. Since we are assuming identical suppliers, we will suppress the subscript i in what follows.

9. It is straightforward to show that the law of one price in the equilibrium in Wu and Kleindorfer [36] holds here as well. What it says is that there can only be one price in the equilibrium if it exists.

10. $h(v, n)$ is quasi-concave and differentiable in v, as $D(v, a)$ is well behaved.

11. In the single supplier case, Condition 1 is replaced by $p = \max\{\text{argmax}_p(p - c(a))D(p, a), D^{-1}(K, a)\}$, as solved in Wu et al. [37].

12. Note that there is, for most equipment purchases in the chemical industry, only a very thin spot market. However, nothing in the LKW framework requires that there be an actual spot market; the results of Theorem 2 continue to hold even when a is very large.

References

1. Bakos, J.Y., and Nault, B. Ownership and investment in electronic networks. *Information Systems Research, 8,* 4 (December 1997), 321–341.

2. Clemons, E., and Kleindorfer, P.R. An economic analysis of interorganizational information technology. *Decision Support Systems, 8,* 5 (September 1992), 431–446.

3. Coase, R.H. The nature of the firm. *Economica, 4,* 16 (November 1937), 386–405.

4. Dai, Q., and Kauffman, R.J. B2B e-commerce revisited: Leading perspectives on the key issues and research directions. *Electronic Markets, 12,* 2 (Spring 2002), 67–83.

5. Day, G.S.; Fein, A.J.; and Ruppersberger, G. Shakeouts in digital markets: Lessons from B2B exchanges. *California Management Review, 45,* 2 (Winter 2003), 131–150.

6. Deng, S.M., and Yano, C.A. On the role of a second purchase opportunity in a two-echelon supply chain. Working paper, Department of Industrial Engineering and Operations Research, University of California, Berkeley, September 2002.

7. Donohue, K. Efficient supply contracts for fashion goods with forecast updating and two production modes. *Management Science, 46,* 11 (November 2000), 1397–1422.

8. Dyer, J.F. Specialized supplier networks as a source of competitive advantage: Evidence from the auto industry. *Strategic Management Journal, 17,* 4 (April 1995), 271–291.

9. Golovachkina, N., and Bradley, J.R. Seller-manufacturer relationships under forced compliance contracts. Working paper, Johnson Graduate School of Management, Cornell University, Ithaca, June 2002.

10. Han, K.; Kauffman, R.J.; and Nault, B.R. Who should own "IT"? Ownership and incomplete contracts in interorganizational systems. Working paper, MIS Research Center, Carlson School of Management, University of Minnesota, Minneapolis, April 2003.

11. Hart, O., and Moore, J. Property rights and the nature of the firm. *Journal of Political Economy, 98,* 6 (December 1995), 1119–1158.

12. Helper, S., and MacDuffie, J.P. B2B and modes of exchange: Evolutionary and transformative effects. In B. Kogut (ed.), *The Global Internet Economy.* Cambridge, MA: MIT Press, 2003, pp. 331–380.

13. Helper, S., and Sako, M. Supplier relations in Japan and the United States: Are they converging? *Sloan Management Review, 36,* 3 (March 1995), 77–84.

14. Herter, J. F. Optionality in contract manufacturing in the electronics industry: An empirical study of current and potential applications. Ph.D. dissertation, Leipzig Graduate School of Management, Handelshochschule Leipzig (HHL), Leipzig, Germany, September 2002.

15. Hitt, L.; Wu, D.J.; and Zhou, X. Investment in enterprise resource planning systems: Business impact and productivity measures. *Journal of Management Information Systems, 19,* 1 (Summer 2002), 71–98.

16. Joskow, P. Contract duration and relationship-specific investments: Empirical evidence from coal markets. *American Economic Review, 77,* 1 (March 1987), 168–185.

17. Kaplan, S., and Sawhney, M. E-hubs: The new B2B marketplaces. *Harvard Business Review, 78,* 3 (May–June 2000), 97–103.

