ANALYZING INTERORGANIZATIONAL INFORMATION SHARING STRATEGIES IN B2B E-COMMERCE SUPPLY CHAINS

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ABSTRACT

Information sharing in procurement occurs in many rich and varied industry contexts in which managerial decisions are made and organizational strategy is formulated. We extend the current theoretical results to understand how information sharing ought to work in procurement contexts that involve investments in interorganizational information systems and collaborative planning, forecasting and replenishment practices. Our primary research question is: How and under what circumstances does a firm that plays the role of a buyer in supply chain management decide to share information on key variables, such as point-of-sale consumer demand data with its supplier, up the supply chain? The answers that we provide are based on the analysis of a sequential form game-theoretical model of buyer and supplier profits in the presence of uncertainties about final consumer demand, as well as the different operational cost regimes associated with information sharing and information withholding strategies, and the information technologies that support them. Our results provide normative guidance to supply chain buyers about how to interpret different demand uncertainty scenarios to improve the likelihood that their decisions will maximize the value of their firms.

KEYWORDS: B2B e-commerce, economics of IS, e-procurement, information sharing, organizational strategy, supply chain management.

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INTRODUCTION

Recent increases in computing power have dramatically enhanced the use of algorithm-based optimization approaches by firms aimed at managing supply chain management related uncertainties (Aviv, 2001; Kumar, 2001). This phenomenon has prompted increasing integration of systems and sharing of information across firms (Raghunathan, 1999; Strader, et al., 1999; Ball et al., 2002). In addition, it has promoted new managerial approaches, such as Web-based electronic data interchange (EDI), vendor-managed inventory and collaborative planning, forecasting and replenishment (CPFR) (Aviv and Federgruen, 1998; Clark and Lee, 2000; Seidmann and Sundararajan, 1997; Yao et al., 2001) and new contractual approaches in procurement (Cachon and Lariviere, 1999; Kleindorfer and van Wasselhove, 2003). A common feature of all these approaches is their exploitation of the value that interorganizational information sharing arrangements create. This occurs in supply procurement when it is accompanied by appropriate business process capabilities (Riggins and Mukhopadhyay, 1994).

A common goal of firms in the sharing of procurement information is effective inventory management, cost minimization, protection against supply disruptions and against bullwhip effects, where demand variability is amplified across the firms up the value chain (Lee, et al., 1997). Buyer firms benefit from the cross-functional value of information sharing, improving production planning and transforming marketing and sales strategy (Seidmann and Sundararajan, 1997).

Yet, intimate knowledge of the market conditions is often buyer's strategic asset. Also, because suppliers may use such information against buyers, this tempers the latter’s desire to adopt IT and risk losing competitive advantage in procurement (Whang, 1993). The result is that buyers have a diminished incentive to share information due to the risk exposure (Laffont and Tirole, 1999), while still taking advantage of the strategic value of their private information (Chen, 1998; Gavirneni, et al., 1999).

This paper explains and identifies the circumstances under which buyers might choose to share or to withhold information from their suppliers. It focuses on the consequences of this choice for their information technology (IT) adoption decisions, and extends the existing theoretical understanding of information sharing in e-procurement in supply chains.
The possibility of the buyer withholding information in this paper arises from supplier opportunism (Clemons, et al., 1993; Seidmann and Sundararajan, 1997; Whang, 1993). We find that under some circumstances information withholding strategies can nonetheless yield full information. This occurs if the supplier is able to infer buyer’s private information, causing the buyer to be worse off because of its initial reluctance to invest in the appropriate IT. Interestingly, it is also possible that information sharing can lead to the buyer being better off, if the supplier’s inference is incomplete, so that the final equilibrium is informationally inefficient. Should information withholding lead to a buyer being unwilling to adopt IT, a classic “asset hold-up” problem occurs (Schmalensee and Willig, 1989).

In the food industry, Nakayama (2000) shows that information exchange plays a role in the power relationship between supermarkets and suppliers, impacting trust and IT adoption. An instance is when food retailers use EDI for inventory coordination. Suppliers’ knowledge of the buyer’s parameters leads them to monitor and control the buyer’s mark-up more effectively, reducing the buyer’s incentive to share point-of-sale (POS) data with its suppliers.

This incentive of the buyer to withhold information is distinct from the incentive to distort order information when a supply shortage is anticipated (Lee, et al., 1997) or to exaggerate the forecast of final demand to induce the supplier to build larger capacity (Cachon and Lariviere, 2002). This issue has also been treated by economists in more general terms, especially for interfirm strategic information sharing in monopolistic, duopolistic, oligopolistic and competitive settings (e.g., Gal-Or, 1985; Li, 1985 and 1999; Raith, 1996). Other related studies in Operations Management include Lee, et al. (2000) and Gavirneni, et al. (1999) and Cachon and Fisher (2000). The authors treat the advantages of information sharing in reducing inventory and increasing supply chain efficiency, but do not discuss buyer incentives to withhold information. Whang (1993) focuses on information “garbling” versus information sharing strategies of a supplier versus its downstream buyer. Our perspective is different, but similar to another one offered by Li (2002). He focuses on information sharing and withholding strategies in horizontal competition. The incentive of the buyer to share or withhold information from the supplier is driven by the leakage of information to potential rivals, not by supplier opportunism. We share with Li (2002) the
notion of information inference stemming from observed actions of the firm. But the inferring party in our analysis is the supplier, not the competing buyers.

Information sharing in supply chain management involves strategic considerations related to IT adoption. The information sharing game takes place in an environment of uncertainty in which the final demand facing the buyer and the ability of the supplier to fulfill the buyer’s orders are each subject to independent random shocks. Radhakrishnan and Srinidhi (2003) consider demand side variability as the main influence. We also consider an independent supply-side variability due to random errors. For example, Dell reports a significant degree of statistical error in the procurement process that was reduced by sharing information with its suppliers—from 200 errors per million orders to just ten (Perman, 2001). Another unique feature of this work emerges that has not been seen elsewhere in the literature: a firm’s output and pricing decisions will have a shorter time horizon than decisions on IT investments associated with information sharing.

In the following section, we discuss the theoretical perspectives that provide the foundation for our modeling approach. Next, we develop a number of propositions regarding the impact of uncertainties in procurements and market demand on managerial decisions. We then analyze buyer-supplier information sharing strategies by modeling the buyer's investment decisions in appropriate IT platform solutions. These solutions are obtained in a sequential game of extensive form between the supplier and the buyer. The results fall into three scenarios regarding the extent of final demand that supply chain faces. We characterize the results with propositions that guide a managerial decision maker on how to think through the available strategy choices. In the final section, we extend the basic model to include many suppliers.

MODELING INFORMATION SHARING IN SUPPLY CHAIN MANAGEMENT

Different perspectives have developed in recent research on information sharing and the related strategies that firms develop. Lee and Whang (2000) note the trade-off that buyers in procurement consider by asking: What is the minimum set of information to share with supply chain partners without risking potential exploitation? Gal-Or (1985) showed how information sharing can lead to socially
efficient results, even if they are not optimal from a specific firm’s point of view. Seidmann and Sundararajan (1998) analyzed how information sharing by firms along the supply chain can reduce costs and diminish vertical transactional inefficiencies. There may also be strategic implications, as horizontal information leaks may occur. Nakayama (2000) studied the strategic value of supply chain information in the food industry. He learned that buyer-supplier power is a driver of buyers’ willingness to adopt EDI. His survey finds evidence that power shifts towards suppliers that have EDI links. Kinsey and Ashman (2000) also have found that insufficient trust deters retail grocers from sharing critical information with their suppliers. Other industries have seen similar considerations related to information and knowledge sharing arise as well (e.g., in electronic banking, financial risk management, and healthcare insurance).

