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Proprietary and Open Systems Adoption in E-Procurement: A Risk-Augmented Transaction Cost Perspective

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ABSTRACT: We present an economic model that enables the study of incentives for business-to-business (B2B) e-procurement systems investments that permit inventory coordination and improved operational control. We focus on the information technology adoption behavior of firms in the presence of transaction costs, agency costs and information uncertainty. We conclude that it is appropriate to rethink the prior theory and develop an extended transaction-cost theory perspective that incorporates the possibility of shocks. We distinguish among three kinds of B2B e-procurement systems platforms. *Proprietary platform procurement systems* involve traditional electronic data interchange (EDI) technologies. *Open platform procurement systems* are associated with e-market Web technologies. *Hybrid platforms* involve elements of both. We specify an analytical model that captures the key elements of our perspective, including the conditions under which strong conclusions can be made about the likely observed equilibrium e-procurement solutions of the firms. Our results explain the coexistence of both proprietary and open platforms, showing that larger firms tend to adopt costlier procurement technology solutions, such as proprietary EDI, which provides greater supply certainty. Smaller firms adopt less costly procurement technologies that entail greater supply uncertainties, such as open platform procurement systems. Two guidelines emerge for practitioners: (1) adoption of standard e-procurement platforms needs to be understood in terms of the controllable risk tradeoffs that are offered to small and large firms, and (2) gauging the business value impacts of exogenous shocks is critical to decision-making.

KEY WORDS AND PHRASES: e-procurement, information system economics, information technology adoption, information technology infrastructure, open platforms, proprietary platforms, supply chain management, transaction costs, uncertainty handling.

THE APPLICATION OF THE WEB TECHNOLOGIES to supply procurement transactions has led to significant growth in Internet-based supply chain management systems. The new approaches represent an IT-driven transformation of traditional business processes on a massive scale [30, 56], including fundamental changes in the business processes in global supply chain management [54]. This "e-transformation" of procurement processes has resulted in the new technologies becoming a "hook up or lose out" value proposition for the senior managers that invest in them [14]. Table 1 describes some of the key features that make the new e-procurement technologies attractive. Yet it is highly surprising that despite the overwhelming evidence of the advantages of e-procurement systems, proprietary systems such as electronic data interchange (EDI) continue to persist, even with their higher infrastructure costs to support procurement [19].

The purpose of this paper is to explain this puzzle. We begin by distinguishing between "proprietary" e-procurement and "open-platform" e-procurement systems, in terms of how they are specified, who controls them, and the nature of their participants. A key distinction is the extent to which an individual firm or a small group of firms defines the exchange protocols, the transaction formats, and the internal operations of the procurement system. *Proprietary platform procurement systems* tend to be customized to the needs of individual firms. These buyers and suppliers have incentives to specify the software and hardware infrastructure requirements to best match

Table 1. Buyer–Supplier Benefits in B2B E-Procurement Systems

Supplier benefits	Buyer benefits
Small-order aggregation	Lower cost to find and select suppliers
Lower customer acquisition costs	Better negotiation of larger orders, greater transparency
Lower transaction costs	Lower transaction costs
Reduced time to market	Less need to invest in supplier IT infrastructure
Less need to invest in buyer IT infrastructure	Reliance on market competition to establish standards, not third-party software vendor
Reliance on market competition to establish appropriate standards	Less concerns about information poaching by supplier
Control of development	Control of development

Source: Adapted from Transora (www.transora.com).

their own procurement or supply services infrastructure capabilities. Prior to the Internet, such systems were offered via secure dedicated lines and private networks, and tended to connect a buyer to a preferred group of suppliers. Traditional EDI systems are the most recognizable example.

Today, firms still use proprietary software with the Internet in the form of Web-based proprietary EDI, permitting them to work with a focal group of preferred suppliers.[1] By contrast, *open platform procurement systems* tend to exhibit greater neutrality with respect to the infrastructure capabilities of buyers and suppliers. Such systems involve numerous suppliers, industry consortia, and third-party electronic intermediaries. They are seen in market settings where an electronic intermediary or business-to-business (B2B) e-market firm, instead of a buyer or a supplier, develops a market mechanism to serve participating firms. This takes advantage of the technology standards of the Internet and nonproprietary e-business software capabilities. Yet open platform procurement systems are less likely to be utilized by larger firms, firms with more power, and firms with preferred suppliers.

To explain why, researchers point to the desirability of *buyer–supplier coordination* [7]. But how such coordination plays out in the choice of technology platform is subject to debate. Some argue that by reducing transaction costs of procurement, open B2B e-commerce platforms improve interfirm coordination [23] and, thus, should be the platform of choice. However, buyer–supplier coordination is the key attractive feature of proprietary EDI systems. If so, then the potential value of such systems may keep firms from switching to the open platforms. Such adoption inertia then will be reinforced by the supply risks, technology switching costs, and market uncertainties. We will argue, extending the "move-to-the-middle" theory of Clemons et al. [17], that firms make their adoption decisions with these considerations in mind. Our new theoretical perspective incorporates the role of stochastic shocks in final demand in the retail market and exogenous upstream shocks in supply.

Procurement activities may occur on a regular or irregular basis, involving the same or different trade partners. Prices for supply items may be stable or unstable, affecting the buyer's financial risk and its perception of value. Other concerns include Internet security breaches, supply discontinuities due to supplier bankruptcy, and difficulties in financial settlement. These risks go beyond those that a buyer experiences with a few suppliers. Moreover, these risks and costs are not the commonly understood operational and opportunism risks or coordination costs that are described by Clemons et al. [17].

Our formulation of a *risk-augmented transaction-cost model* permits us to bring transaction costs, demand and supply uncertainties, and procurement risk into focus. We discuss the technology support context of e-procurement processes and analyze differences between proprietary and open platform systems solutions. We also explore how adoption outcomes change when a prior adopter of one technology platform can switch to another, and what happens when it is possible to adopt mixed or hybrid platform solutions. An important and key result of our model is the emergence of *coexisting* technology networks. This finding parallels the findings of Belleflamme [8] and Kauffman and Wang [34], who analyzed network technology adoption under oligopolistic market competition.

Preliminary Theory

WE WILL NEXT CONSIDER RELEVANT COMPONENTS of our theory that explains firms' e-procurement platform adoption decision-making.

Transaction Costs, Risks, and Exogenous Shocks

Focusing on the buyer's concerns, we will develop an economic model that shows how transaction cost, risks, and market uncertainties are likely to lead to the coexistence, in equilibrium, of both open platform and proprietary platform procurement systems. We find that a buyer's decision regarding the choice of an e-procurement platform depends on firm size, transaction costs, and participants' sensitivities to risk. (An overview of such costs and risks and their description is provided in Appendix A.)

Our model focuses on uncertainty in both demand and supply, and their differing implications in the presence of open and proprietary systems solutions. We study how the choice of information technology (IT) may reduce procurement uncertainties and, in turn, how aggregate demand-side uncertainties may influence the firm's choice of a procurement systems platform. A key emphasis is on the role of unanticipated inventories that occur due to shocks.

We believe that in order to understand firms' adoption of procurement technology platforms, it is important to extend the transaction costs perspective to incorporate such demand and supply shocks. In effect, firms' investments in supply chain management systems are a decision in financial risk management. To our knowledge, neither the stream of research on interorganizational systems (IOS) and EDI in the 1990s (e.g., [13, 28, 45, 46, 50, 51, 57]) nor the more recent work on e-market technology investments [6, 18, 19, 20, 47] has addressed the issues of adoption in e-procurement with the perspective on technological choices and managerial uncertainties that we have identified.

Buyer–Supplier Relationships

IT investments have been recognized as capable of transforming how markets work and how firms interact with markets and among themselves. Malone et al. [43] offered a novel perspective on *electronic markets and hierarchies,* predicting that changes in the patterns of mercantile exchange in the presence of new information and communication technologies would induce firms to increasingly transact in electronic market settings. Subsequently, Clemons et al. [17] proposed a *move-to-the-middle hypothesis,* arguing that as IT increases firms' organizational capacity to process information, coordination costs and operational and opportunism risks would all fall. This would lead to more electronic transactions, as Malone et al. [43] predicted, but also the resulting transaction economies of scale and other factors would favor a move toward relationships with a focal set of suppliers and not the market-at-large, unlike what Malone et al. predicted.

