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INFORMATION SHARING AND STRATEGIC SIGNALING IN SUPPLY CHAINS*

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Abstract

Information sharing in procurement occurs in rich and varied industry contexts in which managerial decisions are made and organizational strategy is formulated. We explore how information sharing ought to work in procurement contexts that involve investments in inter-organizational information systems (IOS) and collaborative planning, forecasting and replenishment (CPFR) practices. How and under what circumstances does a firm that plays the role of a supply chain buyer decide to share information on key variables, such as point-of-sale consumer demand data with its supplier, up the supply chain? This is a key issue that crosses the boundary between supply chain management and information systems (IS) management. The answers that we provide are based on our use of a game-theoretic *signaling model* of buyer and supplier strategy in the presence of uncertainties about final consumer demand. We also explore the connection between operational costs that are associated with the firm's information sharing and information withholding strategies. Our results provide normative guidance to supply chain buyers about how to interpret different demand uncertainty scenarios to improve their decisions and generate high value. From the IS management perspective, we show the impacts on the firm of different information sharing approaches that are made possible by present day technologies.

Keywords: Anticipated over-supply, collaborative planning, forecasting and replenishment (CPFR), demand forecasting, economic analysis, information sharing, information systems (IS), signaling, supply chain management

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1. Introduction

Prior to the emergence of supply chains and the powerful information systems (IS) that support them, the practice of inventory management amounted to designing solutions for single firms as stand-alone organizational units. For example, the seminal work by Stohr (1978) on optimal order design, based on an optimum mix of physical stocktaking and the perpetual inventory method, focused on a single firm as the decision-making unit. Supply chains later introduced a strategic dimension into inventory management that had not existed before (Fisher 1997, Agrawal & Pak 2001). This was because inventory management came to include comprehensive technology-based coordination (Raghunathan 1999, Sahin & Robinson 2002) and collaboration across firms (Chen 2005, Nachtmann 2004). This led to such strategic issues as the *bullwhip effect* (Chen, Drezner, Ryan & Simchi-Levi 2000, Lee & Whang 2000) and the *demand-garbling effect* (Whang 1993). It also made possible timely and advanced information sharing and information withholding, but they had both positive and negative effects (Bourland, Powell & Pyke 1996, Chen 2001, Lin, Huang & Lin 2002, Shore & Venkatachalam 2003, Wu & Cheng 2008). In addition, there were *negative externalities* that were projected when buyer firms (that we will call "buyers") introduced various kinds of IT to their supplier firms (or "suppliers") that had not shared information before (Grover & Segars 1999, Riggins & Mukhopadhyay 1999). Another issue that arose was the possibility of *cost transparency*, and how this played out in the market among other firms that would come to know about it (Sinha 2000).

The recent increases in computing power that have dramatically enhanced the use of algorithm-based optimization approaches have been aimed at strategically managing supply chain uncertainties (Agrawal & Pak 2001, Cisco Strong 1999, Aviv 2001, Kumar 2001). They also make *information sharing* the central aspect of inventory management in supply chains (Raghunathan 1999, Strader, Lin & Shaw 1999, Ball, Ma, Raschid & Zhao 2002, Fiala 2005). There is a common feature of all of the new managerial approaches. They included Web-based electronic data interchange (EDI), vendor-managed inventory and collaborative planning, forecasting and replenishment (CPFR) (Clark & Lee 2000, Clark, Croson & Schiano 2001, Robinson, Sahin & Gao 2005, Seidmann & Sundararajan 1997, Yao & Dresner 2008, Yao, Evers & Dresner 2001, 2007), as well as the new contractual approaches to procurement (Cachon & Lariviere 2001). The key similarity is their exploitation of the value that interorganizational information sharing arrangements create. Effective information sharing occurs in supply procurement when it is accompanied by the appropriate business process capabilities (Riggins & Mukhopadhyay 1994). It is also made possible by digital intermediaries who stress information transparency in business-to-business electronic markets (Wang & Benaroch 2004, Zhu 2002, 2004a, 2004b, 2005).

A common goal of firms in the sharing of procurement information is effective inventory management. They hope to achieve cost minimization, protection against supply disruptions and against bullwhip effects, where demand variability is amplified across the firms up the value chain (Lee, Padmanabhan &

Whang 1997). Buyers benefit from the cross-functional value of information sharing, improving production planning and transforming marketing trategy (Seidmann & Sundararajan 1997). Yet, intimate knowledge of the market conditions is often a buyer's strategic asset (Arcelus, Pakkala & Srinivasan 2002). Also, because suppliers may use such information against buyers, this tempers the buyers' 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 (Arcelus et al. 2002, Laffont & Tirole 1999), while they still wish to take advantage of the strategic value of their private information (Chen 1998, Gavirneni, Kapuscinski & Tayur 1999).

This paper explains and identifies the circumstances under which buyers might choose to share or withhold information from their suppliers in the presence of CPFR supply chain practices. 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. It is especially relevant in contexts where buyers and suppliers are connected via the Internet, and where business-to-business (B2B) e-commerce is occurring. The possibility of buyers withholding information arises from *supplier opportunism* (Clemons, Reddi & Row 1993, Seidmann & 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 the 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 withholding 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 & Willig 1989).

In the food industry, for example, Nakayama (2000) shows that information exchange plays a crucial 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 (Clark et al. 2001). 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 (Grover & Ramanlal 1999, Grover, Ramanlal & Segars 1999).

