Integrating Long- and Short-Term Contracting via Business-to-Business Exchanges for Capital-Intensive Industries

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This paper surveys the underlying theory and practice in the use of options in support of emerging business-to-business (B2B) markets. Such options, on both capacity and output, play an important role in integrating long- and short-term contracting between multiple buyers and sellers in such markets. This trend is especially important in capital-intensive industries, where improvements in fine tuning the coordination of supply and demand carry large economic benefits. Typically, such options are benchmarked (or defined) on the basis of spot market information conveyed through near real-time B2B transactions. This paper notes a broad set of goods and services currently being traded in both B2B short-run markets and long-term contract markets, and reviews economic and managerial frameworks that have been proposed to explain the structure of contracting in these markets. We provide a general framework based on transactions cost economics, and we use this framework to provide a review and synthesis of existing literature to explain various types of contracting linked to B2B exchanges in capital-intensive industries. The paper concludes with a discussion of implementation challenges and open research questions.

(*B2B Exchange; Real Options; Long-Term Contracting; Capacity; Competitive Equilibrium; Codifiability*)

1. Introduction

Arguably, the central problem in e-business addressed by operations research/management science (OR/MS) is better coordination of supply and demand, including price discovery and reduction of transactions costs of buyer-seller interactions.[1] In capital-intensive industries like chemicals and steel, the out-of-pocket costs of excess capacity and the opportunity costs of underutilized capacity have been important factors driving the growth of exchanges for improving demand and supply coordination through e-business platforms. The emerging reality of such exchanges is, however, complex in terms of product range, protocols for joining the exchange, and rules for operations and settlement. An interesting aspect of this evolution for OR/MS is the parallel development of long- and short-term markets for capacity and output, accompanied by a range of exotic options and forwards as the basic mechanisms supporting transactions. This development builds on the powerful framework of real options, while directly connecting to key operations decisions (capacity planning, staffing, maintenance, and so forth) of the plants

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[1] An interesting recent study of transactions costs in B2B markets by Garciano and Kaplan (2001) suggest that the transactions costs savings alone from B2B exchanges can be a significant portion of the total cost of production and order fulfillment.

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and technology whose output is the focus of contracts. From a practitioner's point of view, the integrated use of these Internet-based contracting mechanisms, as facilitated by the new exchanges, represents an opportunity for further improving supply chain performance and capital asset productivity (Geoffrion and Krishnan 2001).

A central feature of B2B in capital-intensive industries is that contracting needs to assure that most of a plant's output in such industries is contracted for well in advance. Failure to do so for a nonscalable technology is a recipe for last-minute confusion and huge excess costs. However, there is still an important role for short-term fine tuning of capacity and output to contract for, say, the last 10% of a plant's output or a customer's requirements. Doing so requires a conceptual framework, congenial to e-business, that allows contracting to occur at various points of time, constrained by commitment and delivery options and flexibilities. Elements of this conceptual framework for the B2B area of interest here include the following:

(1) Establishing and governing long-term relationships between agents in supply chains (e.g., Grey et al. 2002).

(2) Determining the strategic value and conditions for viability of B2B electronic exchanges, including the design of such exchanges (e.g., Mendelson and Tunca 2003, Santos and Scheinkman 2001).

(3) Price discovery and price structure in the context of electronic exchanges, including the design of auctions (e.g., Peleg et al. 2002).

(4) Supply chain integration, optimization, and informational coordination in the B2B context (e.g., Cachon and Lariviere 2001, Lee et al. 2000, Lee and Whang 2002, Swaminathan and Tayur 2003).

(5) Integrating contracting and market structure with operational decisions (capacity, technology choice, production) for profitable coordination and risk management (e.g., Cohen and Agrarwal 1999, Serel et al. 2001, Wu et al. 2002, Wu and Kleindorfer 2003).

In this paper, we focus on (5) above. The problem we address presumes that relationships and exchanges have been established, together with appropriate price discovery mechanisms. The central problem we address is the efficient integration of contracting and exchange-based procurement in B2B markets.

Examples of the Problems Considered Abound. Some typical examples of the problem examined in this paper include chemicals, commodity metals, semiconductors, and electric power. For example, in the electric power industry, as discussed in Clewlow and Strickland (2000), the deregulation of the sector has led to an explosion of activity by financial and energy intermediaries, offering both futures and options products.[2] These exist through the New York Mercantile Exchange and Chicago Mercantile Exchange in the United States and other exchanges throughout Europe, Latin America, and Asia. These products provide various rights and obligations to buyers and sellers for the purchase of energy delivered at specific places and times.

In the semiconductor industry, as discussed in Brown et al. (2000), normally semiconductor output is done to specifications. But a significant portion of semiconductor foundry capacity is being devoted to programmable semiconductors decreasing the customization and adaptation costs for buyers. The specific character of such semiconductors is then only determined ex post, after logic programming has been completed. This, in effect, allows postponement of the final design of the semiconductor until market demand is known. For this type of semiconductor manufacturing, the use of flexibility contracts, integrated spot markets (e.g., for memory chips), capacity options, new data, and modeling techniques are playing an increasingly important role in promoting efficient risk management.

Commodity chemicals, metals, and plastics are further applications areas for such contracting innovations, and significant exchanges already exist for these commodities, e.g., www.Metalsite.com, www.PaperExchange.com, and others with global reach. Other B2B exchange examples go beyond commodities, and include goods and services "from A to Z,"[3] such as aerospace, broadband, computing

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[2] See, e.g., www.AlphaEnergy.com.

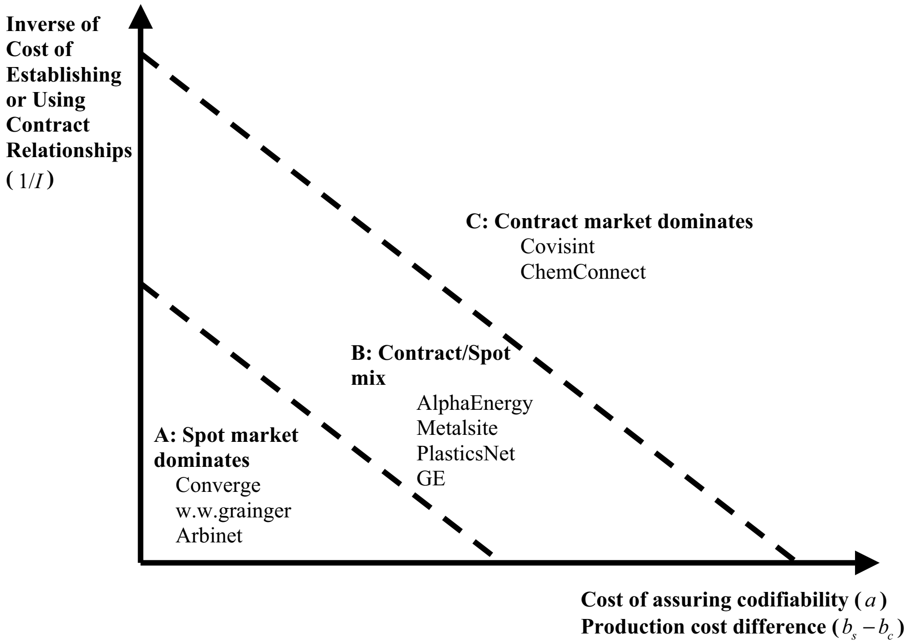
[3] The interested reader may trace the incursion of these transactions in the B2B area through the website tracking a collection of B2B markets (www.business.com).

and electronics products, heavy industrial equipment, solid waste, voice minutes, and so forth.