The move-to-the-middle hypothesis has matched what we have seen occurring in industry. For example, Riggins et al. [51] and Wang and Seidmann [57] report on how marginal returns to suppliers are lower with more suppliers in a procurement network. Buyers, therefore, have to offer incentives to induce supplier participation, including limiting the number of suppliers. Nonetheless, there will be a net overall increase in the number of suppliers. As the number of suppliers participating in an IOS increases, the bargaining power of individual suppliers declines [5], reducing their willingness to invest in systems assets and interorganizational business processes with *noncontractible* elements [4, 6, 49]. This forces buyers to own cross-organizational systems assets for procurement purposes. The result is that even more outsourcing will occur. A key prediction is that reduced transaction costs leads to more interorganizational coordination and collaboration via e-procurement systems.

Such coordination and collaboration will lead to the development of infrastructure for the exchange of demand and supply forecasts, as well as information on inventory levels, enabling the partners to maximize the value of their respective supply chain activities. But coordination and collaboration will also require effective systems integration, causing firms to face unacceptably high costs [18]. Also, interorganizational information sharing tends to create discomfort even among value-maximizing partners [12, 15, 16, 17, 26, 33, 38]. Thus, a critical issue is how to control transaction risk and optimize quality assurance and information sharing, while identifying a value-maximizing scale size for the shared business process infrastructures and activities.

Risk and Uncertainty

Our perspective is that the critical driver in the presence of variability in demand is the extent to which the firm is sensitive to risks related to the financial consequences of procurement. Noncontractibility in buyer–supplier relationships is the basis for such risks [6, 25, 27]. We have discussed, for example, that as the size of the supplier network increases, the bargaining power of any individual supplier in the network will decrease [49], reducing firm-level incentives for participation [4]. Withdrawal of a supplier from participation naturally implies procurement interruptions, leading to stock-outs and other procurement-related risks. Moreover, if the firm faces cyclical market demand (automobiles), or long lead times for procurement (textiles, clothing), its ability to insulate itself from such e-procurement risks is even more critical. One way to do this is to transact with fewer suppliers.[2]

We propose that firms will recognize the key underlying risks in the choices they make about the e-procurement systems and buyer–supplier arrangements. Firms will account for potential effects of investments in maximizing the value of their procurement activities, but the exact nature of the solution that is adopted will imply a more complex interdependence than transaction-cost theory, electronic markets and hierarchies theory, or the move-to-the-middle hypothesis would each suggest.

Firm Size

Firm size is recognized as an important factor in the performance of IT investments in modern organizations [9]. There are several reasons we should see the effects of firm size on technology adoption choices in the e-procurement systems platform context [42]. For instance, larger firms possess more resources, including critical resources such as managerial skills. As a result, they may do better with large and complex software projects with significant cost uncertainty. Another firm-size issue arises in relation to IT adoption decision-making in the presence of technological standards and network effects [21, 22, 31, 32, 35, 55]. Large firms create their own intrafirm network externalities (e.g., electronic banking networks, SAP enterprise systems, and open standard Web servers). As such, their adoption-related signals and choices influence others, in a process that Au and Kauffman [3] have called *rational expectations-based IT adoption decision-making*. Finally, larger firms may be more willing to invest in proprietary systems solutions, while smaller firms with less capital may be reluctant to adopt proprietary e-procurement technology [29]. Their smaller size may predispose them to select solutions with more immediate network externality benefits or lower costs for customization.

Firm size, as we shall see, will enter into the IT platform adoption decision through a novel mechanism: the calculus of the tradeoff between considerations of lower cost versus higher procurement uncertainty. This affects the IT platform choice and turns out to critically depend on firm size.

A Risk-Augmented Transaction-Cost Theory

THE OPPORTUNITY TO MAKE A NEW THEORETICAL CONTRIBUTION in this research lies in refining transaction-cost theory—as Clemons et al. [17] have previously done with their move-to-the-middle hypothesis—relative to what would be observed if firms faced exogenous or stochastic shocks. The contrast between our perspective and Malone et al.'s [43] electronic markets and hierarchies theory relates to the firms' perceptions of risk in the presence of unexpected supply and demand shocks. Oversupply and undersupply risks, technology standards and functionality risks, relationship and business partner IT coinvestment risks, and competitive factors are some examples. Consideration of these risks should modify the basis for business decision compared to when the decisions ignore the inherent risks.

The contrast is plain. In supply chain management, senior managers should adjust their decision-making choices and IT investments beyond the predictions of Clemons et al. [17] relative to buyer and supplier interactions. This should occur, for example, when there are unexpected shocks to procurement activities and there is potential for significant financial losses. Some shocks that may drive costs are risk-related issues, such as exposure to supply chain disruption in seasonal businesses (i.e., "one-shot deal" procurement), unexpected exploitation of a buyers' demand information when final demand information is shared with the supplier [33], or the failure of a key supplier. There are also risks associated with poor procurement quality or shifts in demand for perishable products. Apart from these risks, there are "at-risk" sunk costs that arise when there is the possibility of switching to a different e-procurement platform, as well as the fixed costs of the procurement operation. Finally, senior managers may be sensitive to the difficulties associated with technology coinvestment with other firms, especially when the scale size requires continuous commitment of a large amount of financial capital (i.e., an uncertainty about the noncontractible aspects of IOS). We believe that these risk factors act as effective cost drivers that will change senior managers' decision-making perspective in favor of a greater focus on the risks.

These considerations lead us to propose a *risk-augmented transaction-cost theory:*

- *Definition (Risk-Augmented Transaction-Cost Theory).* This perspective enhances the predictions of the standard transaction-cost theory in supply chain management and interorganizational relationships to recognize the importance of unexpected shocks, especially technology, firm, and market uncertainties (e.g., demand and supply forecast variances in supply chain management, risk and valuation variances in financial risk management, etc.). These act as drivers of observed firm behavior and outcomes in interorganizational relationships that involve, for example, IT investment, contracting and outsourcing, and organizational design and governance of shared business involvement.

To illustrate the efficacy of the new theory, we next develop and analyze a model that applies its general insights to decision making for e-procurement platforms in supply chain management.

An Adoption Model for E-Procurement Systems Platforms

EARLY EFFORTS WERE MADE TO SUPPORT PROCUREMENT using IT-emphasized management of demand uncertainty through inventory demand forecasting and the control of inventory and transportation costs. Cycle times were also reduced through the use of optimization algorithms [37]. Capabilities made possible by increases in computing power have enabled the use of these algorithms in supply chain settings, and now permit firms to manage uncertainties that arise as never before—including unexpected supply and demand shocks. We next develop a model that treats these issues in the context of e-procurement systems platform adoption.

Modeling Uncertainties in E-Procurement

Consider a competitive retail firm (a supply chain "buyer") that is able to exert some price control on its products (i.e., a price setter), but faces critical demand uncertainties. We assume the buyer procures its supplies in a competitive market with supply uncertainties. The retail electronics sector, a long-term and significant sectoral user of EDI, is a case in point. Despite competitive pressures from other firms, the retail electronics giant, Best Buy, boasts significant regional market share for electronics goods where it chooses to compete, permitting it to exert considerable control over its pricing and market segmentation strategies relative to other competitors. Yet, as most consumers know who have shopped at Best Buy's superstores for DVD players and digital televisions, the firm often stocks out of popular electronics products. The stockouts stem from inaccurate supply and demand forecasts.

Four aspects of the buyer stand out relative to supply chain management: the buyer's relative market power related to product demand; its competitive, price-taking behavior in product procurement; its uncertainties about how much to order and whether the supplier can deliver; and its uncertainties about final demand in its consumer marketplace.

Demand and Supply Uncertainties

Demand uncertainties arise because final sales are subject to shocks that the firm's management cannot predict, so that

$$q_s - q_d^f = \delta q_s \Rightarrow q_d^f = (1-\delta) q_s, \tag{1}$$

with $\delta \sim f(0, \sigma_\delta^2)$ and $\delta \in [-1, 1]$. Here, q_d^f is the final level of sales (or final demand, $_d^f$), q_s is the supply quantity received (subject to uncertainty), and δ is the error in management's estimates of final demand due to stochastic shocks. We assume that this is a relative error, so we model it proportional to the magnitude of the supply, δq_s, included in the right-hand side. The random variable δ has a symmetric distribution f with mean 0 and variance σ_d^2. A way to ensure a lower bound on δ is to assume that it has a truncated symmetric distribution, such as the truncated normal distribution, in the interval [–1, 1].