In supply chain contexts, the buyer is concerned with building market power in the presence of choices about whether and how to share inventory information with suppliers. Suppliers tend to have market power, even though there are cases (e.g., Dell, Wal-Mart, Target) where the buyer has close to monopoly power over some of its suppliers. Buyers and suppliers face final demand uncertainties and procurement errors between orders and deliveries that they prefer to eliminate. We focus on cases where the supplier has market power relative to the buyer firm. However, although the buyer is competitive with respect to the supplier, it is large enough to be able to exercise market power relative to its own customer base. In addition, in the final section, we allow for many suppliers and examine how the resulting decline in the suppliers’ market power affects the buyer-supplier information exchange.

**Modeling Preliminaries**

We consider a retail firm that we call “the buyer” that exerts some price control on its products, but faces demand uncertainties. The buyer procures in a competitive market subject to supply uncertainties due to inappropriate forecasting by the suppliers, production disruption or delays in delivery. The critical aspect of this uncertainty that we model is the extent to which the buyer and the supplier face procurement errors due to mismatched orders and deliveries, in terms of timing delays, incorrect product specifications or incorrect quantities.

**Stochastic Demand and Supply Uncertainties.** Demand uncertainties arise because final sales are
subject to stochastic shocks. To represent this, let \( q_s - q_d' = \delta q_s \Rightarrow q_d' = (1 - \delta)q_s \), with \( \delta \sim f(0, \sigma^2) \)

and \( \delta \in [-1, 1] \). \( q_d' \) is the final level of sales (or final demand, \( d' \)), \( q_s \) is supply quantity received from supplier \( s \) and \( \delta \) is a proportional management estimation error of final demand due to random shocks. The random variable \( \delta \) is symmetrically distributed with distribution \( f \), mean 0 and variance \( \sigma^2 \). To ensure that \( q_d' \geq 0 \), \( \delta \) must have a truncated symmetric distribution (such as the truncated normal) in the interval \([-1, 1]\). Supply uncertainties are modeled for a control variable, \( q_o \), that represents quantity to be ordered from a supplier, \( q_o = (1 + u)q_o \), with \( u \sim g(0, \sigma_u^2) \) and \( u \in [-1, 1] \) The distribution \( g \) can be any symmetric truncated distribution. Supply fluctuations are likely to be independent of any random demand fluctuations, so \( \text{cov}(\delta, u) = 0 \). Then, the variable \( q_o \) is the control variable that management wishes to optimize.

Calculating the Buyer’s Profits. A buyer \( b \)'s expected profits, \( E(\pi_b) \), are calculated by integrating its objective function over two uncertainty dimensions, demand and supply, with \( \pi_b(q_s, q_d') \) representing the profit for a given supply quantity \( q_s \) and final consumer demand \( q_d' \), prior to the application of the stochastic process operators:

\[
E(\pi_b) = \int_{-1}^{1} \int_{-1}^{1} \pi_b(q_s, q_d') f(\delta) d\delta.
\] (1)

To calculate expected profits, we evaluate the conditional expectation, \( E(\pi_b(q_o)) \), over \( q_d' \):

\[
E(\pi_b(q_o)) = P(q_o) q_o \cdot \text{prob}(q_o < q_d') + P(q_o) q_o \cdot \text{prob}(q_o > q_d') - c q_o - s \cdot \text{prob}(q_o > q_d')
\] (2)

In this expression, \( P(\bullet) \) is the inverse demand function, \( c \) is total unit cost of obtaining product from distributors, with product procurement cost, \( c_p \), and transaction cost, \( c_t \), of bringing the product to market (in terms of documentation, invoicing, advertisement). The supplier can exert market power over \( c_p \) while \( c_t \) is internal to the buyer. The parameter \( s \) denotes unit should there be excess supplies, so the buyer must absorb the costs of storing or disposing of inventory ordered in excess of that level necessary to meet final consumer demand.

We can express Eq. 2 in \( \delta \) by noting that \( 0 \leq \delta \leq 1 \) for \( q_s \geq q_d' \) and \( 0 < \delta \leq -1 \) for \( q_s < q_d' \) as
This can be simplified because \( q_s \) is a \textit{given} at this stage, and \( P(q_s)q_s \) is independent of \( \delta \). Since \( f(\delta) \) is symmetric in \( \delta \), and the integral covers half the range of \( \delta \), the first integral can be evaluated as \([P(q_s)q_s]/2\). We define the final term, the demand error integral, \( \Omega_\delta \equiv \int_0^1 \delta f(\delta) d\delta \), so the buyer’s conditional profit expectation is:

\[
E(\pi_b(q_s)) = (1/2)P(q_s)q_s + \int_0^1 P(q_s(1-\delta)) \cdot q_s(1-\delta) f(\delta) d\delta - cq_s - sq_s \Omega_\delta.
\]  \hspace{1cm} (4)

**Unanticipated Over-Supply.** \( \Omega_\delta \) represents the mean value of \( \delta \), the extent that actual demand falls short of supply, with \( \delta > 0 \). So \( \Omega_\delta \) indicates the extent to which there is inventory build-up. Also, from \( \delta \in (0,1) \), it follows that \( \Omega_\delta < 1 \). The unconditional value of expected profits is found by integrating the conditional expectation over the supply variance, \( u \), to yield:

\[
E(\pi_b) = \int_{-1}^1 E(\pi_b(q_s)) g(u) du.
\]  \hspace{1cm} (5)

We can obtain an explicit form of \( E(\pi_b(q_s)) \), which will involve stochastic parameters \( \delta \) and \( u \), as arguments of the inverse demand function \( P[q_o(1+u)] \) and \( P[q_o(1+u)(1-\delta)] \). Using Taylor series approximation of inverse demand around the non-stochastic order size, \( q_o \), and integrating the results over the appropriate density functions, the buyer’s expected profit becomes:

\[
E(\pi_b) \equiv (1 - \Omega_\delta) P(q_o)q_o - (c + s\Omega_\delta)q_o + q_o^2 P'(q_o) A(\sigma_o^2, \sigma_o^2, \Omega_\delta) .
\]  \hspace{1cm} (6)

In this expression, the final term, \( A(\bullet) \), involves the variance of the demand error integral and is

\[
A(\sigma_o^2, \sigma_o^2, \Omega_\delta) = (1 - 2\Omega_\delta) \sigma_o^2 + \frac{1}{2} \sigma_o^2 (\sigma_o^2 + \sigma_o^2) - \Omega_\delta .
\]

Finding optimum order quantity \( q_o^* \) requires the concavity of expected profits, \( E(\pi_b) \). This imposes a limit on unanticipated overstock size, \( \Omega_\delta \), so that

\[
\frac{d^2 E(\pi_b)}{dq_o^2} < 0 \Rightarrow \Omega_\delta < \frac{1}{2} \left( 1 + \frac{\sigma_o^2}{2} \right).
\]
The Buyer’s Optimizing Behavior in the Presence of Linear Demand