Several classification schemes for B2B exchanges have been proposed (e.g., Kaplan and Sawhney 2000). Our interest here is on the nature of the buyer-seller relationships in B2B markets. For this purpose, we develop a new classification emphasizing transactions costs (Williamson 1985) and codifiability, where codifiability means the ability to electronically specify product, delivery, and settlement requirements in a verifiable manner (Zander and Kogut 1995). The issue of codifiability of the B2B transaction has been identified as one of the key driving factors for the success of B2B exchanges (Dai and Kauffman 2002, Grey et al. 2002). The implications of transactions costs and codifiability are realized for different goods in different ways, as shown in Figure 1. The horizontal axis measures the codifiability of the transaction, which we capture through two "costs." The first cost, the "adaptation cost," is the unit cost of customizing product purchased in the exchange to the particular use required. The higher the adaptation cost is, the less satisfactory are spot purchases on the exchange relative to contract purchases, which we assume are "made to order" and do not require adaptation cost. The second cost is the incremental production cost associated with producing the good for spot sales versus contract sales. This incremental cost is associated with the lower cost of more stable contract production that allows, through advanced planning, lower cost staffing, maintenance, and other production decisions under contract procurement than the corresponding production cost under "last-minute" production for the spot market (Donohue 2000). We think of these two cost factors as both being driven by the relative codifiability of the transaction. Clearly, the higher these costs, the more contract intensive one would expect the corresponding transaction to be, as shown in Figure 1.

The vertical axis in Figure 1 measures the cost of establishing a reliable relationship, including the verification of credit worthiness, expertise in health and safety requirements, and any idiosyncratic investments required for participants in a B2B exchange to be able to execute legitimate transactions electronically. The cost of establishing this relationship may be represented again by two cost factors. The first is the sunk investment cost required for idiosyncratic investments, e.g., establishing compatible information technology (IT) platforms such as Enterprise Resource

Figure 1 **A Classification of B2B Exchanges and Contracting**



Planning (ERP) systems. The second is the technology and market access condition that represents the opportunity cost of spot market participation relative to contract sales for a given seller. As either of these two costs increase, the stronger the advantages of the spot market.

From Figure 1, we identify three "bands" or regions of types of transactions and associated efficient market structures. We have entered some examples in each of the regions of Figure 1 on current exchanges. The first region encompasses those transactions we would expect to see mediated only via spot markets. These are transactions for low-value items that require little effort to verify product attributes, quality or credit requirements for buyers or sellers. On the other extreme are transactions that, by reason of the required customization and difficulty of verifying the qualifications of buyers and sellers to transactions, can only occur after screening and qualification of sellers and buyers have taken place and all product and delivery requirements have been set through joint negotiations. Such transactions might use B2B exchanges, including options, but then only on the basis of contractually preagreed product and delivery structures, and for a closed group of prequalified buyers and sellers. Depending on the codifiability of such transactions, some limited final adjustment of supply and demand may be possible via the exchange, but even this might be precluded for one-off customized requirements.

The underlying choice of contract versus spot procurement involves both cost and time trade-offs. Contracting requires time and leads to fixed costs to establish the buyer-seller systems and procedures that underlie contract execution. The benefits of contracting are lower variable production and transactions costs, including the costs of poor quality and off-spec product, and a higher probability of order fulfillment in the face of demand volatility. Spot purchases from generalized sellers, and perhaps fulfilled using generalized logistics providers, provide access to a broader competitive market, and allow fine tuning of demand and supply, but possibly at higher unit costs associated with the poorer matching of product specifications and delivery features with the buyer's requirements. Contracting must be done in advance, and sometimes well in advance, of physical delivery requirements, and this may require increased investments in capacity or in customization required of sellers to support contract execution relative to spot market transactions. The trade-off between these costs and risks fundamentally depends on the codifiability of transactions and the volatility of demand.

What are the key implications of these innovations for operations and strategy? The first implication is that B2B exchanges are providing nonmanipulable indices of value for important operational choices (capacity, utilization, contracting (when and how much), technology, and so forth) so that, for the first time, senior management and the market can evaluate the quality of company decisions related to capacity, demand management, and fulfillment. Thus, if the historical probability distribution of price for daily or weekly delivered spot price for a good is known, this provides both the means for better management of contracting decisions for this good, and a clear benchmark for valuing short and long positions by both buyers and sellers. It is for this reason that B2B exchanges are the bow wave of a revolution not only in contracting and financial management, but in the integration of contracting, procurement, capacity management, and technology choice based on these innovations. The challenges and rewards for OR/MS in this domain are huge.

What has changed? Prior to the emergence of B2B exchanges and the contracting innovations of interest here, the focus in procurement was on negotiation, and a host of idiosyncratic aspects of contracting (see Cachon 2002, Lariviere 1999, Tsay et al. 1999 for excellent reviews). Certainly, contracting, screening, and supplier management will remain essential elements of supply chain management, and especially for noncodifiable goods and transactions. But for those elements that, either through closed or open exchanges, can be further refined to cope with ongoing shocks and volatility, the existence of exchanges has introduced a fine-tuning mechanism that improves operational performance and simultaneously helps to value longer-term contractual, capacity, and technology decisions. The vortex or center point of this new perspective is the integration of traditional forms of contracting with shorter-term, market-driven transactions. This integration is the focus of this paper.

This paper is organized as follows. Section 2 presents a modeling framework of short- and long-term contracting. Section 3 follows with the introduction of a taxonomy that allows us to survey key-related contributions in the literature. In particular, we review recent innovative methodological applications (from real options theory and financial engineering) in this domain and build on Figure 1 to provide an integrative perspective on these methodologies. Section 4 explores the challenges in implementing these types of interconnected contracting and spot market strategies, and §5 points to some important open research questions that surround this area of e-business.

2. A Modeling Framework and the Base Case

2.1. A Modeling Framework

Let us consider an analytical framework capturing the basic elements of the above discussion. We first describe a three-period time line for trading in the B2B exchange.

Period 0. Before the fact, at Period 0, capacity and technology choices are made by sellers. As we will see, these choices will be different when rational operations managers know that they can fine tune demand and supply through the B2B exchange than when such an exchange does not exist.

Period 1. At Period 1, with updated information on the distribution of spot prices, sellers and buyers contract with one another, using options and forwards, for delivery of some good (either storable or nonstorable) at the second period.[4]

Period 2. Finally, at Period 2, after possibly additional information updating, options are called, deliveries are made, and additional sales and purchases are made in the short-term spot (or cash) market.

Between Periods 1 and 2, there may be additional trading of options and additional, possibly continuous, updating of information on spot prices. In this paper, to keep matters simple, we will assume a discrete-time framework with no secondary trading. Thus, we will only be concerned with the indicated decision instants: Periods 0, 1, and 2.

Assume the technology of each seller (he) is characterized by (b, K), where b is the seller's short-run marginal cost of providing a unit, and K is the seller's total fixed available capacity in the short run.

The decision variables for the seller are the optimal contract $[s, g]$ to offer to the buyer, where s is the reservation cost per unit of capacity, and g is the execution cost per unit of output.[5] Thus, if $g = 0$, then the contract is a pure forward; if $g > 0$ it is an option. Some options-based contracts are structured as "must produce-must exercise," i.e., with probability 1, they will be exercised on the day by the buyer. For convenience, we will refer to these contracts as forwards as well.