Unexpected shocks in the source of supply can be similarly modeled, but they are relative to a control variable, q_o, that represents the quantity to be ordered from the supplier:[3]

$$q_s - q_o = q_o u \quad \Rightarrow \quad q_s = (1+u)\, q_o, \tag{2}$$

with $u \sim g(0, \sigma_u^2)$ and $u \in [-1, 1]$. Management's error in estimating the supplies it can acquire is given by u, which is also a by-product of random shocks. The distribution g can be any symmetric truncated distribution. The source of fluctuations in the supply chain is independent of any random fluctuations in demand, so that $\text{cov}(\delta, u) = 0$. Then, the variable q_o is the control variable that management wishes to optimize.

Our choice is to model the impacts of risk and uncertainty on procurement system platform adoption choice in a single-period model. We use order quantity levels as a *proxy for firm size and technology capital* that is likely to be employed for supply chain management. We expect to obtain similar information from a short modeling horizon in terms of the firm's technology capital and investments in procurement systems.

Calculating Buyer Profits

We calculate the buyer's expected profits $E(\pi)$ by integrating its objective function over the two uncertainty dimensions:

$$E(\pi) = \int_{-1}^{1} g(u)\, du \int_{-1}^{1} \pi\left(q_s, q_d^f\right) f(\delta)\, d\delta. \tag{3}$$

In order to calculate the expected profits in Equation (3), we first evaluate the conditional expectation, $E(\pi(q_s))$, which holds q_s constant, but integrates over q_d^f, based on

$$\begin{aligned} E\left(\pi\left(q_s\right)\right) = P\left(q_s\right) q_s \Big|_{q_s < q_d^f} \cdot \text{prob}\left(q_s < q_d^f\right) + P\left(q_d^f\right) q_d^f \Big|_{q_s > q_d^f} \cdot \text{prob}\left(q_s > q_d^f\right) \\ - c q_s - s\left(q_s - q_d^f\right) \text{prob}\left(q_s > q_d^f\right), \end{aligned} \tag{4}$$

where $P(.)$ is the inverse demand function, c is the unit cost of obtaining the product from the distributor (as unit cost production plus transaction and processing cost), and s is unit inventory cost. The asymmetric nature of the losses shows up in two ways. First, they occur as revenue, which is determined by whichever of the two quantities, q_s and q_d^f, is smaller. Second, they occur as inventory costs, which arise in the event of oversupply relative to final sales.

We use s to denote the inventory cost, so that storage costs are cumulative over time. (For example, in the food sector where products are perishable and in the retail sector where obsolescence matters, time is critical, and inventory costs may eventually equal or exceed the product's price.) The parameter s is capable of representing time implicitly, if each product line is associated with a different value of s. A manager of a retail firm often tracks inventory turnover. Thus, different values of s can be attributed to each product as a composite of storage costs, storage time and risk of obsolescence.

We express the probabilities in Equation (4) in terms of δ and its density function $f(\delta)$ from Equation (1). Note that for $\delta \in [0, 1]$, we have $q_s \geq q_d^f$, and for $\delta \in [-1, 0]$, we have $q_s \leq q_d^f$. Conditional expected profit in Equation (4) is

$$E\left(\pi\left(q_s\right)\right)=\int_{-1}^{0} P\left(q_s\right) q_s f\left(\delta\right) d\delta$$
$$+\int_{0}^{1} P\left[q_s\left(1-\delta\right)\right]\cdot\; q_s\left(1-\delta\right) f\left(\delta\right) d\delta - cq_s - s\int_{0}^{1} \delta q_s f\left(\delta\right) d\delta. \tag{5}$$

This can be simplified because q_s is given at this stage. This means that $P(q_s)q_s$ is independent of δ in the first integral. And since $f(\delta)$ is symmetric in δ, and the integral covers half the δ's range, the first integral can be evaluated as $(1/2)P(q_s)q_s$. We define the final term, the *demand error integral,* as $\Omega_\delta \equiv \int_0^1 \delta f(\delta) d\delta$. The conditional expectation of profits is given by

$$E\left(\pi\left(q_s\right)\right)=\left(1/2\right) P\left(q_s\right) q_s+\int_{0}^{1} P\left[q_s\left(1-\delta\right)\right]\cdot q_s\left(1-\delta\right) f\left(\delta\right) d\delta - cq_s - sq_s\Omega_\delta. \tag{6}$$

Unanticipated Oversupply in Inventory

Ω_δ is the mean of δ, conditional on $\delta > 0$. Recall that δ is the extent to which actual demand falls short of supply. Thus, Ω_δ represents the extent to which there will be, on average, an unanticipated oversupply or inventory buildup. Since $\delta \in (0,1)$, it follows that $\Omega_\delta < 1$. Although Ω_δ is a distinct feature of $f(\delta)$, Ω_δ should be positively related to variance σ_δ^2, so that a more widespread distribution involves a larger value of Ω_δ. However, Ω_δ contains a signal for oversupply, while σ_δ^2 is pure white noise. But still, expected profits are conditional on supply. The unconditional value of expected profits in Equation (3) is related to this conditional expectation by integrating over the unexpected supply shock, u:

$$E\left(\pi\right)=\int_{-1}^{1} E\left(\pi\left(q_s\right)\right) g\left(u\right) du. \tag{7}$$

The buyer's unconditional expected profits are[4]

$$E\left(\pi\right) \cong \left(1-\Omega_\delta\right) P\left(q_o\right) q_o - \left(c+s\Omega_\delta\right) q_o + q_o^2 P'\left(q_o\right) A\left(\sigma_u^2, \sigma_\delta^2, \Omega_\delta^2\right), \tag{8a}$$

where the final term is given by

$$A\left(\sigma_u^2, \sigma_\delta^2, \Omega_\delta^2\right) \equiv \left(1-\Omega_\delta\right)\sigma_u^2+\frac{1}{2}\sigma_\delta^2\left(\sigma_\delta^2+\sigma_u^2\right)-\Omega_\delta. \tag{8b}$$

Notice in Equations (8a) and (8b) that, although the supply and demand uncertainties, σ_δ^2 and σ_u^2, affect expected profits adversely, the role of the unanticipated oversupply parameter, Ω_δ, is mixed. It affects expected profits adversely via the revenues and inventory costs (first two terms). But it also affects expected profits positively via the slope of inverse demand $P'(q_o)$, which is negative. This observation is tied to the market power of the buyer. In fact, for a competitive firm where demand is horizontal and $P'(q_o) = 0$, unanticipated oversupply, Ω_δ, reduces expected profits unambiguously. Firms with market power can reduce prices to respond to excess inventory buildup when supply exceeds sales (i.e., $q_s > q_d^f$, or $\delta > 0$), moderating the adverse effect of overestimating demand. But the adverse effect of uncertainty, σ_δ^2 and σ_u^2, exists *only* when firms enjoy some market power. It disappears otherwise. This leads us to assert our first proposition:

> *Proposition 1 (Adopting Firm's Supply Shock Absorption Capacity Proposition): Buyers with greater market power are better able to absorb the adverse effect of oversupply shocks, by reducing prices, than those with little or no market power. They are more adversely affected by demand–supply shocks than price-taking buyers.*

We include Appendix B with industry examples to provide evidence for the modeling findings, related to this and the other propositions.