We begin with a brief analysis of the buyer’s order level selection, $q_o$, to maximize expected profits. We examine the case of linear demand, with $P(q_o) = a - zq_o$. This demand structure supports a tractable illustrative analysis. The first order condition for optimization yields:

$$\frac{dE(\pi_b)}{dq_o} = 0 \Rightarrow q_o^* = \frac{1}{2z} \frac{(a-c)-(a+s)\Omega_\delta}{(1+\sigma_o^2)(1+\frac{1}{2}\sigma_o^2 - 2\Omega_\delta)}.$$  \hspace{1cm} (7)

From the expression for $q_o^*$ presented earlier, we know that maximum expected profits are:

$$\pi_b^e* = \frac{1}{4z} \frac{[(a-c)-(a+s)\Omega_\delta]^2}{(1+\sigma_o^2)(1+\frac{1}{2}\sigma_o^2 - 2\Omega_\delta)}.$$ \hspace{1cm} (8)

If the buyer firm is to remain viable in the marketplace, its optimum order size and profits must be positive. Since the denominators of Eqs. 7 and 8 are positive (by the concavity of expected profits), the firm is viable if the numerator in Eq. 7 is positive, i.e., if unanticipated overstock has upper bound, $\Omega_\delta < \frac{a-c}{a+s}$, so $\Omega_\delta$ is limited by $\min \left\{ \frac{1}{2} \left( 1 + \frac{\sigma_o^2}{2} \right), \frac{a-c}{a+s} \right\}$.

In Eqs. 7 and 8, supply and demand uncertainties, $\sigma_\delta^2$ and $\sigma_u^2$, affect expected output and profits adversely, as would be expected, $\frac{\partial \pi_b^e*}{\partial \sigma_\delta^2}, \frac{\partial \pi_b^e*}{\partial \sigma_u^2} < 0$ and $\frac{\partial q_o^e*}{\partial \sigma_\delta^2}, \frac{\partial q_o^e*}{\partial \sigma_u^2} < 0$. However, the effect of the unanticipated over-supply parameter, $\Omega_\delta$, is mixed. The origin of this is found in the expression for expected profits, Eq. 6: $\Omega_\delta$ affects expected profits adversely via the revenues and inventory costs, which are the first two terms in that expression. But it also positively affects expected profits through the slope of inverse demand $P'(q_o)$, which is negative. This is tied to the market power of the buyer relative to the consumers. For a competitive buyer $P'(q_o) = 0$ and unanticipated oversupply, $\Omega_\delta$, reduces expected profits unambiguously. However, buyers with market power can reduce prices when supply exceeds sales (i.e., $q_s > q_d^f$, or $\delta>0$), moderating the adverse effect of overestimating the demand. This leads us to assert:

- Proposition 1 (The Market Power Proposition): Buyers that have greater market power with...
respect to their consumers are better able to absorb adverse effect of oversupply shocks by reducing prices than those with little or no market power.

The overall net effect of inventory overstock is negative, \( \frac{\partial \pi^*}{\partial \Omega} \frac{\partial q^*}{\partial q} < 0 \), if \( \Omega \) has an upper bound, \( \Omega < 1 + \frac{1}{2} \sigma^2 - \frac{a-c}{a+s} \).

**The Supplier’s Optimizing Behavior Relative to the Buyer**

We next analyze the optimizing behavior of the supplier relative to the buyer. To do this, we first decompose the unit cost into its components, the procurement cost and the transaction cost, \( c = c_p + c_t \).

We assume that the seller possesses market power and acts monopolistically, reflected in the supplier’s influence over procurement costs, \( c_p \), that it charges the buyer. Supplier profits are then given by:

\[
E(\pi_s) = (c_p - v)E(q_s(c))
\]

where \( v \) is the unit cost of production, and \( q_s = (1+u)q_o(c) \) is the supply uncertainty. The function

\[
q_o(c) = \frac{1}{2z} \frac{(a-c) - (a+s)\Omega}{(1+\sigma^2)(1+\frac{1}{4} \sigma^2 - 2\Omega)}
\]

is determined by Eq. 7. Thus, Eq. 9 shows a Stackelberg supplier that acts as a “leader,” observing the buyer's downward sloping demand, as a function of the unit cost of procurement, \( c \). Substituting from \( q_s = (1+u)q_o(c) \) into Eq. 9, the supplier's expected profits become:

\[
E(\pi_s) = \int (c_p - v)q_o(c_p + c_t)(1+u)g(u)du = (c_p - v)q_o(c_p + c_t)
\]

The effect of product costs charged by the supplier is positive on supplier profits. They can be passed on to the buyer, due to \( c_p - v \) in Eq. 10. But we know from the slope of the demand that the effect on \( q_o(c_p + c_t) \) is negative since it can trigger an adverse demand response. Substituting for \( q_o(c) \) from Eq. 7 and remembering that \( c = c_p + c_t \), balancing these effects means that the supplier charges the buyer according to:

\[
\frac{dE(\pi_s)}{dc_p} = 0 \Rightarrow c_p^* = \frac{1}{2} [a-c_t - (a+s)\Omega + v]
\]

Notice that an increase in \( \Omega \) reduces the optimum charge by the wholesaler to the buyer, i.e.,
\( \partial c_p^* / \partial \Omega_\delta < 0 \). This leads to our second proposition:

**Proposition 2 (The Procurement Cost-Overstock Link Proposition):** The procurement cost that the supplier charges its buyer is inversely related to the overstock size facing the buyer.

Substituting from Eqs. 7 and 11 into Eq. 10 yields the supplier’s expected profits:

\[
\pi_s^* = \frac{1}{8\pi} \frac{(a - c_r - (a + s)\Omega_\delta - v)^3}{(1 + \sigma^2_u)[1 + \frac{1}{2}\sigma^2_\delta - 2\Omega_\delta]}
\]  

(12)

This expression raises a number of issues. **First**, supplier profits fall with uncertainty in final demand facing the buyer and the uncertainty associated with the variance between the supply of goods and buyer’s orders, based on the second derivatives, \( \frac{\partial \pi_s^*}{\partial \sigma^2_\delta} \). Thus, the buyer and seller along the supply chain benefit from a reduction in the market variance as well as improved coordination between orders and deliveries. **Second**, the effect of unanticipated overstock at the level of final sales to the consumer shows up in different ways: negatively through the numerator and positively via the denominator. To gauge the overall effect, we need to consider the expression for the supplier’s expected profit, \( E(\pi_s) \) from Eq. 10. Differentiating this when it is evaluated at the optimum in \( \Omega_\delta \), we get:

\[
\frac{\partial \pi_s^*}{\partial \Omega_\delta} = \frac{\partial E(\pi_s)}{\partial \Omega_\delta} = \frac{\partial c_p^*}{\partial \Omega_\delta} q_o (c_p + c_r) + (c_p^* - v) \frac{\partial q_o^*}{\partial \Omega_\delta} \]  

(13)

With \( \frac{\partial c_p^*}{\partial \Omega_\delta} < 0 \) per Eq. 11, an increase in \( \Omega_\delta \) reduces the optimum charge by the supplier based on the first term in Eq. 13. The second term, \( \frac{\partial q_o^*}{\partial \Omega_\delta} < 0 \), suggests the effect of \( \Omega_\delta \) on the buyer’s order size is negative, so long as \( \Omega_\delta < 1 + \frac{1}{2}\sigma^2_u - \frac{a-c}{a+s} \) holds. We conclude that \( \Omega_\delta \) also adversely affects seller firm’s profits, \( \frac{\partial \pi_s^*}{\partial \Omega_\delta} < 0 \). We summarize this result as follows:

**Proposition 3 (The Uncertainty Reduction-Profitability Link Proposition):** The seller’s profit level is adversely affected by demand and supply uncertainties and by the unanticipated
excess inventory build-up facing the buyer down the supply chain. Thus, a reduction in the
demand and supply uncertainties and the excess overstock of the buyer will also improve both the
buyer and the supplier’s profits.