The decision variables for the buyer (she) are how much to contract Q at Period 1 with each seller, and at Period 2, how much to execute from the contract q and how much to procure from the spot market x. The buyer's total demand D on the day (at Period 2) is assumed to be common knowledge.[6]

The spot market price P_s is uncertain before it is revealed at Period 2. The spot market price can be

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[4] A forward is a fixed commitment to deliver a specific quantity of a good to a particular delivery point, at a particular, future point in time, at a fixed, prespecified unit price. An option is the right, but not the obligation, to take delivery of (call option) or sell (a put option) a specific quantity of a good at a particular delivery point, at a particular future point in time, at a fixed, prespecified unit price. Options typically face a maturation date, prior to the specified delivery date, which is the latest date at which the option can be executed. If the option is not executed as of that date, it no longer represents a counterobligation for fulfillment. There are a variety of types of options—American, European, and Asian, the details of which will not be analyzed here. For details on definitions, valuation methods, and applications in various markets, see Luenberger (1998) and Hull (2000).

[5] Note that the structure of the two-part contract $[s, g]$ is standard in the options literature and in practice. We thank Andy Huemmler of Exelon Corporation and Robert Levin of the New York Mercantile Exchange for valuable discussions regarding existing options markets, where such contracts are routinely used.

[6] In this setting, note that $q = \min[D, Q]\chi(P_s - g) \leq Q$ must hold, where $\chi(z) = 1$ if $z > 0$ and otherwise $\chi(z) = 0$ if $z \leq 0$.

exogenous (open) or endogenous (closed).[7] The density function of the spot price is denoted $f(P_s)$ with mean $\mu = \mathrm{E}\{P_s\}$; $f(P_s)$ is also assumed to be common knowledge.

The objective of the buyer is to maximize expected utility or expected profit subject to available option contracts. The objective of the seller is to maximize expected profit, jointly obtained from sales in both the contract market and the spot market and subject to the seller's capacity constraint. The attitude of the seller and the buyer can be either risk neutral or risk averse. A key factor influencing their incentives to sign contacts is due to imperfect market access on the day, capturing the inefficiencies of the spot market via a function $m(P_s)$, which is defined as the probability ($m(P_s)$) that the seller can find a last-minute buyer on the spot market when the realized spot price is P_s. This market access probability function will be determined by different factors in different market settings, but generally may be thought of as a measure of the liquidity of the market. In electric power, access will depend on transmission constraints, e.g., where certain sellers may face significant barriers to their participation in the spot market, as dispatched by the Independent System Operator, because of transmission constraints.

2.2. The Base Case and Examples

To illustrate the above framework, we consider a risk-neutral seller and a risk-neutral buyer, transacting some nonstorable good via an open global exchange (i.e., no party can control the spot market price as the market is global). This sets up the base case for our survey (this base case is formally modeled in Wu et al. 2002). In this base case, we assume no adaptation cost and no contract or spot production cost differences. The buyer requires the intermediate input from the seller to meet the buyer's own final demand.

The buyer's problem at Period 1 is to determine the optimal number of options (Q) to contract for with the seller. To do so, the buyer solves her problem by using backward induction. At Period 2, given realized final demand, she derives her optimal portfolio of input purchases from the spot market and from any options she has purchased from the seller in Period 1. Note that the presence of options changes the buyer's behavior. When options are not available, then the buyer's demand function at Period 2 is the normal downward sloping demand curve, $D_s(P_s) = \arg\max[U(D_s) - P_s D_s] = (U')^{-1}(P_s)$, where U is the buyer's Willingness-to-Pay (WTP) function, which is assumed strictly concave and increasing.[8] However, if the buyer has contracted for Q options, then the buyer's optimal demand curve can be shown to be kinked; that is,

$$D = \max[D_s(P_s), Q] = \max[(U')^{-1}(P_s), Q].$$

At Period 1, the buyer's problem is to contract a reservation level Q to maximize its expected utility, i.e.,

$$\begin{aligned}
\underset{Q\geq 0}{\text{Maximize}} \quad & \int \big[U(D) - sQ - gq - P_s x\big] f(P_s)\, dP_s \\
&= \underset{Q\geq 0}{\text{Maximize}} \int \big[U(D) - P_s D + (P_s - g)^+ \\
&\qquad \cdot \min[D, Q] - sQ\big] f(P_s)\, dP_s \\
\text{s.t.} \quad & q = \min[D, Q]\chi(P_s - g) \leq Q \leq K, \\
& \text{where} \quad z^+ = \max\{z, 0\}.
\end{aligned}$$

In the buyer's utility function, the first term is its WTP at P_s, evaluated at the realized demand D, the second and the third term together are the payment for the goods delivered under the long-term contract, and the fourth term is the payment for goods purchased in the spot market.

It is straightforward to show that the buyer's optimal procurement strategy in the presence of options is to reserve $Q = D_s(G^{-1}(s + G(g))) = (U')^{-1}(G^{-1}(s + G(g)))$ at Period 1, where G, the "effective price function," is defined as $G(p) = \mathrm{E}[\min(P_s, p)]$. G^{-1} is the inverse function of G. At Period 2, the optimal strategy for the buyer is rather simple: If $P_s > g$, she will exercise all her options and procure any additional needs from the spot market. Otherwise, if $P_s \leq g$, she will forgo her options but procure her entire needs from the spot market.

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[7] In most operations management (OM) models, demand uncertainty rather than spot market price uncertainty is directly modeled. However, these two approaches are essentially equivalent (Lariviere 1999).

[8] This basically says that the normal demand curve $D_s(P_s)$ at Period 2 is downward sloping.

The price the buyer is willing to pay for this real option is given by rearranging $Q = (U')^{-1}(G^{-1}(s + G(g)))$, which yields[9] $s = G(U'(Q)) - G(g) = \mathrm{E}[(P_s - g)^+] - \mathrm{E}[(P_s - U'(Q))^+]$. Note that the conventional wisdom of $s = \mathrm{E}\{P_s\} - g = \mu - g$ does not hold here, as the seller can only sell a fraction $m(P_s)$ of his capacity if he only wants to sell at the last minute (Period 2). If he wants to sell in advance at Period 1 as options, the price must be less than $\mu - g$ for the buyer to be interested.

Taking the buyer's optimal response into consideration, the seller's problem is to maximize his expected profit (neglecting fixed capacity investment) at Period 1 by bidding a contract in the form of $[s, g]$, i.e.,

$$\begin{aligned}\underset{s,\,g\geq 0}{\text{Maximize}}\quad & \int \big[sQ(s,g) + gq - bq + (P_s - b)^+ \\ & \qquad \cdot\, m(P_s)(K - q)\big] f(P_s)\, dP_s \\ \text{s.t.}\quad & Q = D_s(G^{-1}(s + G(g))).\end{aligned}$$

In the seller's profit function, the first two terms represent the seller's revenue from the contract, the third term is the seller's cost of supplying q units to the buyer, and the fourth term is the seller's profit from the spot market.

Under weak regularity assumptions, it is straightforward to show that the seller's optimal strategy is to bid its unit production cost ($g = b$), by maximizing its profit via the optimal subscription charge s that is proportional to its opportunity cost ($\mathrm{E}[m(P_s)(P_s - b)^+]$) and inversely proportional to the buyer's demand elasticity.[10] These results extend classical results in public economics (Mas-Colell et al. 1995) to the new B2B context.

Why do the seller and buyer have the incentive to use such options-based contracts? First, consider the buyer. At Period 1, the buyer is paying an overall price less than the average spot market price, because $s + G(g) = G(U'(Q)) \leq G(U'(0)) \leq \mu$.[11] The seller is also willing to sell this option, because he is making more profit in the options market than in the spot market per unit of capacity as long as $s > \mathrm{E}[m(P_s)(P_s - b)^+]$, which can be shown to be his minimum requirement to participate in the options market. The buyer is willing to buy this option as long as the combined price $s + G(g)$ is less than μ. Thus, the active options trade spread lies between $\mathrm{E}[m(P_s)(P_s - b)^+] \leq s \leq G(U'(0)) - G(b) \leq \mu - G(b)$. An increase in m, which may be thought of as increased spot market liquidity, effectively shrinks the trade spread, even to the extent of foregoing the options market. Indeed, in this base model, when $m = 1$, the long-term contract market disappears. On the other hand, when the seller has limited or no access to the spot market, reflecting a decrease in m, he has to rely more heavily on long-term contracting and the options trade spread enlarges.