Optimization in the Presence of Linear Demand

As before, a buyer selects order level q_o to maximize expected profits. We examine the case of linear demand, with $P(q_o) = a - bq_o$. A linear demand structure provides a basis for maintaining the tractability of the line of analysis that we use, and offers a reasonable way to think about the key relationships in the model. The first-order condition for optimization yields

$$\frac{dE(\pi)}{dq_o} = 0 \Rightarrow \quad q_o^* = \frac{1}{2b} \cdot \frac{(a-c)-(a-s)\Omega_\delta}{\left(1+\sigma_u^2\right)\left(1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta\right)} \tag{9a}$$

$$\pi^{e*} = \frac{1}{4b} \cdot \frac{\left[(a-c)-(a+s)\Omega_\delta\right]^2}{\left(1+\sigma_u^2\right)\left(1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta\right)}. \tag{9b}$$

The denominators of Equations (9a) and (9b) are positive due to the concavity condition that we impose to ensure optimality. A positive value of output and profit means the numerator must be positive, $a(1 - \Omega_\delta) > c + s\Omega_\delta > 0$. So the strength of the demand per unit a, adjusted for unanticipated oversupply, must exceed the sum of costs. Supply and demand uncertainty, σ_δ^2 and σ_u^2, also adversely affect optimum output and profits. However, the demand error integral, Ω_δ, affects profit and output, decreasing them via the numerator, and increasing them via the denominator. The latter effect arises from the negative slope of the inverse demand function, and shows that larger firms with market power can absorb effects of unanticipated inventory buildup by reducing prices.

IT Adoption in E-Procurement: Platform and Firm-Size Analysis

ALL E-PROCUREMENT TECHNOLOGY STRATEGIES do not offer the same levels of cost savings and risk avoidance. We next consider the roles of proprietary and open *platform type* and *firm size.*

Proprietary Versus Open Platform E-Procurement Systems Adoption

We consider two forms of e-procurement systems:

- *Proprietary platform procurement systems,* φ_1, expose the buyer to relatively high procurement transaction costs, *c,* but the procurement risks, σ_u^2, are low because a limited number of preferred suppliers will be the focus of the IOS. These firms typically have preexisting long-term relationships with the buyer.
- *Open platform procurement systems,* φ_2, cause the buyer to face relatively low procurement transaction costs, *c,* but there are high procurement risks, based on the cost variance σ_u^2. Although there may be more potential suppliers, the buyer may be concerned about potential problems associated with not locking in specific sources of supply.

Our definitions of the platforms are intended to present a contrast, although it should be obvious to the reader that the real world actually involves a *continuum* of technical solutions. The proprietary platform e-procurement systems typically include: traditional EDI; collaborative planning, forecasting, and replenishment (CPFR) systems; and vendor-managed inventory (VMI) and comanaged inventory systems (CMI).[5] The first generation of open platform procurement systems is associated with Internet-based supply chain management systems. Examples of some of the platform vendors include Ariba, i2, and Commerce One, prior to their moves to incorporate other firms' proprietary software to build "suites" of supply chain management software capabilities.

Why do open platforms supporting a large number of firms entail lower procurement transaction costs than the proprietary platforms? They have costs that come in two forms: ex ante precontractual search costs for finding the lowest-cost supplier, and ex post costs of logistics, delivery, documentation and other related costs once a supplier has been identified. Even though it is possible that fewer suppliers (as with proprietary platforms) may mean that some components of the ex post costs may be lower (e.g., documentation with fewer vendors), the ex ante search costs for the lowest prices favors the open platform approach. Further, many components of ex post costs are likely to be lower for the open platforms. The logistics costs of delivery ought to be lower for open platforms because of the lower search costs to find the least costly logistics services. Finally, ex post enforcement and legal issues are also likely to benefit from the greater transparency of open platforms. So we contend that the procurement transaction cost, *c,* will be lower for the open platforms than the proprietary platforms.

We have pointed to the uncertainties that arise due to security problems, supply variances and discontinuities, and financial settlement risks when open platforms are selected. These occur in spite of the open platforms' broader span of market participants and the access they give to more competitive supply prices. The tradeoff between technologies can be shown in a cost-variance model for a given level of expected profits. This tradeoff is seen through the iso-profit curve, $\overline{\pi}^e$, and by totally differentiating Equation (9b) with respect to c and σ_u^2:

$$\left.\frac{d\sigma_u^2}{dc}\right|_{\overline{\pi}^e} = -\frac{1}{2b}\cdot\frac{1}{\overline{\pi}^e}\cdot\frac{\left[(a-c)-(a+s)\Omega_\delta\right]^2}{1+\frac{1}{2}\sigma_\delta^2-2\Omega_\delta}. \tag{10a}$$

When the optimum sales in Equation (9a) and the optimum profits in Equation (9b) are positive, the slope in Equation (10a) will be negative:

$$\left.\frac{d\sigma_u^2}{dc}\right|_{\overline{\pi}^e} < 0. \tag{10b}$$

This negative slope describes the tradeoff when the firm's choice of procurement systems platform achieves lower procurement costs, but a higher supply variance. Through marginal analysis of the second derivative of the iso-profit curve, we also can find the sign of curvature of the tradeoff. So differentiating Equation (10a) with respect to c to obtain

$$\left.\frac{d^2\left(\sigma_u^2\right)}{dc^2}\right|_{\overline{\pi}^e} = \frac{1}{2b}\cdot\frac{1}{\overline{\pi}^e}\cdot\frac{1}{1+\frac{1}{2}\sigma_\delta^2-2\Omega_\delta} > 0. \tag{11}$$

Now from the signs we observe in Equations (10b) and (11), we can see that the firm will face a tradeoff curve that is convex to the origin, as in Figure 1.

This leads us to assert a second proposition:

> *Proposition 2 (Procurement Risk-to-Cost Convexity Proposition): A buyer's iso-profit curve associated with e-procurement system platform adoption is convex in the parameter space of supply procurement risks versus costs.*

This proposition suggests that firms may be able to tolerate high procurement costs or high supply variance, but they will not be able to maintain equivalent profitability with a convex combination of both. Instead, they will need to adopt a procurement systems platform that effectively balances both to achieve high profitability. (Also see Appendix B for an example.)

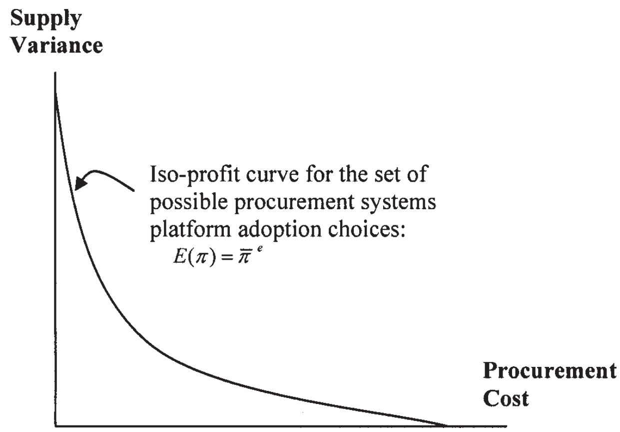

Figure 1. Buyer's E-Procurement Platform Adoption Iso-Profit Curve

Differential Adoption in Large and Small Firms

Is a firm's willingness to adopt an open versus a proprietary platform procurement system likely to depend on firm size? How will this relate to a risk-augmented transaction-cost theory? To answer, we must relate firm order size to firm profits from Equations (9a) and (9b):

$$q_o^* = \frac{2\pi^{e*}}{(a-c)-(a+s)\Omega_\delta}. \tag{12}$$

Equation (12) shows that the per-unit profits, π^{e*}/q_o^*, decrease as a function of unit costs c. So, among firms of the same size in terms of the proxy, optimal order quantities q_o^*, profits may be smaller for those with higher costs. Among firms that earn the same expected profit, π^{e*}, and lie on the iso-profit curve shown in Figure 1, larger firms will have higher unit procurement costs, based on q_o^* in Equation (12). These lie on the lower part of iso-profit curve. Among firms that earn profits, π^{e*}, the smaller ones will tend to be those with lower procurement costs. They will lie on the upper part of iso-profit curve. The proportion of size and profits depends on their unit procurement costs.[6] See Figure 2.