Interpretation

This finding explains the mechanism by which recent inventory build-ups among large retail firms
(e.g., Hewlett-Packard/Compaq, Dell, Best Buy, etc.), led by the slowdown in consumer spending,
reverberated through the supply chain, causing a generalized slowdown and a decline in firm profits.

Combined with our Procurement Cost-Overstock Link Proposition, and the inequality, \( \frac{\partial c^*_p}{\partial \Omega} < 0 \), we
obtain an explanation for why firms may be concerned about the consequences of adopting IT to support
sharing information.

A decline in unanticipated overstock, \( \Omega \), due to better knowledge of the market, contributes to the
buyer’s profits in the short run, but also raises the cost that the supplier charges the buyer, due to the
expected opportunistic behavior on the part of the supplier, adversely affecting the buyer’s profits. By the
same token, a better forecast of final demand and the resulting decline in the value of \( \Omega \) tends to improve
the supplier’s profits. This finding is echoed by Seidman and Sundararajan (1998). As a result, the
supplier may have an incentive to subsidize the buyer’s adoption of information sharing technologies and
technology platform strategies (Riggins, Kriebel and Mukhopadhyay, 1994 and 1995; Riggins and
Mukhopadhyay, 1999) such as CPFR and vendor-managed inventory. This is Nakayama’s (2000)
observation: sharing inventory data reduces supply uncertainties, and benefits the buyer and the supplier.

Consider the perspectives of the buyer and supplier in other settings. Although they may be able to
gain from information sharing, there are still ways in which they will be in conflict. In our model,
procurement costs play that role. Since sharing information begins with the buyer in these cases, there
may be some reluctance on the part of the buyer to engage in information sharing, especially if the
expected loss from sharing information exceeds the expected gains. The question then is to understand
the circumstances under which an information sharing strategy dominates an information withholding
strategy in the game between the buyer and the seller. We next will expand on the initial model to incorporate the buyer’s aversion to the potentially damaging loss associated with sharing information.

ANALYZING INFORMATION SHARING IN A SEQUENTIAL SUPPLY CHAIN GAME

Our emphasis now shifts to the analysis of buyer-supplier information sharing optimization in CPFR systems. We focus on the buyer's IT investment decision in the context of a sequential game-theoretic model in extensive form between the supplier and the buyer. (See Figure 1.)

Figure 1. A Sequential Form Game Theory Model for CPFR Information Sharing

Note: Adopting CPFR permits the buyer to drive the value of the demand error integral $\Omega_\delta$ to 0, but the operational costs of matching orders to demand remain. Path 1 is the information sharing strategy path, and results in net long-run expected profit for the buyer of $\Gamma_1$. Path 2 is the information withholding strategy path for the buyer. The long-run expected profit for this decision is $\Gamma_2$. Along Path 1, the information of the buyer and the supplier are the same. However, along Path 2, the buyer decides to procure without sharing its private information about final demand, with the result that the supplier and buyer will have asymmetric information.

The difference in the time horizon between the two decisions means that the buyer may act strategically with respect to it supplier, even as it acts myopically with respect to prices and quantities. In our model, the buyer observes the dependence of procurement costs, $c_p$, on unanticipated over-supply, $\Omega_\delta$. The buyer’s profits arising from this strategic behavior are found by substituting the supplier’s cost Eq. 11 into the buyer’s profit Eq. 8:
Strategy Options for the Buyer

This analysis leads to several strategic options for the buyer firm. The most interesting one is where the buyer firm has the incentive to use information on final demand (e.g., POS data) to raise its own profits, but to withhold information from its supplier to keep down that part of product's procurement cost, adversely affecting the latter’s profits.

Another option that is available to the supplier is to increase the buyer’s incentive to adopt by subsidizing the investment costs associated with procurement platform information sharing solutions. Whether the buyer accepts or rejects this offer will depend on the supply chain environment, including the size of the critical parameters (e.g., firm size, investment cost, etc.) and the degree of uncertainty in market demand. What is interesting is that even in the absence of buyer CPFR and its information sharing capabilities, the supplier may be able to extract information from the buyer based on the latter's periodic order quantities. The subgame-perfect equilibria arise from the buyer's choice of the most profitable strategy—whether to adopt CPFR and share information—given the supplier's response.

Assumptions. We assume the buyer gathers consumer and market data with POS scanners. The data do not automatically help to reduce the size of the estimated error in final demand, $\sigma^2$ and the unanticipated over-supply, $\Omega$, unless the retail firm has adopted other technologies to analyze and interpret the market data. We further assume that the buyer has adopted IT capabilities that permit effective internal use of shared information, and EDI for communication with the supplier. The adoption of internal IT capabilities and EDI cause the buyer’s costs of handling supplies, $c$, to decline, and it is able to forecast demand more effectively, reducing uncertainty. This causes the variance of the demand error forecast, $\sigma^2$, and the unanticipated over-supply, $\Omega$, to fall.

For simplicity, we also will assume that demand-related uncertainty is eliminated, so that the demand error forecast, $\sigma^2$, and the anticipated over-supply $\Omega$ will be equal to zero. The drop in demand

\[
\pi_b^* = \frac{1}{4} \frac{[(a - c_p^* - c_i) - (a + s)\Omega_x]^2}{(1 + \sigma_p^2)(1 + \frac{1}{2}\sigma^2_\delta - 2\Omega_\delta)}
\]

\[
\sigma^2 = \frac{1}{2} [a - c_i - (a + s)\Omega_\delta + v]
\]
uncertainty benefits the buyer. This will benefit the supplier too, if the buyer is willing to enter into full-fledged information sharing of market information and data with the supplier, as with CPFR adoption. Another advantage of full-fledged information sharing is the reduction in supply uncertainties that arise from supply chain coordination, so that $\sigma^2_u$ also goes to zero.

**Buyer and Supplier Impacts.** Although the supplier benefits, the buyer faces trade-offs. The buyer benefits from the reduction in supply and demand uncertainties. But sharing final demand information increases the supplier’s ability to exercise market power via product procurement costs, $c_p$. So the buyer may not share despite the potential gains to both sides. The evidence suggests that the supplier may be willing to subsidize the buyer in its sharing of this information (e.g., the food industry, Nakayama, 2000). Riggins, et al. (1994), and Seidmann and Sundarajan (1998) model transfer payments of this type in supply chain management.

The buyer’s decision about whether to share information using CPFR will depend on parameters describing the business environment of the B2B relationship. If the buyer rejects the supplier’s offer, then the former will continue to rely on its own internal enterprise systems, and not have access to CPFR. If the buyer fails to adopt CPFR, then its ability to obtain and share information will be incomplete, and will not extend to the most sensitive market data.