We may extend the base model to allow contract production to be cheaper than spot production, reflecting the benefits of advanced planning. Thus, assume that contract production has variable cost b_c and spot production has variable cost b_s with $b_c < b < b_s$. Then, the above options trade spread stretches in both ways, $\mathrm{E}[m(P_s)(P_s - b_s)^+] < \mathrm{E}[m(P_s)(P_s - b)^+] \leq s \leq G(U'(0)) - G(b) \leq \mu - G(b) < \mu - G(b_c)$, indicating a stronger incentive for both parties to contract (i.e., trade options). In particular, even when the seller has a perfect market access with $m = 1$, he still engages in options trading as long as $b_c < b_s$.

Below, we provide some numerical examples to highlight the key points in the framework as illustrated in Figure 1.

Numerical Examples. Suppose the spot market price follows an exponential distribution, $f(y) = e^{-y/30}/30$, which is assumed to be common knowledge.

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[9] The first equality holds due to the definition of the G function. The second equality makes use of the following identity: $\mathrm{E}[(P_s - z)^+] + \mathrm{E}[\min(P_s, z)] = \mu$.

[10] The exact formula for the optimal s is the following:

$$s = \begin{cases} \dfrac{\mathrm{E}[m(P_s)(P_s - b)^+]}{[1 - 1/\varepsilon_s(Q)]}, & Q < K, \\ G(U'(K)) - G(b), & Q \geq K, \end{cases}$$

where $\varepsilon_s(Q)$, the demand elasticity w.r.t. the subscription charge, is defined as

$$\varepsilon_s(Q) = \frac{s}{Q}\left|\frac{\partial Q}{\partial s}\right| = -\frac{s}{Q}\frac{\partial Q}{\partial s}.$$

[11] The first inequality makes use of the fact that $G' = 1 - F > 0$ and the assumption that $U' > 0$ and $U'' < 0$. The second inequality makes use of the following property of the G function: $\lim_{p\to\infty} G(p) = \mu$.

Table 1 Summary of Parameters and Results for Numerical Examples

Case	m	$(G(b_c), G(b), G(b_s), K)$	$(s, G(g), Q)$	(π_c, π_s, π)
1	0.0	(—, 10, —, 10)	(10, 10, 10)	(100, 0, 100)
2	0.5	(—, 10, —, 10)	(15, 10, 5)	(75, 50, 125)
3	0.5	(7, —, 12, 10)	(16, 7, 7)	(112, 27, 139)
4	1.0	(7, —, 12, 10)	(20.5, 7, 2.5)	(51.25, 135, 186.25)

Suppose the WTP function is $U(z) = 30z(\ln(30/z) + 1)$. Seller's technology is given by $(G(b_c), G(b), G(b_s), K)$ as in Table 1. Assume further that $m(P_s) \in [0, 1]$ is simply a constant. For any given offer $[s, g]$ by the seller, the buyer's optimal contract strategy is $Q = [30 - (s + G(g))]^+$.

Case 1. First, let us assume that the seller has no access to the spot market, i.e., $m = 0$, so that the seller's profit relies entirely on the options market. The seller's optimal bidding strategies are $s = (30 - G(b))/2$, where $g = b$. The buyer's optimal contract strategy $Q = [30 - (s + G(b))]^+ = 10$. The equilibrium is $(s, G(g), Q) = (10, 10, 10)$. The seller obtains an optimal expected total profit of $\pi = 100$.

Case 2. Now suppose the seller has some access to the spot market with $m = 0.5$, i.e., the seller can sell 50% of his residual capacity on the spot market. Consequently, the seller demands a higher price

$$s = (30 - G(b) + \mathrm{E}[m(P_s)(P_s - b)^+])/2 = 15$$

for his options (this shrinks the options trade spread), while keeping $g = b$. In responding, the buyer contracts less capacity relative to the previous $Q = 10$ to the current $Q = [30 - (s + G(b))]^+ = 5$. The new equilibrium solution is $(s, G(g), Q) = (15, 10, 5)$. But the seller's overall profit increases from previous $\pi = 100$ to $\pi = 125$. This is so because although his contract profit π_c decreases from 100 to 75, he makes additional profit from the spot market $\pi_s = 50$.

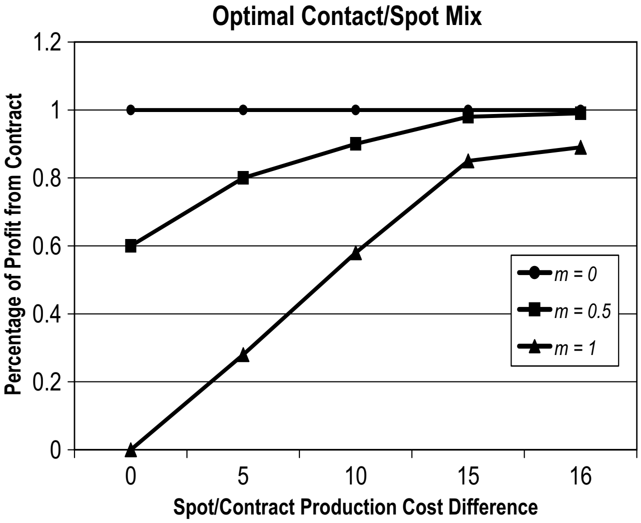
Case 3. In the third case, building on Case 2, suppose the seller has two production modes with $G(b_c) = 7$ and $G(b_s) = 12$. The seller now demands a higher price $s = (30 - G(b_c) + \mathrm{E}[m(P_s)(P_s - b_s)^+])/2 = 16$ for his options, but with $g = b_c$. The buyer actually contracts more ($Q = [30 - (s + G(b_c))]^+ = 7$) by taking advantage of a lower overall price. The equilibrium solution is $(s, G(g), Q) = (16, 7, 7)$. The seller's overall profit increases to $\pi = 139$, with a major impact coming from the options market $\pi_c = 112$, with an additional $\pi_s = 27$ from the spot market.

Case 4. Finally, building on Case 3, suppose the seller has perfect market access with $m = 1$. Not surprisingly, the seller demands the highest option price $s = (30 - G(b_c) + \mathrm{E}[m(P_s)(P_s - b_s)^+])/2 = 20.5$ for his options, while keeping $g = b_c$. The buyer reduces her contracting capacity ($Q = [30 - (s + G(b_c))]^+ = 2.5$). The equilibrium solution is $(s, G(g), Q) = (20.5, 7, 2.5)$. The seller obtains the highest overall profit of $\pi = 186.25$, with a major impact coming from the spot market $\pi_s = 135$, with an additional $\pi_c = 51.25$ from the contract market. The key insight of this example is that, when contract production is cheaper than spot production, options contracts can still play an important role, even if the seller has unlimited liquidity and no adaptation cost in the spot market. These results are summarized in Table 1.

Figure 2 illustrates the essence of these examples and their connection to Figure 1. In Figure 2, using the base parameters given in the preceding examples, we show the impact of production cost differences and market access conditions on the intensity of options-based contracting. As shown, heavier reliance on contracting emerges when contracting enjoys larger production advantages relative to last-minute production for spot market procurement. As spot market access conditions deteriorate (i.e., m decreases), we also see, as expected, heavier reliance on contracting. Except for the polar case of $m = 1$ and $b_c = b_s$, options improve supply-demand coordination, significantly at times.