From this result, the following proposition emerges:

> *Proposition 3 (Adopting Firm's Self-Selection Proposition): Buyers will rationally self-select into different groups. Smaller buyers will adopt e-procurement platforms that entail lower costs but higher supply variance (i.e., open platforms). Larger buyers will adopt platforms that entail higher procurement costs but lower supply variance (e.g., the traditional proprietary platforms).*

This finding matches what has been happening in industry. The larger, more established firms emphasize the maintenance of smooth supply lines by reliance on proprietary e-procurement systems, such as EDI. They appreciate the extraordinary costs associated with "scrapping everything" and fully committing to vendors who have

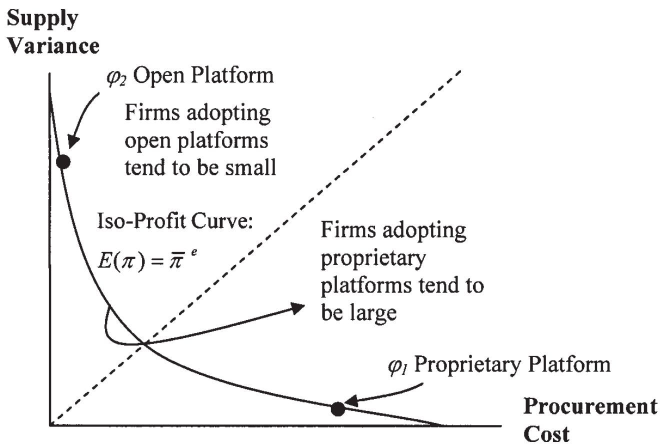

Figure 2. E-Procurement Platform Adoption and Firm Size

yet to demonstrate they are able to achieve critical mass in the market. Over time, these firms' suppliers have recognized the diminution of bargaining power associated with "tied procurement systems."

For a large firm, all of the concerns with respect to operational success that a small firm might face are going to be amplified—the transaction costs, the market uncertainties, and the related risks. Large firms have complex operational procedures and systems and highly specialized business processes. They work in ways that are idiosyncratic to the complexities of the firm as a multifaceted business organization. So technology adoption for core business processes goes beyond operational importance. Typically, whatever choices are made end up being strategic because of the extent to which operational success tends to be dependent on the quality of the associated systems performance outcomes.

The same holds true for the market uncertainties that large firms face. With greater equity and market value at stake, a larger number of stakeholders for firm and managerial performance, and a broader set of interactions with the market, the managerial concerns are well founded. The same goes for the technology-induced risks. Larger software applications take longer to build, are more prone to implementation delays, and are more costly to implement effectively. So, in spite of the greater managerial skill base and knowledge of technology within large firms, large applications still are more susceptible to outright project failure than smaller applications. In addition, larger organizations operate with an exponentially complex network of buyers, tiered suppliers, and market intermediaries, due to the spectrum of the specific supplies they must procure.

E-Procurement Systems Adoption with Platform Switching

One of the best-known results in microeconomics characterizes the adoption inertia that ensues when a new technology is superior but presents an adopter with risks due to the variance of adoption and implementation cost, in the presence of an older, better-established technology that has a larger *installed base.* A similar situation has developed with respect to technology platforms that support e-procurement. EDI is tried and true, and knowledge of how to make it work is widespread. It produces measurable value due to improvements in procurement operations [36, 44, 45]. But new technologies are now available to replace EDI.

Will the new open systems platforms be perceived as having the potential to create enough value so traditional users of EDI in supply chains will make the switch? To answer, we model a third kind of platform. A *hybrid adaptable procurement system platform,* φ_3, is a more technologically flexible platform. It gives the adopter access to lower procurement transaction costs, c, through its Internet connectivity. But the procurement risks given by σ_u^2 are also low, similar to the proprietary solutions.

Hybrid platform procurement solutions assure supply continuity by virtue of their adaptability in the marketplace and their ability to cater to the larger firms' traditional supplier bases. Examples of adaptable and flexible approaches are found among some of the e-commerce technology solution industry innovators, such as Ariba and Commerce One, as well as firms that provide logistics technologies, such as UPS and Manugistics. Such systems may achieve both cost and supply variance reductions. Consider the impacts of this new kind of technology through the lens of our risk-augmented transaction cost theory, as shown in Figure 3.

An example of a buyer that has adopted these hybrid capabilities is CVS Inc., the pharmacy outlet firm, which filled more than 12 percent of all prescriptions in the United States in 2001. The firm adopted the Ariba Buyer and Spend Management System to reduce lead times for store purchasing from an average of seven to ten days from the store order to no more than three or four days [2]. This achieved cost reductions (represented by the horizontal arrow pointing to the left in the figure). Also, the proprietary tools associated with this technology (e.g., forecasting tools) led to improvements in the supply variance (as shown by the vertical arrow in the figure). The technological capabilities offered by Ariba are open platform solutions; they are implemented in the Web context. They are also proprietary platform solutions in that the management functions they support are made possible by software tools that are unique to Ariba. In addition, Schonfeld [53] reported on IBM's ambitious new systems approach for integrating clients' diverse technologies, based on open platform technologies like Linux. This way, IBM is able to adapt to the client's proprietary systems, making the e-procurement system a hybrid adaptable platform.

The figure also shows that both large and small firms will have an incentive to move to the hybrid e-procurement system platform. This implies a higher profit, as depicted by the higher iso-profit curve. We expect that the buyers will cluster around the new, more adaptable form hybrid platform, as the arrows in Figure 3 show. This result can be summarized as:

> *Proposition 4 (Hybrid E-Procurement Platform Adoption Proposition): The emergence of a more adaptable hybrid platform that reduces both procurement costs and supply uncertainty will attract both large and small buyers, and will dominate both the proprietary and the open platforms.*

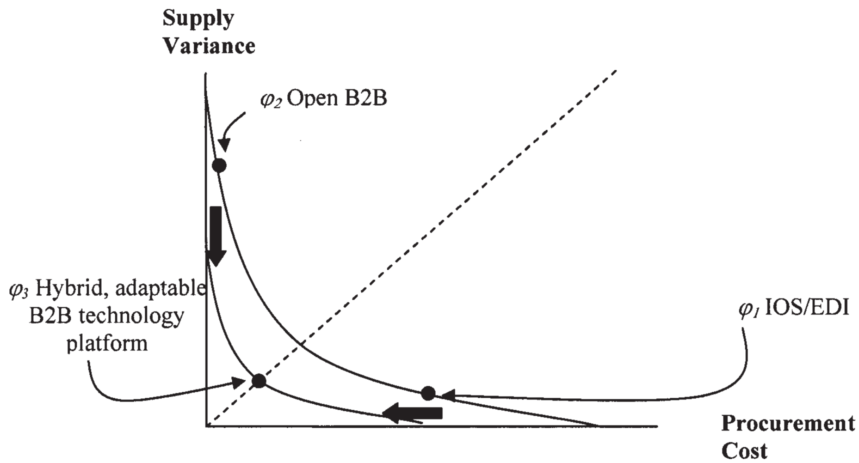

Figure 3. Adaptability Impact of a Hybrid E-Procurement System Platform

This proposition reflects what we currently are seeing in the market, with the movement of firms to technology solutions that blend elements of the old with elements of the new platforms. In addition to the dimensions that we have focused on in this analysis, supply variance and procurement cost, it is natural to recognize that the added flexibility inherent in hybrid platforms offers value of its own to the adopting firm. Although we do not model the option value of the potential flexibility benefits, the attractiveness of this kind of solution should go beyond the narrow value bounds that we describe. Indeed, it cannot be worth less.

Although a hybrid e-procurement platform solution offers "win-win" possibilities in terms of reduced procurement costs and reduced supply variance, a firm with a large installed base and large investments in an existing technology may require an even greater incentive to switch. If the gains from such systems changes are large enough to cover the switching costs, they will overcome the adoption inertia and persuade the management that a switch is valuable.

Demand Variance

To understand the effect of demand variance, σ_δ^2, on the tradeoff relationship between cost c and supply variance σ_u^2, note that

$$\frac{d}{d\sigma_\delta^2}\frac{d\sigma_u^2}{dc}\bigg|_{\bar{\pi}^e} > 0$$

and

$$\frac{d}{d\sigma_\delta^2}\frac{d^2\sigma_u^2}{dc^2}\bigg|_{\bar{\pi}^e} < 0$$

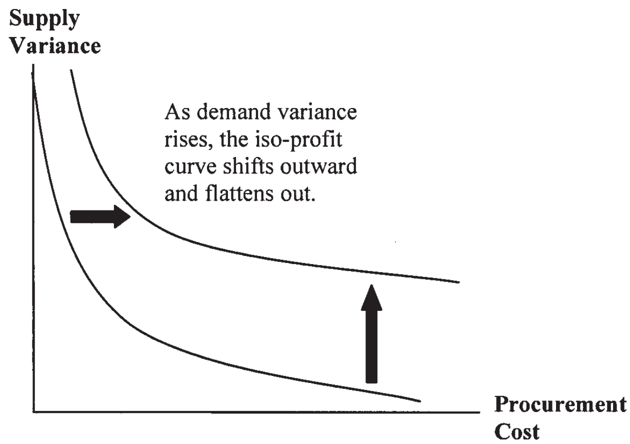

Figure 4. Shift of Buyer's E-Procurement Platform Adoption Iso-Profit Curve

from Equations (10a) and (11). Also, the profit Equation (9b) shows that profits, π^{e*}, fall in σ_δ^2.