**The Buyer’s Adoption of the Supplier’s Offer of CPFR: Information Sharing**

The buyer’s profits with respect to the dependence of procurement costs, $c_p$, on the unanticipated over-supply $\Omega_\delta$ was presented in Eq. 14. The buyer’s strategy options are based on evaluating the associated profit stream under different informational schemes. We will evaluate net long-run profits, by taking into account the amortized fixed cost of IT. We first analyze the case in which the buyer adopts the CPFR approach that the supplier offers. With full-fledged information sharing through CPFR, the supply and demand error variances are eliminated, as shown by Path 1 in Figure 1. When this is the case, the buyer’s profit function becomes:

$$
\pi_{b,\ast|\text{info sharing}} = \pi_{b,\ast} (\Omega_\delta = 0, \sigma_\delta^2 = 0, \sigma_u^2 = 0, c_i < c_i) = \frac{1}{16\pi} (a - c_i - \nu)^2
$$

(15)
The buyer's net long-run profit, $\Gamma_1$, from this decision is its equilibrium profit from Eq. 15, adjusted downwards for the annualized cost to finance the fixed cost of adoption. If $r$ is the interest rate, $F_1$ is the fixed cost of an enterprise system, and $F_2$ is the fixed cost of IT to support additional internal analysis of the information that the supplier shares with the buyer (e.g., category management), the net long-run profit for Path 1 for the buyer is:

$$\Gamma_1 = \frac{1}{16\pi} (a - c, v) - r(F_1 + F_2)$$

(16)

The Buyer’s Rejection of the Supplier’s Offer of CPFR: Asymmetric Information

This case, described by Path 2 in Figure 1, is interesting to analyze because it can explain the observed IT investment behavior. We pointed out earlier that supply chain buyers tend to under-invest in IT that promotes information sharing because they are concerned about trust and seller opportunism. In the food industry this issue has been particularly significant. Kinsey and Ashman (2000) point out that this may be why market leaders that have adopted product bar codes and scanner technology have lagged behind in the adoption of e-procurement and information-driven replenishment practices such as CPFR.

We can explain this by recognizing why information is a strategic asset for the firm, to be guarded and withheld when circumstances warrant. Consider $\frac{dE_\phi}{dc_p} = 0$ and $\frac{\delta c_p}{\delta \Omega_3} < 0$. The unit cost of procurement, $c_p$, rises to the buyer as a result of smaller values of the demand forecasting error integral, $\Omega_3$, representing a reduction in unanticipated over-supply. So we see that improved information to the supplier as a result of CPFR-type information sharing arrangements has the paradoxical potential to raise the buyer’s costs. Thus, buyers who act strategically with respect to information sharing would observe this adverse dependence on procurement costs arising due to the information sharing arrangements with the supplier. Thus, the buyer may find it beneficial to withhold sales information from the supplier, foregoing the benefits of CPFR from inventory coordination with the supplier, so $\Omega_3$ stays the same.

Although the supplier remains uncertain about the state of final demand facing the buyer, the buyer still can estimate its final demand without undue uncertainty by adopting other internally-focused IT
approaches for use with its own POS scanner data. The buyer’s decision to withhold its data as proprietary information means that it will now be different from the supplier's, leading to an information asymmetry. The buyer’s profits under this strategy arise from evaluating the maximum expected value of the buyer’s equilibrium profits in Eq. 14. We take special care to distinguish the information uncertainty experienced by the buyer, $\Omega_\delta^b$ and $\sigma^b_\delta$, from that of the supplier, $\Omega_\delta^s$ and $\sigma^s_\delta$. In the maximization of the buyer’s expected profits in Eq. 8, the buyer’s own information effect enters directly, but the information effects from the wholesaler operate only via the unit cost parameter, $c_p^*$. To be consistent with full-fledged information sharing, we present the buyer’s expected profits for the no information sharing case based on Eq. 14:

$$\pi^*_{b-e^*}| \text{no info sharing} = $$

$$\frac{[(a - c_p^* - c_t)-(a + s)\Omega^b_\delta)^2}{4z(1 + \sigma^2_u)(1 + \frac{4\sigma^b_\delta}{2} - 2\Omega^b_\delta)}$$

$$\left[c_p^* = \frac{a - c_t - (a + s)\Omega^s_\delta + v}{2}, \Omega^b_\delta = 0, \sigma^b_\delta^2 = 0, c_t' < c_t \right]$$  (17)

The supplier perceives a demand error integral, $\Omega_\delta^s$, for anticipated over-supply. Similar to the information sharing strategy, the internal transaction costs to the buyer, $c_t'$, are less due to its internal IT investments. The supplier is aware of this lower transaction cost and uses $c_t'$ to evaluate $c_t$, which appears as $c_p^*$ in Eq. 17, the procurement cost expression, and also directly in the profit term. The amortized fixed costs of the related IT are the same as in the information sharing strategy. To evaluate Eq. 17, we assume that the buyer has access to full information about final consumer demand (which it withholds from the supplier), so that $\Omega_\delta^b = (\sigma^b_\delta)^2 = 0$, while $\Omega_\delta^s$ and $(\sigma^s_\delta)^2 > 0$. The net long-run profit from adopting an asymmetric information strategy, $\Gamma_2$, is:

$$\Gamma_2 = \frac{[(a - c_t' - v) + (a + s)\Omega^s_\delta)^2}{16z(1 + \sigma^2_u)} - r(F_1 + F_2)$$  (18)

So, it appears that the net long-run expected profit for the buyer, $\Gamma_2$, rises with $\Omega_\delta^s$.

\[\square\]  **Proposition 4 (The Buyer’s Information Withholding Proposition):** The effect of a buyer that withholds proprietary market information from its supplier is to increase the buyer’s profits, all else equal.
Compared to the information sharing strategy payoff in Eq. 15, the price paid for the buyer's refusal to share information is the supply uncertainty and poor procurement coordination, represented by $\sigma_u^2$. We next discuss the equilibrium value of $\Omega_s^\delta$ and examine this trade-off.

**EQUILIBRIUM ANALYSIS FOR THE ASYMMETRIC INFORMATION STRATEGY**

Before we can examine what the outcome of the information sharing game will be for the supplier and the buyer, the nature of the information that they possess must be more closely examined. We next discuss what determines the equilibrium value of the demand error integral for the supplier, $\Omega_s^\delta$, and further examine what is involved in the analysis of the trade-offs.

**Revealed Equilibrium Signal with Asymmetric Information: Case of Multiple Equilibria**

The key aspect of the asymmetric information exchange between the buyer and the supplier is that despite the buyer's withholding of sensitive final demand data from the supplier, the latter is still able to extract valuable information. This occurs because the exchange is based on orders arriving from the buyer that the supplier fills. To help the reader to see this, we begin by noting that market equilibrium between the buyer and the supplier arises if an expectation realization condition is satisfied: the expected quantity of orders forecasted by the supplier matches the *certainty equivalence level* of orders by the buyer. This equality comes from applying the expression for the optimal order quantity,

$$q^*_o = \frac{1}{2z} \frac{(a-c)-(a+s)\Omega_s^\delta}{(1+\sigma_u^2)(1+\frac{1}{2}\sigma_s^2-2\Omega_b^\delta)}$$

Let

$$q^*_s \mid \text{order quantity expected by supplier} = q^*_b \mid \text{order quantity received from buyer}$$

$$\Rightarrow \frac{1}{2z} \frac{(a-c'_i-c_p(\Omega_s^\delta)-(a+s)\Omega_s^\delta)}{(1+\sigma_u^2)(1+\frac{1}{2}\sigma_s^2-2\Omega_s^\delta)} = \frac{1}{2z} \frac{(a-c'_i-c_p(\Omega_b^\delta)-(a+s)\Omega_b^\delta)}{(1+\sigma_u^2)(1+\frac{1}{2}\sigma_b^2-2\Omega_b^\delta)}$$

(19)

The unit cost, $c$, in $q^*_s$, consists of a transaction cost component and a procurement cost component, and depends on the demand-related error integral, $\Omega_s^\delta$, as in Eq. 17. The superscript $s$ marks the uncertainty as seen from the perspective of the supplier. Yet, in fact, $c_p(\Omega_s^\delta)$ shows up to both parties in the same way. Why? The supplier has access only to information it perceives. But the buyer knows this...
to be the case for the supplier. So although the supplier acts strategically in terms of supply quantity, the buyer is able to act strategically with respect to the signals in the game. The buyer operates on the basis of its own information, $\Omega^b_\delta$ and $(\sigma^b_\delta)^2$.