18. Kisiel, R. Covisint hit by fall in revenue from auctions. *Automotive News Europe* (July 29, 2002) (available at europe.autonews.com, accessed June 13, 2003).

19. Kleindorfer, P., and Wu, D.J. Integrating long-term and short-term contracting via business-to-business exchanges for capital-intensive industries. *Management Science,* Fall 2003, forthcoming.

20. Laseter, T.M.; Long, B.; and Capers, C. B2B benchmark: The state of electronic exchanges. *Strategy + Business, 25* (4th quarter 2001), 33–42.

21. Lee, H., and Whang, S. The impact of the secondary market on the supply chain. *Management Science, 48,* 6 (June 2002), 719–731.

22. Levi, M. B2B: Supplier management, investments in information systems, and codifiability. Ph.D. dissertation, Wharton School, University of Pennsylvania, Philadelphia, 2002.

23. Martínez-de-Albéniz, V., and Simchi-Levi, D. Competition in the supply option market. Working paper, OR Center, Massachusetts Institute of Technology, Cambridge, April 2003.

24. Mas-Colell, A.; Whinston, M.D.; and Green, J.R. *Microeconomic Theory.* New York: Oxford University Press, 1995.

25. Mendelson, H., and Tunca, T.I. Liquidity in industrial exchanges. Working paper, Graduate School of Business, Stanford University, April 2003.

26. Novak, S., and Eppinger, S.D. Sourcing by design: Product complexity and the supply chain. *Management Science, 47,* 1 (January 2001), 189–204.

27. Santiago, T. Singapore eyes DRAM futures to attack price fluctuation. *EE Times,* September 19, 2002.

28. Slater, G., and Spencer, D. A. The uncertain foundations of transaction costs economics. *Journal of Economic Issues, 34,* 1 (March 2000), 61–87.

29. Spinler, S.; Huchzermeier, A.; and Kleindorfer, P.R. Risk hedging via options contracts for physical delivery. *OR Spectrum, 25,* 3 (2003), 379–395.

30. Walker, G., and Weber, D. Supplier competition, uncertainty, and make-or-buy decisions. *Academy of Management Journal, 30,* 3 (September 1987), 589–596.

31. Williamson, O.E. *Markets and Hierarchies: Analysis and Antitrust Implications.* New York: Free Press, 1975.

32. Williamson, O.E. *The Economic Institutions of Capitalism.* New York: Free Press, 1985.

33. Williamson, O.E. *The Mechanisms of Governance.* New York: Oxford University Press, 1996.

34. Wilson, C. A model of insurance with incomplete information. *Journal of Economic Theory, 16* (December 1977), 167–207.

35. Wise, R., and Morrison, D. Beyond the exchange: The future of B2B. *Harvard Business Review, 78,* 6 (November–December 2000), 86–96.

36. Wu, D.J., and Kleindorfer, P. Competitive options, supply contracting and B2B exchanges. Working paper, Department of Operations and Information Management, Wharton School, University of Pennsylvania, Philadelphia, April 2003.

37. Wu, D.J.; Kleindorfer, P.; and Zhang, J.E. Optimal bidding and contracting strategies for capital-intensive goods. *European Journal of Operational Research, 137,* 3 (March 2002), 653–672.

38. Zander, U., and Kogut, B. Knowledge and the speed of transfer and imitation of organizational capabilities: An empirical test. *Organization Science, 6,* 1 (January–February 1995), 76–92.

Appendix

Model Assumptions of WK

A1: Buyer's willingness-to-pay (WTP) $U(z)$ is assumed to be strictly concave and increasing so that $U'(z) > 0$, $U''(z) < 0$, for all $z > 0$.

A2: No excess capacity. For any last unit provider k (i.e., with the maximum index g_k), then $D_s(g_k) \geq Q_1 + ... + Q_{k-1}$.

A3: Proportional bid–tie allocation. When there is a bid–tie among a set of suppliers, then the buyers' demand for this supplier's output is proportionally allocated to the suppliers according to their bid capacity.