Figure 4 shows our results, indicating that the iso-profit curve shifts out and becomes flatter as it shifts, resulting in the following conclusion:

> *Proposition 5 (Demand Variance–Supply Variance Balance Proposition): As the buyer's profits fall with higher demand uncertainty, the tradeoff between costs and supply variance shifts in favor of giving greater weight to the role of supply variance (indicated by the nature of the "tilt" in the shifting of the iso-profit curve).*

The demand variance gives a reading of market uncertainty for the buyer and plays a role in the firm's decision process of whether, when, and what e-procurement platform to adopt. We can analyze the firm's platform decision here by revisiting our criteria for platform adoption. Suppose a firm that currently owns a legacy system platform for procurement is considering whether to adopt the hybrid platform, φ_3, when demand uncertainty, σ_δ^2, rises. We see from Equation (9b) that profits fall, since $\partial\pi^{e*}/\partial\sigma_\delta^2 < 0$. Given that there are fixed costs of switching from the firm's existing legacy system to the new hybrid platform, ϕ_3, this implies a reduction in the firm's ability to switch to the new platform. In effect, it results in an *outward* shift of the iso-profit curve, moving it further away from ϕ_3. This forms our final proposition:

> *Proposition 6 (Buyer's Demand Variance–Platform Adoption Proposition): Higher demand uncertainty lessens a buyer's incentive, on average, to adopt a new e-procurement platform.*

Demand variance creates instabilities in the revenue and cost flows of the buyers. The higher the demand variance, the greater will be the risk and exposure of the buyer to the possibility of financial loss. Why? When demand variance occurs—especially in terms of stocking out in the presence of high demand—the buyer is forced to go to the spot market to replenish stock, with the likelihood that it will experience unfavorable prices. This gives the buyer an incentive to create long-term contracts and other arrangements to buffer it from higher costs, including working with a group of preferred suppliers. Spot buying will not be nearly as attractive; it will diminish a buyer's willingness to go into an e-procurement market. The same outcome is true on the low-demand side. With excess inventories, a buyer will be forced to bear the fixed costs of procurement, which include the e-procurement platform expenses, as well as the vendor management costs and the costs of the relationship with an electronic intermediary.

Discussion

OUR ANALYSIS HAS IMPORTANT IMPLICATIONS for the managerial selection of IT platforms for e-procurement. Our first proposition, the "Adopting Firm's Supply-Shock Absorption Capacity Proposition," suggests that a buyer's ability to absorb the disadvantageous effects of random oversupply shocks is founded on its market power and capacity to set prices. This also suggests the structure of the market in which the adoption decision for e-procurement platforms occurs. This creates expectations for the buyer's management relative to the impacts that e-procurement should have. Irrespective of the specific choice, if the buyer is able to reduce prices and increase sales, then its incremental revenues are likely to ameliorate the negative consequences of sudden oversupply. In contrast, we learned that the effects of greater uncertainty with respect to both demand and supply shocks may have greater consequences for buyers with more market power.

We also noted that the iso-profit curve associated with the tradeoff between procurement risk and procurement cost is convex for the adoption of a B2B e-market platform procurement technology decision. Our second proposition, the "Procurement Risk-to-Cost Convexity Proposition," informs managerial decision-makers that their platform choices should be viewed in terms of the *relative* risk-to-cost balance that is achieved. Along this procurement risk–procurement cost iso-profit curve, the differences in the impacts of the e-procurement platform adoption choices materialize. Our third proposition, the "Adopting Firm's Self-Selection Proposition," suggests the different perspectives of large and small buyers. Since small firms face critical constraints on their spending for infrastructure development, they will spend fewer dollars to create e-procurement platform solutions, and be willing to accept the higher supply variances that emerge from procuring supplies in a public exchange. When the opportunity to switch to another e-procurement platform arises, it is natural for the buyer to seek solutions that reduce both procurement costs and the uncertainty of supplies. In recent years, we have seen such opportunities become available, as the emerging technical solutions that are based on open source technologies are increasingly integrated to reduce adopter costs while still providing connectivity between buyers and suppliers.

Our fourth proposition, the "Hybrid E-Procurement Platform Adoption Proposition," posits that such emerging solutions will attract both large and small buyer firms, in spite of their being affected by shocks in demand and supply. However, accompanying the new potential for value associated with such solutions is the possibility that the sunk costs invested in a prior solution (e.g., standard EDI, Web-based EDI, etc.) may create friction on the part of firms that may consider moving to the superior technology. This is also natural, since there are inevitably risks that occur with implementation and systems integration. However, the perspective that we offer is aimed at analyzing and potentially influencing the behavior that buyers exhibit as they estimate the threshold level of business value that makes switching economical. Our fifth proposition, the "Demand Variance–Supply Variance Balance Proposition," points out why larger buyers will be in a better position to bear the effects of excess inventory, based on their unit production and unit inventory costs relative to smaller buyers. The final proposition, the "Buyer's Demand Variance–Platform Adoption Proposition," points out that the link between a high demand variance and the resulting impacts diminishes the impetus of the buyer to adopt a new e-procurement platform, including the open platform and hybrid platform choices.

In our analysis, we distinguished between the switch from older systems and the newer open standard to the hybrid procurement technology solutions. We argued that the greater the infrastructure updating cost, the greater the extent of the inertia that will need to be overcome before a firm will make a switch. In this context, e-procurement platform vendors must recognize that subsidies may be necessary for platform updating to occur to maximize total benefits for all parties involved [51, 52]. Yet the marketplace has been difficult, making it harder even for the reasonably well-established platform vendors to find the slack resources to subsidize other firms. Indeed, many observers would argue that the primary subsidies in this industry sector have come from venture capitalists, who have yet to realize *any* real returns on the significant sums of money they have spent during the past seven years in B2B e-commerce infrastructure technologies. The fact that the economy has not shown stable growth only compounds the difficulties that platform vendors are facing in having their e-procurement solutions adopted.

Limitations

BEFORE WE CONCLUDE, IT IS IMPORTANT TO POINT OUT the primary limitations of our modeling approach to the reader. One limitation of the model is its reliance on the assumption of linear demand-based profit maximization. This may constrain the applicability of our findings in certain settings—for example, in procurement in public organizations where cost control is the key, and when senior managers have knowledge of nonlinear demand (e.g., hospital medical and emergency supplies, seasonal building supplies, etc.). In addition, the model lacks consideration of *investment timing* and *vendor selection tactics* when a hybrid of open and proprietary e-procurement solutions is selected. A third limitation is that we do not consider the possibility of *vendor-side subsidies* and the role of *changing market psychology* with respect to the upside benefits of e-procurement solutions. Vendor-side subsidies permit buyers and suppliers to adopt *sponsored technologies,* which develop network externalities and user benefits at a different rate and for different reasons than what a technology purist might argue is a "first-best" technological solution in a given setting. Thus, we view modeling sponsorship and subsidies as some of the next steps with this research. Finally, we do not treat the market's rational expectations about technology adoption involving *specific* vendors [3]. Some, such as Ariba and Commerce One, are among the technology firms whose equity prices and viability have been hardest hit in the past few years. Clearly, vendor reputation and future expectations of the market matter, especially among new market entrants, where adopter expectations about future success are key.