In Figure 2, we have focused only on production cost differences, but similar results would obtain if the buyer had to pay additional adaptation costs when procuring at the last minute from the spot market. These effects represent advantages for contract versus spot procurement. On the other side of the coin,

Figure 2 **Impact of Options to the Seller's Overall Profit**



Note. The horizontal axis is the spot/contract production cost difference measured by $G(b_s) - G(b_c)$. The vertical axis is the ratio of the seller's profit from the optimal use of the options market over the seller's expected overall profit from both the options market and the spot market. From bottom to top, the lines represent a decrease of spot market access probability, ranging from perfect access ($m = 1$) to no access ($m = 0$). The region below the curve is the percentage of overall profit obtained from selling the options. The seller's technology parameters, the buyer's parameters, and other parameters are the same as in the examples.

there may be additional costs to set up and negotiate contract procurement, and these would obviously work to the advantage of spot procurement. Figure 1 represents the general outcome of this analysis, where all of these effects are represented.

3. Literature Review

Using the above framework, we now review the relevant literature in economics and finance, operations management, and management information systems. As Birge (2000) points out, these streams of work are not consistent in general, as the OM literature does not adopt principles of the former, such as efficient market theory and the capital asset pricing model, while the financial economics literature generally does not consider operational conditions such as capacity limits and cost heterogeneity.

Table 2 provides a taxonomy of various contract forms documented in the literature. The classification is based on whether the contract price is prenegotiated or competitively determined, and whether the model is originally developed based on Internet exchanges.

The literature on contracting in economics has been driven by the transactions cost framework developed by Coase (1937), Klein et al. (1978), and Williamson (1985), and subsequently formalized in the principal-agent literature (Laffont and Tirole 1998). The basic hypothesis of this approach is that transactions with one or more buyers will be structured so as to minimize the total production and transactions cost of these transactions, including contracting, incentive, and monitoring costs. One of the key elements of B2B markets is arguably the reduction in transactions cost associated with automating transactions and providing appropriate IT platforms to support these (Kaplan and Sawhney 2000). These problems are usually modeled in a context in which relationship-specific investments are required for efficient contracting, and such investments become the subject of holdup behavior (what Williamson 1985 terms "ex post opportunism") after they are made. Clearly, a well-specified ex ante contract with verifiable information, as suggested by Williamson (1985), can be an important element in reducing these incentives. In the framework proposed above, the reader will note the salient position of transaction costs, defined by Kenneth Arrow as the "costs of running the economic systems" (Williamson 1985, p. 8). This reflects the horizontal axis in Figure 1.

A key question addressed in the economics literature has been the efficiency of various contracting structures. A well-known result in the economics contracting literature is Allaz and Vila (1993), which examines the efficiency of pure forward contracts (signed at Period 1) in an oligopoly setting but with a deterministic spot market (e.g., P_s is fixed and common knowledge). Assuming homogeneous sellers and instantaneous scalability (with no capacity limitations) at Period 2, they provide an important benchmark on the factors that can influence the efficiency of forward markets. They show that forward markets can yield inefficient outcomes because of strategic use of these markets by sellers with market power. These results have been extended and generalized in Kamat and Oren (2002).

Table 2 **A Classification Framework and Selected Literature on Models of Forwards and Contracts**

Seller number	Type	Contract characteristics	Models	Price mechanisms (negotiation vs. auction)	Spot market	Goods storable or not	Example industry
Single seller	Forward	Backup agreement	Araman et al. 2001	Auction	None	Storable	
		Quantity flexible	Cachon and Lariviere 2001	Negotiation	None	Storable	
		Buy back	Donohue 2000	Negotiation	None	Storable	Fashion, printing
		Return policies	Eppen and Iyer 1997	Negotiation	None	Storable	
		Two-mode production	Erhun et al. 2000	Negotiation	Deterministic	Storable	
		Information sharing	Lee and Whang 2002	Auction	Closed	Storable	Electronics
		Risk sharing	Mendelson and Tunca 2003	Auction	Closed	No	
		Closed exchange	Padmanabhan and Png 1995	Negotiation	None	Storable	
		Secondary market	Pasternack 1985	Negotiation	None	No	
		Deterministic multispot	Serel et al. 2001	Negotiation	Closed	Storable	
		Dual sourcing	Tsay 1999	Negotiation	None	Storable	
	Options	Open exchange	Barnes-Schuster et al. 2002	Negotiation	None	Storable	
		Contingent claim	Birge 2000	Negotiation	None	Storable	
		Pay to delay	Brown et al. 2000	Negotiation	None	Storable	Semiconductor
		Capacity planning	Majd and Pindyck 1987	Auction	None	No	
		Correlated demand	Spinler et al. 2003	Auction	Open	No	Electric power
		Valuation	Triantis and Hodder 1990	Auction	None	No	
		Valuing flexibility	Wu et al. 2002	Auction	Open	No	Electric power
	Forward	Deterministic spot market	Allaz and Vila 1993	Auction	Deterministic	No	
		Closed exchange	Mendelson and Tunca 2002	Auction	Closed	No	
Multiseller	Options	Capacity expansion	Cohen and Agrarwal 1999	Negotiation	Closed	Storable	
		Heterogeneous technology	Dixit and Pindyck 1994	Auction	None	No	Manufacturing
		Codifiability	Levi et al. 2003	Auction	Open	No	Chemicals
		Capacity gaming	Peleg et al. 2002	Mix	Closed	Storable	Manufacturing
		Rollout spot market	Wu and Kleindorfer 2003	Auction	Open	No	Electric power
		Contract selection	Wu et al. 2003	Auction	Open	No	

The financial economics literature provides basic pricing results for derivative instruments traded on standard contracts in liquid markets. The classic papers in this area are Bachelier (1900) and Black and Scholes (1973). What these authors did was to characterize, in a perfectly competitive market, the value of an option that could be continuously traded, when the price of the underlying asset on which the option was based varied according to one or another stochastic process, typically a Gaussian diffusion process (e.g., Schwartz 1997). Standard contracts studied included options of various types (depending on execution timing and the structure of final payoffs) and firm commitment forwards. Recent results include general approaches to the pricing of real options (Dixit and Pindyck 1994, Majd and Pindyck 1987, Triantis and Hodder 1990, Trigeorgis 1996), new methods of estimation and risk management based on options (see Schwartz 1997 and Clewlow and Strickland 2000 for recent advances and reviews), and a growing body of empirical validations of these approaches (e.g., Robinson and Stuart 2002). The essential characteristics of the financial engineering modeling in the literature on (real) derivative instruments include continuous time stochastic dynamics for the underlying spot price and ongoing trading opportunities among market participants for the derivatives. Option instruments and valuation models allow for different degrees of flexibility w.r.t. execution, including fixed expiration dates (European options), flexible expiration dates (American options), and various exotic options, such as Asian options that have payoffs that are based on average spot performance over a given period (Merton 1992). Applications of financial engineering methods abound in the management of currency risks, credit risks, insurance and reinsurance, and especially in the management of treasury functions, including cash management (Crouhy et al. 2001). These classical results also provide the underlying analytical framework for derivative instruments in the contracting markets of interest here.

In discussing options, it is important to distinguish between financial options and real options. Financial options are defined on the basis of financial indices, such as the price of a given stock. The theory developed for financial options typically assumes complete and efficient markets, with the price of such options then arising from the nature of the stochastic process defining the evolution of the index in question interacting with ongoing trading. Real options, on the other hand, arise from the nature of contingent decision making over time, and are based on the specific context involved. Real options arise from recognizing and valuing the flexibility to alter decisions over time. The classic example, explored in some detail in Dixit and Pindyck (1994), is the option to delay an investment outlay for a capacity expansion until market demand is revealed. The ability to fine tune the size of the capacity expansion to actual market conditions is clearly worth something, the options value of delay. Other options include the option to abandon a project before completion, or to speed up or slow down a project once begun.