As was the case in evaluating buyer’s profits, we assume that the buyer has access to full information about final consumer demand (which it withholds from the supplier), so that $\Omega^b_\delta = (\sigma^b_\delta)^2 = 0$, while $\Omega^s_\delta$ and $(\sigma^s_\delta)^2 > 0$. Eq. 19 has two roots; just one corresponds to complete information. These are

$$(\Omega^s_\delta)_1 = 0 \text{ and } (\Omega^s_\delta)_2 = \frac{2}{2-\alpha} - \frac{a-c^i-v}{a+s},$$

respectively. The parameter $\alpha < 1$ is characteristic of the underlying density function, where we have assumed that $1/2(\sigma^s_\delta)^2 = \alpha \Omega^s_\delta$, with $\alpha < 1$, to eliminate $(\sigma^s_\delta)^2$ in favor of $\Omega^s_\delta$. This assumption is based on the definitions of $\Omega^s_\delta = \int_0^1 \delta f(\delta) d\delta$, and

$$\sigma^s_\delta = \int_{-1}^{1} \delta^2 f(\delta) d\delta,$$

and the fact that $\delta^2 < \delta < 1$. Figure 2 depicts the quantity curves for the two-sided certainty equivalent in Eq. 19, and the intersection associated with the two solutions.

**Figure 2. Determination of Information Equilibrium in Supply Chains**

With an increase in informational asymmetry $\Omega^s_\delta$ due to information that the buyer withholds from the supplier, the quantity ordered by the buyer rises, but the quantity expected by the supplier falls,
though with a discontinuity at $1/(2-\alpha)$. For the supplier’s expected quantity to fall in $\Omega^s$ we must have $1/(2-\alpha) > (a - c_o' - v) / (a+s)$. This guarantees that the second root of Eq. 19 is positive, $(\Omega^s_2) > 0$. But it also guarantees that $(\Omega^s_2) > 1/(2-\alpha)$.\(^1\) Thus, the discontinuity creates *separating multiple equilibria*. It follows that the initial level of informational asymmetry determines which equilibrium value of $\Omega^s$ is reached. This is an instance of what we have referred to earlier as a *path dependency*.

**Information Convergence and Separating Equilibria**

Our model is an example of a *signaling model* (e.g., Spence, 1973). In this case, the buyer’s behavior carries an unintended signal about the expected state of final demand through the orders placed up the supply chain. Suppose the buyer begins with an initial level of market uncertainty corresponding to the mean unanticipated over-supply of $\Omega_o$. The buyer’s actions reveal information about the market to the supplier, so the level of uncertainty to the supplier, $\Omega_s$, will gradually decline from its original level of $\Omega_o$. But where does the final equilibrium occur? The answer depends on the relative size of $\Omega_o$ compared to the discontinuity point of $(\Omega^s)_{\text{Discontinuity}} = 1/(2-\alpha)$. We distinguish among three scenarios:

- **Scenario A (Low Demand Uncertainty):** Initial demand uncertainty is low, so that $(\Omega^s_1) = 0 < \Omega_o < 1/(2-\alpha) < (\Omega^s_2)$. $(\Omega^s_1) = 0$ will be binding and the supplier’s inference will lead to full information convergence.

- **Scenario B (Medium Demand Uncertainty):** Initial demand uncertainty is of intermediate size such that $(\Omega^s_1) = 0 < 1/(2-\alpha) < \Omega_o < (\Omega^s_2)$. $1/(2-\alpha)$ will be binding and the supplier’s inference leads to information convergence.

- **Scenario C (High Demand Uncertainty):** Initial demand uncertainty is large such that $(\Omega^s_1) = 0 < 1/(2-\alpha) < (\Omega^s_2) < \Omega_o$. $(\Omega^s_2)$ will be binding and the supplier’s inference converges to this point.

\(^1\) There is also a case in which $q_0^* \mid \text{order quantity expected by supplier} \text{ rises with } \Omega_s$. However, this case is ruled out since it leads to the result that $2 - \alpha < \frac{a - c_o' - v}{a + s}$. This is impossible since $2 - \alpha > 1$, while $\frac{a - c_o' - v}{a + s} < 1$.\(^1\)
Due to the underlying discontinuity in supplier profits in Figure 2, the information convergence will
be towards either \((\Omega_s^* \delta_1)\) or \((\Omega_s^* \delta_2)\) (depending on the position of \(\Omega_s^\delta\)), yielding:

\[\square \text{ Proposition 5 (The Inferred Equilibrium Proposition). If demand uncertainty is low, then}
\]
supplier inference from the buyer’s orders leads to an equilibrium with full information
\((\Omega_s^* \delta_1) = 0\) (Scenario A). If demand uncertainty is moderate then supplier inference leads to an
equilibrium so the supplier faces some uncertainty, \(I(1-\alpha)\) (Scenario B). With higher uncertainty,
supplier inference leads to an equilibrium with greater uncertainty, \((\Omega_s^* \delta_2)\) (Scenario C).

Our results suggest that high information asymmetry cannot be rectified in a market with a high
degree of uncertainty, but it can be when demand uncertainty is lower. So information withholding
strategies are more harmful in markets with high levels of uncertainty. Yet, it is the high degree of
demand uncertainty that may yield higher “information rents” to the buyer, leading it to withhold
information (since learning by the supplier is incomplete).

**Strategy Dominance and Information Convergence**

When should the buyer switch strategies? Consider the profit streams of the buyer under the
information sharing strategy and the information withholding strategy associated with \(\Gamma_1\) (Eq. 16) and \(\Gamma_2\)
(Eq. 18), respectively. We view relative profitability of the two schemes as a function of market
uncertainty that is reflected in the value of the demand error integral \(\Omega_s^\delta\) and study the values of \(\Omega_s^\delta\) to
characterize when a switching strategy is appropriate. The two profit functions \(\Gamma_1\) and \(\Gamma_2\) are equal at a
point a value of demand error integral, say \(\Omega_{T_\delta}^T\), that defines the threshold value of market uncertainty for
switching IT strategies, as follows:

\[
\Omega_{T_\delta}^T = \left[1 + \sigma_s^2\right]^{1/2} - \left[a - c_s^* - v\right] \left[a + s\right]
\]

(20)

When we compare \(\Omega_{T_\delta}^T\) with the second root \((\Omega_s^* \delta)^2\) solution to the certainty equivalence expression
in Eq. 19, we find that, depending on the positions of two information parameters (initial market
uncertainty \(\Omega_s^\delta\) and switching uncertainty \(\Omega_{T_\delta}^\delta\), and the profit advantage of withholding information,
three outcomes are possible: the strategic value of the information withholding vanishes or is actually reversed, or its relative margin diminishes but it remains dominant. We distinguish three demand scenarios again: low, medium and high uncertainty.