A final limitation of our model and results is that they are developed and stated within the context of a *firm-size proxy for inventory policy,* the order quantity. We do not permit the possibility of a secondary market mechanism to dispose of or trade away excess inventory [39]. Nor do we directly include the details of optimal inventory policy-making, and how it ties in with technology platform selection. The optimization of periodic inventory replenishment policy is likely to vary for the buyer by supplier, by product type, and based on expectations of future period demand and supply forecasts, in lieu of inventory from just one period. Firms that are able to recalibrate inventory reorder points flexibly, as they obtain new information, are likely to want to hold out larger portions of their average purchase levels for spot buying, which will tend to favor the selection of e-market–based procurement solutions, and contracts with suppliers who are willing to share the gains associated with more informed purchasing approaches. If a buyer's supply chain partners are willing to provide this kind of "slack" and operational flexibility, and split the gains so that they might be shared by all firms, they will reduce the buyer's perception of risk and appreciate the nature of its self-interest. This will diminish the buyer's emphasis on the procurement system-side cost considerations. These issues are complex and managerially relevant, and we hope to treat them more fully in future research.

Conclusions

WE MODELED THE TRADEOFFS IN THE CHOICES that firms must make when they consider the adoption of open platform procurement systems (such as Internet-based B2B e-markets) versus proprietary platform procurement systems, as well as some recently emerged hybrids. We did so to introduce a new *risk-augmented transaction-cost perspective* that builds upon electronic markets and hierarchies theory [43] and move-to-the-middle theory [15]. The types of systems that we have discussed generally match what we have seen emerging in industry during the past decade, with the move from EDI and other post-EDI proprietary solutions to the adoption of e-market and open platform solutions by new technology vendors. Our model characterizes the choice of a procurement system platform that brings along with it a tradeoff between less costly but also more uncertain sources of supply, compared to more secure but costlier sources of supply. We emphasize the importance of shocks, which is new in the transaction-cost literature. We also provide a new theoretical lens though which to view and interpret what occurs in the marketplace, and how managers should make decisions about B2B procurement platform choices.

When firms take into account the procurement risks and uncertainties, our model instructs senior managers to look for a specific pattern of behavior among them in the presence of the new technologies. Larger firms are more likely to trade off demand and supply uncertainties with higher procurement costs. They will more often settle for proprietary systems. They also will tend to adjust the related transaction costs for the uncontrollable risks that they face. Smaller firms, in contrast, will emphasize lower-cost but less certain supply sources. They will tend to opt for more open platforms and access to a larger number of suppliers. Thus, despite the attractiveness of the open platforms, both the open platform and proprietary platform procurement systems are likely to coexist in the market.

We have also been able to characterize the circumstances for which an open e-procurement platform may dominate existing proprietary platform EDI technology. The tendency toward standards-based platform solutions is generally beneficial. But there are also other countervailing considerations that will affect the actual choices that firms make. For example, there is a value-maximizing opportunity associated with selecting adaptable systems that can integrate with buyer firms' traditional EDI-based technology infrastructure. Such benefits form the basis for the attractiveness of the open platform solutions' characteristics. Thus, we predict a convergence of both large and small buyer firms to procurement technology that mixes open and proprietary elements.

Our main result is ironic: the increased supply chain management cost sensitivity of the smaller buyers is a consequence of their higher exposure to oversupply risks. Smaller firms are forced to take even greater risks to lower their procurement costs. We see these risks in practice with the difficulties that firms face to make their e-procurement technology investments and their adoption of B2B e-market solutions pay off. In addition to supply shocks as a source of uncertainty, we also have included demand uncertainty in our model. We have found that the model also works well to explain and predict technology adoption behavior in the aftermath of the historical decline of the dot-coms. With the recent economic slowdown, we also have seen inventory buildups that are similar to the unanticipated inventory buildup that we model. One consequence is that the differences between the procurement systems adoption patterns of the larger and smaller buyer firms may intensify.

We remind the reader that there is still much to be learned before we can provide definitive guidance for senior managers about how to get the various aspects of their procurement systems right. But recognizing the important role of shocks and the effects of demand and supply uncertainties on procurement costs and procurement system platform choice is a step in the right direction.

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Notes

1. Proprietary EDI-based procurement systems should be considered as part of a set of e-procurement platform choices. They required specific kinds of hardware and software, depending upon where they were implemented (e.g., region, industry, product area). EDI focused on common transaction sets and communication protocols. This led to common database elements in the EDI technical solutions. The earlier EDI solutions share some characteristics with open systems. Today's solutions go significantly beyond transaction sets and database designs in the standards that they employ, however.

2. Firms with unstable demand face other issues. For example, suppliers may be asked to absorb some of the buyers' risks in the form of excess supplies, or to change delivery schedules. Buyers may then choose to favor fewer suppliers to avoid lowest-cost suppliers with no risk-sharing and cost absorption capacity.

3. Other articles on supply chain management emphasize the role of optimal order quantity policy [10, 11, 24, 40, 41]. Policy recommendations that flow from the single-period modeling formulation that we develop may not reflect a decreasing period order quantity. Nor will they adequately reflect the products that can be traded. An important potential cost that the buyer will bear is to unload excess inventory. In a single-period model, there is no market structure to permit the sale or the carryforward of inventory for sale at some discounted price. Also, there are no interaction effects between newly produced and secondhand, but nearly new, inventory, where product and inventory type (perishable versus nonperishable) will matter. Our translation of the cost impacts of stale inventory in one cost term is a reasonable proxy for markdowns or clearance, as well as the discounted cost-of-carry into future periods. See also Kauffman and Mohtadi [33] and Radhakrishnan and Srindhi [48].

4. We can use Equation (6), which provides an explicit form of $E(\pi(q_s))$, to obtain the unconditional expected profit. Since q_s is treated stochastically, Equation (2) can be used to express q_s in terms of the nonstochastic buyer's order quantity q_o. This involves δ and u as arguments of the inverse demand function of $P[q_o(1 + u)]$ and $P[q_o(1 + u)(1 - \delta)]$. Further analysis involves a Taylor series approximation of inverse demand around q_o to linearize the demand function. This expansion is carried out to the second term, and the results can be integrated over the appropriate density functions and simplified.

5. Actual industry practices are more complex. *Product sharing alliances* and *platform convergence strategies* bring together proprietary and open platform capabilities for supply chain management. Examples include Ariba (www.ariba.com), Novopoint (www.novopoint.com), and Transora's (www.transora.com) adoption of Synchra Systems Inc.'s (www.synchrasystems.com) proprietary supply chain CPFR software suite in 2000 and 2001 [1]. This suggests the possibility of identifying *mixed strategy technology adoption approaches.* Recognizing the inherent limitations relative to real-world decision-making, we limit ourselves to modeling *pure-play technology adoption strategies.*

6. We include firms of different sizes in Figure 1. The iso-profit curves stratify the space for families of firms, with each characterized by a profit level. Changes in the costs c enter linearly in Equation (9a), but quadratically in Equation (9b). So changes in c compensated by changes in supply variance σ_u^2 can leave profits in Equation (9b) unchanged. This can cause changes in quantity, q_o^*. So the iso-quant and iso-profit curves actually intersect. We focus on iso-profits, not iso-quants, to control for and equalize firms' ability to adopt IT. This approach is analogous to organizational, behavioral, and economics-based empirical modeling and econometric estimation research, where there is a need to obtain a reading on a specific effect, while controlling for other effects that may co-determine the overall outcome of interest.

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Appendix A. Open and Proprietary Systems: Costs, Risks, and Uncertainties

	Proprietary system solutions		Open system solutions	
Issue areas	Buyer side	Supplier side	Buyer side	Supplier side
Transaction costs	Costs higher than for open system solutions. Reduces benefits of competitive market. Value sharing may diminish benefits of wider supplier search.	Costs higher for buyer search. Short-term costs lower for business partners. Longer-term costs may be higher, due to supplier lock-in.	Lower costs for supplier search due to information and communication technology effects. Less need to distrust supplier's or intermediary's technology.	Lower costs through search for buyers. Reduces reliance on decision-making to determine appropriate exchange standard.
Risks	Primary risk is inability to switch. Secondary risk is commitment to a proprietary infrastructure, when technology is changing.	Primary risk is technology stranding. Secondary risk is uncertainty about future maintenance and enhancement.	Switching ability is improved, diminishing potential cost pressure. Commitment risk to proprietary infrastructure is avoided.	Lock-in diminished. Shift from contracts to spot market buying. Greater price and quality competition. Buyers may switch.
Market uncertainty	Multiperiod sharing of uncertainty costs. Lock-in may lead to insufficient supply. Must accede to information sharing in operations.	Multiperiod interaction encourages risk sharing, so buyer will not switch. Buyer shares information to help supplier forecast demand effectively.	Supplier participation diminishes risk of insufficient supply. Diminution of strong ties to focal supplier unlikely.	Uncertainty in competitive procurement marketplace affects supplier's solution. More info sharing. "Move-to-the-middle."