In the context of supply chain contracting, an additional distinction is required in the types of options involved, that between purely financial options and those connected to physical delivery of a particular good at a particular time and place. The entire discussion here has been focused on physical delivery options to fulfill a buyer's sourcing needs. These options would entail delivery at a particular time and place (e.g., FOB Pittsburgh). In these markets, options backed by physical delivery are central to the buyer's problem of arranging for sufficient supply to meet the buyer's demand. But, it should be noted, that once a functioning spot market exists, this market can be used to define financial options on the basis of the spot price. Major buyers would then find it in their interest not only to arrange optimal sourcing from the contract and spot markets, for physical delivery of goods, but also to use the financial options defined in the market as risk hedging instruments. Thus, in livestock or grain markets, options serve both the purpose of fulfilling sourcing requirements for buyers, but the same markets allow price discovery through active parallel trading of options for purely financial hedging purposes. It is this mix of physical and financial instruments that characterizes well functioning and liquid spot markets. Normally, the mix of options in such markets going to physical delivery is low, perhaps on the order of 1% of total transactions, the remaining trading being purely financial to hedge residual risk. The key insight from the financial economics literature is that including the possibility of such financial hedge instruments in the overall planning process can have fundamental effects on whether or not to undertake projects in the first place and on their overall value (e.g., Kleindorfer and Li 2002, Hull 2000).

While financial economists were clearly the pioneers in developing options theory, OR/MS researchers have also made significant contributions to the application of options thinking. Our primary focus here is on the OM literature related to contracting and options. Most early OM work considered prices and contract terms arising through a negotiation framework between a single buyer and a single seller rather than through a competitive, market-equilibrium approach (Tsay et al. 1999). Demand uncertainty is typically assumed to be exogenous, where excess demand may be lost, possibly with additional penalties, and excess supply may be sold in a "salvage market" (which may be thought of as a fixed-price spot market). A basic review of these results can be found in Cachon (2002), Lariviere (1999), and Tsay et al. (1999). These predetermined contracts have different forms, e.g., backup agreements (Eppen and Iyer 1997), information sharing contracts (Cachon and Lariviere 2001), pay-to-delay capacity reservation (Brown et al. 2000), buy-back contracts (Padmanabhan and Png 1995, Pasternack 1985), and quantity flexibility (QF) contracts (Tsay 1999), including various risk-sharing and penalty clauses (Li and Kouvelis 1999).

Most of these contracts can be fruitfully viewed as special cases of two-part tariff options by setting contract parameters $[s, g]$ appropriately. This insight was apparently first explored in Barnes-Schuster et al. (2002), where the authors show that backup agreements, QF contracts, and pay-to-delay contracts are special cases of their options-embedded model (one seller, one buyer, two period).

Birge (2000) uses the capacity planning context (at Period 0 of the framework in §2) to explore the parallels and differences between real options and financial options, and their relationship to optimal hedging and planning. He shows the relevance of both financial and real options in managing risks arising from operational decisions. In particular, he shows that operating decisions, such as capacity expansion, will be fundamentally affected by accounting for both real options associated with flexibility choices and risk-hedging benefits from financial options. The key insight from Birge (2000) is that if either revenue or costs associated with a given product line are correlated with some well-defined price (or cost) index arising from a competitive market, then this price index can be used to define an appropriate derivative or options instrument that provides not only risk-hedging benefits, but also can and should influence the nature of the underlying operations decisions whose outputs are correlated with the index.

Donohue (2000) studies efficient supply contracts for fashion goods using a dual-mode production model, allowing buy back. In such a two-mode production environment, the slow mode needs more lead time but incurs a relatively cheap unit production cost (b_c), while the fast mode has a quick turnaround but incurs a higher unit production cost ($b_s > b_c$). The optimal contract in Donohue (2000) has the following structure. In Period 1, using current available (forecasted) demand information, the buyer orders from the seller via a long-term contract at a relatively cheap price; just before Period 2, the buyer can make additional orders with updated demand information but at a higher price. At the end of Period 2, the buyer returns any unsold units to the seller at a prespecified unit price. There is no spot market in this model. The contract is assumed to satisfy "forced compliance" (Cachon and Lariviere 2001), i.e., it is a "must produce-must use," a forward. As Donohue (2000) notes, this type of contract structure can coordinate the seller and the buyer in terms of channel efficiency.

We now review recent work and some initial results on the modeling of options trading via B2B exchanges. Araman et al. (2001) consider a buyer who can procure from a seller either via a contract, an Internet exchange (spot market), or a combination of both. Their contract is a pure forward ($g = 0$) with a penalty if the buyer does not call the fully reserved capacity with the seller on the day. Thus, the spot market (the exchange) is only used to fulfill the residual demand after the reserved capacity has been fully used. They show that the spot market is beneficial from the buyer's perspective, that both contracting and the spot market are sustainable, and that a mix between these two is optimal.

Spinler et al. (2003) generalizes the single-seller results of Wu et al. (2002) to the state-dependent case, whereby the WTP functions characterizing demand for buyers could themselves depend on the state of the world (e.g., both demand and spot price might depend on temperature). They show the optimal Wu et al. (2002) structure basically goes through, but the results are more complicated, where the demand for options by the buyer depends on the correlation between buyer demand and spot price.

Mendelson and Tunca (2003) investigate the case of a closed spot market, where spot market price is endogenously determined (in a single-seller context; a framework for the multiple sellers' case has been outlined in Mendelson and Tunca 2002). That is, the more capacity is withheld from the contracting market for sale in the spot market, the lower the resulting spot price distribution. Within this closed spot market setting, they focus on the impact of establishing the spot market (B2B exchange), where the seller plays the role of Stackelberg leader. They derive necessary and sufficient conditions for the existence of the exchange. They analyze the impact of the exchange on the participants as a function of information quality. A surprising result is that the introduction of the exchange ($m > 0$) does not necessarily benefit the participants. This is because the exchange contributes to price volatility and quantity uncertainty. As a result, the seller and the buyers can all be worse off with the exchange than without, driving participants away from the exchange (spot market) to contracting. On the other hand, when the exchange is highly liquid, volatility will not be amplified by the exchange and buyers and the seller will completely rely on the exchange, even to the extent of foregoing contracting altogether. The corresponding conditions in the framework of §2 are when the seller has perfect spot market access and/or when the cost of assuring codifiability is low (i.e., $m \to 1$).

Lee and Whang (2002) consider the impact of the Internet-based secondary market, where buyers can resell and trade their excess inventory at Period 2. Under the assumption of zero transaction costs, they show that the introduction of a secondary market always improves allocative efficiency but the welfare of the supplier may or may not increase.

Peleg et al. (2002) consider a "rollout" spot market, with demands and purchases occurring at both time periods and unmet demand at Period 1 carried over to Period 2. The buyer makes purchases from his current seller at Period 1, and inventories any excess input if Period 1 demand does not exhaust the ordered amount. If demand exceeds the ordered amount, then excess demand is backlogged going into Period 2. At the beginning of Period 2, and prior to observing Period 2 demand, the buyer may make additional purchases for delivery "on the day" under one of three arrangements: continued sourcing from the same seller as in Period 1 (i.e., use long-term, relationship-based strategic partner); an auction on the spot market (i.e., use a short-term strategy based solely on the use of procurement auctions); and some combination of both. They show that any of these three strategies can be optimal depending on the market characteristics (e.g., price distribution of the auction good) the buyer is facing and the seller's technologies. They show, in general, that Internet-based reverse auctions can be beneficial to the buyer.