With low market uncertainty, $\Omega^o_\delta < \Omega^T_\delta$ (call this Scenario A), the information sharing strategy always dominates: $\Gamma_2 (\Omega^o_\delta) < \Gamma_1$. For medium market uncertainty, $1/(2-\alpha) > \Omega^o_\delta > \Omega^T_\delta$ (Scenario B) information is initially withheld (as $\Gamma_2 (\Omega^o_\delta) > \Gamma_1$) but the information withholding “rent” will dissipate in the long run, due to information leakage to the supplier. There is full information convergence, i.e., the system converges to $(\Omega^{*}_\delta)_1 = 0$, because $\Omega^o_\delta$ is on the same side as $(\Omega^{*}_\delta)_1$ relative to the discontinuity, $1/(2-\alpha)$. At this point the buyer will be worse off than if it had adopted a full information strategy to begin with, because the final profitability position is now reversed, i.e., $\Gamma_2 (\Omega^{*}_\delta)_1 < \Gamma_1$. Finally, with high demand uncertainty, $\Omega^o_\delta > \max [\Omega^T_\delta, (\Omega^{*}_\delta)_2] > 1/(2-\alpha)$ so that $\Gamma_2 (\Omega^o_\delta) > \Gamma_1$ initially (Scenario C). Once again, as in Scenario B, information is initially withheld but leaked over time.

However, unlike Scenario B, information leakage to the supplier is incomplete or partial because the discontinuity $1/(2-\alpha)$ prevents $\Omega^*_\delta$ to fall to the level of $(\Omega^{*}_\delta)_1 = 0$, settling instead at $(\Omega^{*}_\delta)_2 > 0$. With some residual information rent for the buyer, was the buyer’s initial decision to withhold information correct in retrospect? The answer to this question depends on whether the value of $(\Omega^{*}_\delta)_2$ to which the system settles is less than the threshold $\Omega^T_\delta$ or exceeds it. Suppose $(\Omega^{*}_\delta)_2 < \Omega^T_\delta$ (call this Scenario C1). Then the buyer will be worse off ex post (i.e., $\Gamma_2 ((\Omega^{*}_\delta)_2 < \Gamma_1$), despite some residual information rent remaining, reversing buyer’s information initial advantage. Next, suppose $(\Omega^{*}_\delta)_2 > \Omega^T_\delta$ (call this Scenario C2). Then the buyer will still be better off ex post ($\Gamma_2 ((\Omega^{*}_\delta)_2 > \Gamma_1$) maintaining the buyer’s information initial advantage (i.e., $\Gamma_2 ((\Omega^{*}_\delta)_2 < \Gamma_1$).

Scenarios B and C1 suggest that the buyer that withholds information captures greater initial profits. However, due to the supplier’s inference, information converges to a new equilibrium profit that makes the information withholding strategy an inferior outcome for the buyer than if it had implemented an information sharing strategy to begin with. This adverse path dependence arises because the firm’s
benefits from its information sharing strategy are no longer available while the benefits of the information withholding strategy vanish due to learning by supplier. To summarize:

□ Proposition 6 (The Buyer's Feasible Strategies Proposition). An information sharing strategy or an information withholding strategy may both be feasible strategies for the buyer. However, in some circumstances an information withholding strategy locks the buyer into a path-dependent lower long-run profit due to information leakage to the supplier.

THE CASE OF A SINGLE BUYER AND MANY SUPPLIERS

Supply chains with a single large buyer and numerous smaller suppliers increasingly characterize a significant number of industries in the United States. Examples include such leading firms such as Dell, Wal-Mart, Target, Best Buy and the like. To interpret how information sharing strategy ought to be formulated for the case of a single buyer and many suppliers, we extend our preceding analysis.

Modeling Extension

We assume \( i \) identical suppliers indexed by \( i = 1, \ldots, I \). Supplier \( i \)'s expected profits are:

\[
E(\pi_i') = E[c_s(q_o^*)q_s'] - vE(q_s'), \quad i = 1, \ldots, I
\]  

(21)

Here, \( q_s^i = (1 + u_i)q_o^i \) allows the procurement disturbance \( u_i \) to vary among suppliers despite the fact that suppliers are identical otherwise. The other variables are defined as before. Each supplier will exert limited market power: it may be able to supply the single large buyer with a unique product. We will show that the incentive for information withholding by the buyer will diminish when the suppliers are numerous. Assuming the same symmetry assumptions on the distribution of \( u_i \) as we did earlier for \( u \), the total order size from the buyer to all suppliers is still given by Eq. 7. Breaking down total unit cost in Eq. 7 into procurement cost, \( c_p \), and transaction cost, \( c_t \), the cost can be stated via \( q_o^* \) as:

\[
q_o^* = \frac{1}{2z} \cdot \frac{(a - c_p - c_t) - (a + s)\Omega_s}{[1 + \frac{1}{4}\sigma_s^2 - 2\Omega_s]} \equiv V - W; \quad c_p \Rightarrow c_p(q_o^*) = \frac{1}{W}(V - q_o^*)
\]  

(22)
where  \( V = \frac{1}{2\pi} \frac{(a-c_T)-(a+s)\Omega_\delta}{[1+\sigma^2_u](1+\frac{1}{2}\sigma^2_\delta -2\Omega_\delta)} \) and  \( W = -\frac{1}{2\pi} \frac{1}{[1+\sigma^2_u](1+\frac{1}{2}\sigma^2_\delta -2\Omega_\delta)} \) to make the major relationships clear. Applying the expectation operator, deriving the first order condition for each supplier \( i \), and noting that all suppliers sell at the single price \( c_p^* \), yields:

\[
c_p^* = \frac{1}{I+1} \frac{V}{W} + \frac{I}{I+1} \nu = \frac{1}{I+1} [(a - c_T) - (a + s)\Omega_\delta] + \frac{I}{I+1} \nu, \tag{23}
\]

### Supplier Competition Reduces Opportunistic Behavior

We note several interesting aspects of Eq. 23. When \( I = 1 \), it reduces to Eq. 11, verifying the consistency of the main results. But, as \( I \) increases, the size of the mark-up over the manufacturing cost \( \nu \) falls, as we would expect. In fact, as \( I \) becomes very large, \( c_p^* \) approaches \( \nu \), so that the suppliers become fully competitive. Further, note that our key relationship, the impact of information about the buyer’s market on the supplier’s ability to charge \( c_p^* \), becomes more limited, the larger is \( I \)

(i.e., \( \partial | \partial c_p^* / \partial \Omega_\delta | \partial I < 0 \)). This suggests the following proposition:

\( \square \) **Proposition 7 (The Supplier Competition Proposition).** *Competition among suppliers reduces suppliers’ opportunistic behavior by reducing their market power, since competition diminishes their ability to charge the buyer higher prices based on the use of its market data.*

### Buyer’s Profits Under Information Sharing with Many Suppliers

The buyer’s profits are found by substituting for procurement costs, \( c_p^* \), from Eq. 23 into buyer profits, Eq. 8, from before, to yield:

\[
\pi_p^* = \frac{1}{4\pi} \left( \frac{I}{I+1} \right)^2 \frac{[(a - c_T - \nu) - (a + s)\Omega_\delta]^2}{(1+\sigma^2_u)(1+\frac{1}{2}\sigma^2_\delta -2\Omega_\delta)} \tag{24}
\]

An interesting result from Eq. 24 is that \( \partial \pi_p^* / \partial I > 0 \), which means that the more suppliers, the larger are the buyer’s profits. This result arises from the dampening effect of \( I \), the number of suppliers on procurement costs, \( c_p^* \), per Eq. 23. But because the adverse effects of information sharing on the buyer

\(^2\) Although a second type of generalization—*many buyers facing a single supplier*—is another logical possibility, our analysis of it adds little new insight beyond reinforcing the influence of the market power of the suppliers relative to buyers, which we have already modeled. So we include no further discussion.
are also more limited with a larger number of suppliers (as we saw, \( \frac{\partial c_p}{\partial \Omega} \) falls with \( I \)), it must follow that buyers are now both more willing to invest in IT to support information sharing with their numerous suppliers and less reticent to withhold information.