Notes: To understand the basis for effective managerial decision-making, it is useful to compare and contrast how open and proprietary platform procurement systems are perceived in terms of their transaction costs, financial risks, and market demand and supply uncertainties by the buyers and suppliers who invest and participate in them. We compare and contrast the buyer and the supplier perspectives. The contrasts shown here are high level. They do not reflect the ways that ownership of a proprietary platform procurement system by a buyer or a supplier will shift the risks between the parties. Nor do they reflect governance arrangements in open platform procurement systems that might diminish the importance of the noncontractible aspects of the relationship [26].

Appendix B. Examples from the Industry Press to Illustrate the Modeling Propositions

Proposition 1 (Adopting Firm's Supply-Shock Absorption Capacity Proposition): *Buyers with greater market power are better able to absorb the adverse effect of oversupply shocks, by reducing prices, than those with little or no market power. They also are more adversely affected by supply and demand uncertainties than are competitive buyer firms.*	Dell Computer, a major vendor of personal computers and server technologies, enjoys considerable market power in the markets it serves, in spite of the high level of competition that occurs in its technology industry sector. Dell's capabilities to reduce prices and move products based on noncurrent generation chip sets and other internal hardware are legendary. However, one of the firm's greatest vulnerabilities in the market is its inability to satisfy the pent-up demand of consumers in the market in the presence of supply problems for computer components that hold up shipments. Personal computer manufacturers, such as Dell and Gateway, recognize that the costs associated with stock-outs go far beyond individual customers who are affected. Instead, they have ripple effects that are transmitted marketwide. (Comments based on personal experience interacting with Dell and Gateway.)
Proposition 2 (Procurement Risk-to-Cost Convexity Proposition): *A buyer's iso-profit curve associated with procurement system platform adoption in the parameter space of supply procurement risks versus costs is convex.*	Optiant Inc., a supply chain management software solutions provider, issued a press release in early 2002 that illustrates this proposition. "Contrary to widely-held rules of thumb, increasing buffer inventory amounts is not the answer to increasing customer service levels. In fact, keeping extra inventory around to buffer shocks like those caused by September 11 is very costly and doesn't necessarily guarantee improved service to customers. For the U.S. economy a 5 percent increase in inventory levels would represent an extra working capital of $75 billion. In terms of associated expenses, carrying this additional inventory will cost businesses across the U.S. a total of about $18 billion." The firm also recommends that senior managers in supply chain management "[b]alance supply and demand while counterbalancing risk. Planning supply chain strategies around demand uncertainty (including forecast error, unexpected spikes/dips in demand) and supply unpredictability (including limited capacity, supplier delays, and critical parts shortages) equips corporations with agile supply chains that can handle uncertainty." Optiant Inc., Manufacturers Will Make 2002 the Year for Optimizing Supply Chain Performance, Press release, Optiant Inc., Somerville, MA, January 8, 2002. Available at www.optiant.com/news_pressrel_resolutions.htm, last accessed April 19, 2004.

Proposition 3 (Adopting Firm's Self-Selection Proposition): *Buyers rationally self-select into different groups. Smaller buyer firms adopt procurement systems platforms that entail lower costs but higher supply variance (i.e., open platforms). Larger buyer firms adopt procurement systems platforms that entail higher procurement costs but lower supply variance (e.g., the more traditional proprietary platforms).*	Celestica Inc., a large Toronto, Canada-based electronics supplier, illustrates the importance of adopter technology self-selection. "Celestica promotes collaboration and teamwork to improve flexibility, reduce costs, and maintain our lead in technology and innovation at the manufacturing level. We work with customers to build tighter relationships through on-site planners. We work with suppliers to enhance our supplier-managed inventory programs. We work within Celestica to maximize the advantages of our open architecture to enhance application interfaces. . . . Yet how can a unified supply chain access current product demand information? And how does a unified supply chain align suppliers, OEMs and the EMS [electronic manufacturing services] provider to sudden inventory changes? A dynamic replenishment strategy involves on-site planning at OEMs' facilities to successfully execute a global, unified supply chain operation, as well as anticipate supply changes. . . . Advanced Planning Systems software, as offered by leading software companies, delivers to the EMS provider an additional tool to forecast sudden changes in supply and order rates, as well as access to historical patterns of demand. This decision support simulation application draws information from ERP systems to estimate line-capacity thresholds, supply shortages, order increases and their impact on delivery dates. Suppliers and OEMs can pull this information along the unified supply chain, making each link more responsive and flexible to market fluctuations. . . . As Web-based EDI and integrated advanced planning become more common, the unified supply chain will prove to be an even greater strategic business tool that not only delivers bottom-line, quick-to-market results, but competitive advantage." Building a Global Unified Supply Chain, White Paper, Celestica, Inc., Toronto, Canada. Available at www.celestica.com/pdf/03-22-99-2.pdf, last accessed April 19, 2004.
Proposition 4 (Hybrid Platform Procurement System Adoption Proposition): *The emergence of a more adaptable hybrid platform that reduces both procurement costs and supply uncertainty will attract both large and small buyers, and will dominate both the proprietary and the open platforms.*	Ariba Buyer is a hybrid technology solution in that it provides connectivity with legacy systems that support procurement, with current open systems technology associated with the World Wide Web. The following quotation involving Dell Inc. illustrates the attractiveness of a hybrid technology platform solution in terms of its capabilities to lower procurement costs. "Trading inventory for information is a key to Dell's supply chain success, and in this day of point solutions aimed at tackling small problems quickly, Dell again is proof that following its own course is the way to go. Dell runs what is said to be the world's largest implementation of i2 Technologies Inc.'s software, running its Dell-specific DSi2 solution on 120 servers, managing more than 250 suppliers responsible for delivering over 3,500 components. . . . Dell implemented Ariba Buyer over a seven-month period, interfacing the procurement solution with nearly 20 of Dell's legacy systems, including links to Oracle Financial for purchase order, cost center and accounting code data. The result—called Dell Internet Requisition Tool—provides automated processing of fully validated orders. The system reduced the time to complete a requisition by 62% and the cost by 61%, in addition to reducing the number of errors." D.G. Jacobs, Anatomy of a Supply Chain, *Total Supply Chain Technology News*, March 2003, 20–22 (available at www.totalsupplychain.com). See www.ariba.com and Ariba Procurement Solution Overview, www.ariba.com/solutions/procurement_overview.cfm, last accessed April 19, 2004.

(continues)

Appendix B. Continued.

Proposition 5 (Demand Variance Proposition): *As the buyer's profits fall with higher demand uncertainty, the trade-off between costs and supply variance shifts in favor of giving greater weight to the role of supply variance (indicated by the nature of the "tilt" in the shifting of the iso-profit curve).*	Retail firms that have highly seasonal fashion and customer products (e.g., textiles, apparel, and clothing) tend to be more subject to the adverse effects of oversupply stocks. They include apparel manufacturers Kimberly Clark, Haggar Clothing Co., Sara Lee Knit Products, Fieldcrest Cannon, and retail stores JC Penney, Lands' End, L.L. Bean, and Target. These firms have sponsored research on the effects of retail demand uncertainty related to the performance of their supply chains. They note the relatively high importance of agile, reactive, and custom manufacturing; flexibility and short lead time; modular design and product differentiation; and small lot sizes. Firms in the same industries that produce and sell more basic apparel (nonfashion) tend to emphasize large lot size, and maximum quality for minimum cost, along with minimum inventory costs. See Demand Activated Manufacturing Architecture Project (DAMA), as referenced in J. Lovejoy, Principles of Supply Chain Management, TexExchange.com, www.texexchange.com/theLibrary/principles_SCMhtml, last accessed April 19, 2004.