Erhun et al. (2000) study the value of a deterministic multiperiod spot market for capacity and supply chain coordination, using a game-theoretic model. In their model, there is one seller and one buyer. The buyer produces a product by using the capacity she buys from the seller. Before production occurs, she can procure capacity via reservation and subsequent multiperiod spot markets. After the buyer makes her capacity reservation, the seller sequentially announces spot markets prices period by period. They show that the introduction of the multiperiod spot markets can reduce or eliminate double marginalization, and the resulting subgame perfect Nash equilibrium is Pareto efficient for all parties in the supply chain.

Wu and Kleindorfer (2003) capture the interaction of competing technologies with alternative market structures, which accommodate both the extent of competition (in terms of the number of sellers) and the relative cost and access advantages of alternative sellers. The essential results in Wu and Kleindorfer (2003) are the following. First, it is shown that greedy contracting is optimal for the buyer, i.e., it follows a merit order based on the index $s_i + G(b_i)$, where $[s_i, b_i]$ is the bid of seller i. Second, the necessary and sufficient conditions for market equilibrium are characterized. One key condition is the "one price law," i.e., each seller who participates in the options market, must sell the option at the same price (i.e., the same $s_i + G(b_i)$), consistent with previous studies in economics. Third, in the absence of cost advantages of contract production across spot production, the two-part tariff structure of equilibrium contracts is efficient, while a pure forward contract is not.

It is interesting to note that competition in options markets improves efficiency. Complex flexibility provisions and penalty costs (as in Li and Kouvelis 1999, Araman et al. 2001) are not required; the standard options structure with competition achieves efficiency. This starkly contrasts with the inefficiency of pure forward markets in the well-known result of Allaz and Vila (1993). The difference here is in contract design; remove the restriction that contracts must all be pure forwards ($g = 0$), and the noted inefficiency disappears under competition (Wu and Kleindorfer 2003).

The Wu and Kleindorfer (2003) results have also been generalized to integrate long-term capacity decisions at Period 0 with contracting and spot market decisions, where the long-term decisions are modeled in a game-theoretic framework with payoff functions based on the anticipated short-run game among sellers that will materialize via the exchange given their capacity decisions (Wu et al. 2003). This long-term game illustrates the nature of efficient technology mixes likely to survive in long-run equilibrium when firms with heterogeneous cost structures compete. The model is capable of characterizing, in the long run, the sellers into four disjoint groups: participation in the options market only; in both the options market and the spot market; in the spot market only; and in neither market (those forced out of business). Note that these results assume the standard proportional bid-tie capacity allocation rule in case of a seller bid tie.[12]

Cohen and Agrarwal (1999) model the long-term vs. short-term contract selection problem for a risk-averse buyer sourcing components from sellers. In their multiperiod model, a relationship-specific investment cost for long-term contracting is introduced. Their model allows the buyer to trade off the benefits of price certainty and learning, and the investment costs associated with long-term contracting, against the flexibility and near-zero investment associated with short-term contracting. They show that long-term contracting may not always be optimal and develop conditions (e.g., the buyer's risk attitude, market price uncertainty, and the magnitude of required investment) under which short-term contracting will be preferred by the buyer.

When will forward contracts be efficient? Levi et al. (2003) provide an explicit modeling of codifiability and relationship-specific investment, and show when the Wu and Kleindorfer (2003) optimal two-part options contract is equivalent to a pure forward. This result effectively integrates several competing conjectures on the efficiency of forward contracts. Specifically, they show that a pure forward contract is efficient under the following conditions: $b_c < a$ or $b_s - b_c$ is big enough. Under these conditions, the contract $[s, b_c]$ becomes equivalent to $[s + b_c, 0]$. With initial empirical validation, their model brings the following insights into the literature: (1) cost differences drive higher relationship-based investment; (2) lower codifiability results in a shift to extensive use of contracts; and (3) assuming common cost shifts across buyers, as adaptation costs increase, overall demand decreases and there is a shift to more intensive use of contracts but with fewer suppliers.

4. Implementation Challenges

As noted in the introduction, B2B exchanges have been driven by the reduction in transactions costs for electronic procurement and by the improved coordination of supply chains resulting from improved contracting and fulfillment practices. The theory developed here has already found numerous applications in capital-intensive industries, where the benefits to improved coordination of supply and demand are significant. To profit from these opportunities, a number of implementation challenges must be overcome. These include, foremost

(1) Developing the internal capabilities to integrate operations, sales, and procurement with external orders, derived from both long-term contracts and shorter-term exchange transactions.

(2) Developing a strategy and supporting technology defining who will participate in the contract and spot markets (which includes the public versus private exchange choice), and the governance and operation of supporting exchanges.

Concerning (1), requisite internal capabilities for B2B have been the focus of thousands of papers in trade magazines and the popular press and, more recently, have been the subject of deeper research. The issues include whether and under what conditions ERP systems have paid off (Hitt et al. 2002), and the requirements to achieve fully linked or networked organizations for interacting with close supply chain partners and arms-length market participants. Accomplishing the needed changes in IT infrastructure to support B2B contracting presents one of the significant challenges of the past decade, both in terms of innovations in corporate strategy and in changes and improvements in internal processes and their links to the value chain.

In addition to the general challenges of taking advantage of new B2B opportunities via the Web,

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[12] When several sellers have the same winning bid price, this rule allocates their capacity to buyers in proportion to the amount of capacity sellers have bid into the market. Such allocation rules can have fundamental effects on existence and structure of equilibrium outcomes as discussed in Wu and Kleindorfer (2003).

there are special challenges associated with integrating long- and short-term contracting along the lines of this paper. First and foremost, it is foreign territory for most organizations to integrate finance and operations, and this is precisely what is required to have the full benefit of the options approach described here. Companies wishing to do so must radically expand the traditional focus of procurement on cost, quality, and dependability to include tracking of spot market conditions, valuing options in operational and hedging terms, and linking these activities to an appropriate risk-management structure. Companies that have done this well have recognized the need to develop capabilities in trading, data management, financial reporting, and management. These include new skills in pricing and valuation of contracts, new approaches to managing the portfolio of sourcing options for key manufacturing inputs, and an entirely different approach to customer and customer segment valuation and management. We consider two examples—electric power and semiconductors—to illustrate these points.

Electric Power. An important area of application of these concepts is energy. Kleindorfer and Li (2002) present a detailed roadmap to implementation of these concepts in electric power, which we briefly summarize here. They consider the problem facing an electric power utility, the "buyer," who may own or lease generation, and that has a trading division that can sign contracts for Power Purchase Agreements (PPAs) and puts, calls, and forwards based on an underlying wholesale spot market. The buyer has some retail customers that are supplied by its wholly-owned distribution subsidiary called the Disco. Retail prices are regulated, and assumed fixed over the planning horizon of the problem. The buyer's problem is to determine an optimal set of purchasing contracts to fulfill its retail demand obligations, and perhaps engage in additional speculative trading for profit. One requirement arising from regulation is that retail customers must be served by the Disco, either from the buyer's portfolio of owned generation, PPAs, and options or forwards, or from the spot market at the prevailing wholesale price at the time the retail customers make their demand. It is generally recognized that this feature of customer demand at regulated prices, together with the weather-driven level of spot prices and the nonstorability of electric power, makes electricity supply a risky business.

This type of problem gives rise to what is known as the optimal portfolio problem for electric power sourcing. The portfolio in question is characterized by different levels of time-indexed instruments (puts, calls, forwards, and so forth) that might be called upon either to fulfill retail demand or simply as part of profit-oriented trading/hedging activities by the buyer's trading division. In this framework, owned generation and certain PPAs that have been precommitted have a fixed execution price (e.g., the marginal running cost of own generation), but may be thought of as available at a reservation price of zero. Purchased forwards, which are prepaid, fixed obligations to deliver power may be viewed as call options having a zero execution price that, therefore, will always be executed by the buyer on the day. Forwards sold by the buyer have the same characteristic, i.e., they may be viewed as options contracts with a zero execution price (that therefore, will be executed on the day). With these understandings, the options framework developed here envelops all of the essential contract forms/sources of power that are typically traded or used in existing electric power markets.