To check this intuition, we recalculate the net gains functions, \( \Gamma_1 \) and \( \Gamma_2 \), under the information sharing and withholding strategies. The net gains from information sharing are found, as before, by setting \( \sigma_w^2 \) and \( \Omega_s \) in Eq. 24 to zero and subtracting the fixed costs of technology, \( F_1 \) and \( F_2 \). This yields:

\[
\Gamma_1 = \frac{1}{4z} \cdot \left( \frac{I}{I+1} \right)^2 (a - c_r - \nu)^2 - r(F_1 + F_2)
\]

(25)

Note that \( \frac{\partial \Gamma_1}{\partial I} > 0 \), so the buyers gain more from information sharing strategies when there are many suppliers. This leads to the following proposition:

\[ \Box \text{ Proposition 8 (Buyer’s Information Sharing Strategy with Many Sellers). Buyers facing a large number of suppliers will be more willing to share sensitive market data with them; their gain from an information sharing strategy is greater with many sellers.} \]

Evidence of aggressive supply chain and information sharing practices by such firms as Wal-Mart with its numerous suppliers provides real world support for this finding.

To explore how the number of suppliers that the buyer faces may influence the selection of an information withholding strategy, we need to recalculate \( \Gamma_2 \), the net gains from information withholding. To do this, we follow the procedure outlined previously relative to Eq. 18 of distinguishing between the buyer’s and the seller’s information set. The result is:

\[
\Gamma_2 = \frac{1}{4z} \cdot \left[ \frac{I}{I+1} (a - c_r - \nu) + \frac{1}{I+1} (a + s) \Omega_{s} \right]^2 - r(F_1 + F_2)
\]

(26)

Consistent with our prior finding for one supplier, this expression reduces to Eq. 18 when \( I = 1 \). An interesting result emerges through the interpretation of the numerator of this expression. We observe that as \( I \) rises, the first term increases while the second term falls. Closer scrutiny reveals that the first term is associated with the market power effect: as the number of suppliers increases, the buyer’s profits rise. This term also is present in the information sharing strategy result, as we saw from Eq. 25. The second
term, however, is unique to the strategy of withholding information, since it multiplies the demand error integral, $\Omega'$. Since this term declines as $I$ goes up, we see that the retailer's gains from information withholding also declines as the number of its suppliers increase. Why? With a larger number of suppliers, the aggregate potential for opportunism declines (as we saw in the Supplier Competition Proposition), reducing a buyer's gain from protecting itself against such opportunism. We summarize this finding in our final proposition:

\begingroup
\begin{itemize}
\item Proposition 9 (Buyer's Information Withholding Strategy with Many Suppliers). Buyers facing a large number of suppliers will be less willing to withhold sensitive market data from them; as their gain from such a strategy is reduced when there are many sellers.
\end{itemize}
\endgroup

We summarize the results from the last two propositions in Figure 3 below.

\textbf{Figure 3. Buyer's Willingness to Share Information As a Function of Number of Suppliers}

It appears that the market structure of procurement in different industries will be revealing in terms of what we can predict about firms' information sharing strategies. Specifically, we expect that supply chains where the concentration is at buyer end (e.g., electronics or micro-processor chip-making) is where more information sharing will occur. But industries where there is concentration at the supplier end (e.g., steel, consumer goods or food) may face greater hurdles to engender information sharing among supply chain partners. However, within each industry there may be variations among supply chains in terms of concentration. The evidence in the food industry suggests that buyers situated at the end of larger supply chains are more apt to invest in IT to support information sharing than buyers associated with smaller supply chains (King, et. al. 2002).
CONCLUSION

New supply chain strategies and technologies have contributed to the cost reductions and increased procurement coordination that we have observed over the past few years across many industries. Yet, the continued expansion of supply chain practices depends on firms’ willingness to share sensitive information about demand, operating costs, and their customer relationships.

How likely is the continued adoption of IT-based supply chain practices, in the light of firms’ efforts to achieve an appropriate balance between profit-maximizing sharing or withholding of inventory and sales information? We explored this question using a sequential game-theoretic framework that emphasizes the buyer’s uncertainty with respect to final consumer demand in a supply chain setting. We found circumstances where information sharing and withholding might take place, depending on the degree of initial uncertainty about market demand. But our most interesting result is that a buyer who finds information withholding to be efficient initially may find itself locked into a less efficient outcome in the long run, as the upstream firms along the supply chain are able to infer the buyer’s private information about demand patterns for what it sells. This signaling mechanism becomes operative through orders that a buyer places with the supplier. It permits the supplier to infer information about final demand that the buyer is likely to face, permitting the supplier to potentially engage in profit-maximizing opportunistic behavior.

Our results are consistent with some of the findings in prior research (especially Radharkrishnan and Srinidhi, 2003, and Cachon and Fisher, 2000). They communicate the general theoretical perspective that information sharing will only be implemented by supply chain partners when the buyer and supplier are no worse off by exchanging information. We also learned that the industry structure of procurement may be a critical determinant for effective information sharing strategy for the firm. The more suppliers arrayed around a buyer, the more willing a buyer ought to be to make IT investments that support information sharing in supply chain management.

We also developed a basis for why the observed information sharing strategy choices may be path-dependent for the buyer. Our interpretation of how the buyer’s decision about which strategy to adopt is
predicated on the idea that adoption is not forced (Cachon and Lariviere, 2001) and that information is shared without player dishonesty or inaccuracies in the shared information (Brown, 1999). By withholding all shared information except procurement orders, the supplier is unable to know more than the buyer’s ordering signals can communicate about demand.

We note the following limitations of the current analysis. First, the generality of our findings is limited by the linear demand structure. Second, we made no effort to ascertain optimal inventory policies in our analysis of optimal information sharing strategies, so this may affect the comparability of our results to those of other papers that have emphasized the inventory policy aspects. Third, we also limited our analysis to supply chains with a single-tier supplier structure. With multiple tiers, we expect somewhat different information sharing dynamics. In particular, we expect to observe a diminution of the likelihood of first-tier suppliers’ strategic opportunism as the distance increases across the supply chain, from buyer to primary supplier to secondary and tertiary supplier. The strategic benefits associated with the use of the buyer’s demand information can only be leveraged once in full by one supplier, or in multiple pieces by a number of the tiered suppliers. However, this will diminish the available strategic gains that are possible, and hence, it will also tend to dampen suppliers’ interest in opportunism.

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