The implementation challenges faced in solving this portfolio optimization problem include the above noted organizational challenges. In addition, the buyer must have data and modeling resources that allow the buyer to model spot price distributions that are essential to valuing and selecting options contracts for the optimal portfolio. In electric power, in both Europe and North America, third-party data providers and systems for tracking and forecasting spot prices have arisen to support this activity, but utilizing these in ongoing trading and sourcing decisions requires a significant investment in professionals who not only understand the electric power market, but also the valuation methods for options-based contracts reviewed here. See Clewlow and Strickland (2000), Kleindorfer and Li (2002), and Mount (2002) for details.

Semiconductor Industry. The global semiconductor industry is approaching $200 billion in annual sales, supporting electronic, and computer and telecommunications markets of more than a trillion dollars annually. The industry is capital intensive, with new foundries now requiring on the order of $3 billion in investments and with rapid technological progress, following the celebrated Moore's Law.[13] The industry has also been characterized by huge swings in profitability and available capacity, and risk-management activities have, therefore, become increasingly important. There has also been considerable unbundling and outsourcing of semiconductor manufacturing (including the growing trend toward contract manufacturing), so that rebundling and contracting issues are essential elements in the new business model emerging in the global semiconductor sector. This provides a real opportunity for OR/MS to apply options-based approaches to medium- and long-term contracting to provide better approaches for risk-management and capacity planning. Existing contract forms in semiconductors are complicated, but they have clearly begun to reflect a concern with flexibility and uncertainty. In particular, contracts between major buyers, such as Dell, TI, Motorola, and AMD, and selected suppliers, such as Xilinx and Infineon, are closely related to the form of contracts reviewed here.

Options-based contracts of interest in the semiconductor sector take the following general structure, focusing on a single buyer and a single supplier (e.g., a contract manufacturer or pure play foundry) for some commodity chip such as a 64 MB DRAM. The buyer can satisfy her needs through a combination of long-term contracting with the supplier and purchases in the DRAM spot market.[14] The contract covers a horizon of T periods (e.g., T months), with an order being placed under the contract at some agreed point in time prior to each of the T months in the contract. The magnitude of each monthly order is required to be between some floor (minimum take) M and some ceiling $M+K$, where the amount of contract flexibility K is one of the key contract parameters. Evaluation of alternative contract forms involves a detailed examination of the impact of various contract features (price, length of contract, allowed ordering flexibility, and so forth) on expected profits and downside risks. As in the case of electric power, the central capability required to do this evaluation is data on spot prices and alternative contract prices (the so-called sweet price of various types of semiconductors) and the ability to use this data to evaluate options-based contracts of the above form. Data, modeling, and forecasting capabilities to support this activity are provided by industry think tanks such as Semico Research Corporation.

The semiconductor example raises a general point concerning the extent to which options-based contracts will be used in various industrial sectors in the future. Two scenarios have been suggested by practitioners. We call the first "Commodities Only, Please!" which embodies the hypothesis that commodity markets will be the only place where contracting and spot purchases can be efficiently integrated. In this scenario, achieving the requisite liquidity and scope for efficient B2B exchanges will require that the goods traded be commodities. Contrast this with a second scenario we call "The New Economy Dream Comes True!" In this second scenario, increasingly flexible transaction management and contracting systems will promote the use of B2B exchanges across a broad spectrum of procurement transactions. Coupled with new product design activities focused on improving modularization of products, this scenario calls for major extensions of B2B beyond commodities and into more complex products and services. Industry observers and the evolving reality of B2B exchanges seem to support the second scenario. For example, in semiconductors, increased flexibility at the manufacturing level is being achieved by increased standardization, interchangeability, and programmability of many classes of semiconductors. The effect of this trend is to decrease the customization and adaptation costs on the buyer side. Given the magnitude of the changes involved for the entire supply chain in semiconductors, the risks associated with strategic choices

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[13] For details on the recent evolution of the semiconductor industry, see *Semico Tracker Newsletter* (2003). Moore's Law was formulated in 1965 by Gordon Moore and states that the number of transistors that can be accommodated on a chip will double every 18 months.

[14] Even when the spot market is not used for sourcing, it is often used as a benchmark for contract pricing and, therefore, essentially serves as the value benchmark for contract evaluation.

in this domain are extensive. Similar risks and uncertainties face many other capital-intensive sectors, as we begin to digest the consequences of contracting and design innovations triggered by the revolution in B2B markets.

5. Open Questions

We have argued that the benefits from the evolution in B2B markets occur in two areas: (1) in the improvement of the physical transactions of procurement for a given set of buyers and sellers and (2) in the valuation and management of risks associated with capacity planning and sourcing. Thus, the open questions associated with B2B exchanges and contracting can be described under two general headings. First, are the needed model-based developments to capture the essence of the supply-demand coordination problem and the necessary options-based instruments to achieve efficiency. Second, is the continuing development of theory to understand the necessary guidelines for the structure and governance of sustainable business models for the exchanges.

Concerning model-based developments, Table 2 is one snapshot of existing research on instruments for B2B contracting. As can be seen there, most results to date have not considered multiperiod or continuous-time models, which would allow consideration of trading of options in a secondary market between the time they are first signed and their maturation date. Active trading in such secondary markets is commonplace in well-developed exchanges, and assures such important features as nonarbitrage conditions. Open spot markets are markets for which the price is assumed to be independent of the actions of individual market participants, while the price in closed spot markets may depend on actions of participants. Open markets are most appropriate where large numbers of buyers and sellers are active. Closed markets are most appropriate where, by reasons of market power or the thinness of trading partners, only a few prequalified participants can appropriately trade with one another on the exchange.

Table 2 shows just how incomplete existing research results are relative to the needed developments on various classes of options-based instruments and their valuation. Even for the nonstorable goods case, one can see that there are currently major gaps in our knowledge. For example, except for the papers by Mendelson and Tunca (2002, 2003), there is no work on closed markets. Also, state-dependent demand analysis is represented only by a single paper (Spinler et al. 2003), although state-dependent demand can be expected to be central to markets (like energy) in which weather plays a significant role. Similarly, as pointed out in the review paper by Tsay et al. (1999), notwithstanding continuing interest in the OM literature on storable goods, the issue of competition has been largely ignored. While this may have been appropriate when only long-term contracts were the vehicle for exchange, the changed circumstances wrought by the B2B revolution have brought competition center stage.

The second needed area of research concerns the structure of sustainable B2B exchanges. Two factors that seem to find emerging agreement among researchers and practitioners are liquidity and codifiability of transactions. Liquidity is often discussed in terms of the scale of operations of the exchange and ability to satisfy the demands of a sufficiently large group of buyers and sellers to attract continuing use. Beyond these issues, there is wide disagreement on the necessary features for assuring sustainability of B2B exchanges (see, e.g., Dai and Kauffman 2002). A key research challenge would be this. How can OR/MS model and justify the dynamics and evolution of B2B exchanges and provide useful guidance for the development of such exchanges?

Perhaps the most important research challenge for B2B markets is the continuing development of the integration of finance and operations, as noted by Birge (2000) for risk management in general. In our view, the emerging framework presented in this paper on the use of B2B exchanges and supporting options instruments is likely to be a central feature underlying this integration. As always, empirical validation and testing in specific sectors is the foundation of harvesting the benefits of these innovations.

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