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 & 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., Clarke 1983, Gal-Or 1985, Li 1985, 1999, Malueg & Tsutsui 1998, Raith 1996, Shapiro 1986). Other related studies in Operations Management include Lee, So & Tang (2000) and Gavirneni, Kapuscinski & Tayur (1999) and Cachon & 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. This supports *information inference* stemming from observed actions of the firm (Li 2002), 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 and information signaling. Supply chain management information sharing 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 subject to independent random shocks (Raghunathan 2001, 2003). Radhakrishnan & Srinidhi (2008) consider *demand-side variability* as the main influence. We also consider independent *supply-side variability* due to random errors. For example, Dell reported that a significant degree of statistical error in its procurement process was reduced by sharing information with its suppliers – from 200 errors per million orders to just 10 (Perman, 2001). Even companies like Campbell Soup, whose business setting is characterized by predictable and stable demand, have observed that resource planning for production, distribution, transportation and warehousing can be unpredictable, causing supply chain-wide inefficiencies, which lead to both stockouts and stockpiles (Chopra, Reinhart & Dada 2004, Fisher 1997). ZD-Net reports that despite the manufacturer's focus on driving costs and time out of their supply chains through Web-based integration efforts, a much larger potential for savings is associated with error in the data that communicate the information about the product and its components (Friedman, Hill, Folger, Cearley & Gold 2002).

When supply errors lead to an excess of supplies delivered by the manufacturer or supplier, the relevant question is: Who pays for the excess supply? When the supplier provides goods in excess of the amounts requested, the possibility arises of the buyer returning the excess at no extra cost. Two factors work against this. First, a part of the excess may arise due to the buyer's over-estimation of the final demand in which case buyer would have a contractual obligation to accept some of the excess. We will show why this is the case later in this article. Second, determination of who bears these costs depends in part on the market power relations between suppliers and retailers. For example, independent college bookstores bear some of the costs of unused books when the supplies exceed the number of books purchased. When the costs of returning goods to the supplier is positive, the buyer may either choose to store the goods for the future – thus resulting in storage costs – or return the goods to the supplier, who bears some (or all) of the costs. The buyer also may reduce the price (a price mark-down) to clear the market. Finally, we must allow for the possibility that a large retailer like Wal-Mart, with immense market power relative to its suppliers, may force any excess supply costs onto the suppliers. Thus, the costs of excess supply are generally non-negative, including the possibility of both positive as well as zero costs of excess supply to the retailer.

We will discuss the theoretical perspectives that provide the foundation for our modeling approach. We develop some propositions regarding the impact of uncertainties in procurements and market demand on managerial decisions. We analyze buyer-supplier information sharing strategies by modeling the buyer's investment decisions in appropriate IT platform solutions. These solutions are obtained using a game-theoretic *signaling model* involving the supplier and the buyer. The results fall into several scenarios regarding the extent of final demand that the supply chain faces. We characterize the results with propositions that guide a managerial decision-maker on how to think through the available strategy choices. We extend the basic model to include many suppliers.

2. Modeling Information Sharing in Supply Chain Management

Different perspectives have developed in recent research on information sharing and the related strategies that firms develop in the presence of CPFR supply chain practices. Lee & 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 & 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 & Ashman (2000) also 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 (Cachon & Fisher 2000, Cachon & Lariviere 2001, Chen 2001, 2005). 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, which they may do in collaboration with one another (Corbett, Blackburn & van Wassenhove 1999, Mahajan, Radas & Vakharia 2002, Zhao, Xie & Wei 2002). We focus on cases where the supplier has market power relative to the buyer. 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, we will allow for many suppliers and examine how the resulting decline in the suppliers' market power relative to the buyer affects the buyer-supplier information exchange.

2.1 Modeling Preliminaries

We consider a retail firm, 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 its suppliers, production disruptions, or delays in delivery. The critical 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 (Chen 1999), incorrect product specifications (Dewan, Jing & Seidmann 2000), or incorrect quantities (Mahajan, Radas & Vakharia 2002).

Stochastic Demand and Supply Uncertainties Demand uncertainties arise because final sales are subject to stochastic shocks (Zhao, Xie & Wei 2002). To represent this, we use a classic demand and supply representation. We let $q_s - q_d{}^f = \delta q_s$ and $q_d{}^f = (1-\delta)q_s$, with $\delta \sim f(0, \sigma_d^2)$ and $\delta \in [-1,1]$. $q_d{}^f$ is the final demand, and q_s is supply quantity received from supplier s. The final demand might be visible through a point-of-sale system that captures orders from customers in the marketplace. δ is management estimation error of final demand due to random shocks. This relationship can be established between supply and demand as an observation of the operation of supply chain management in the marketplace that reflects their economic relationship. It is typical, given the nature of information sharing that occurs in supply chain management systems, that buyers share information with suppliers that makes this forecasting possible — subject to random error in estimation, of course. The random variable δ is symmetrically distributed with distribution f, mean 0 and variance σ_δ^2. To ensure that $q_d{}^f \geq 0$, δ must have a truncated symmetric distribution in the interval $[-1,1]$. Supply uncertainties are modeled for q_o, that represents the quantity to be ordered from a supplier, $q_s - q_0 = q_0 u \rightarrow q_s = (1+u)q_0$, with $u \sim g(0,\delta_u^2)$ and $u \in [-1,1]$. The distribution g can be any symmetric truncated distribution; it does not have to be a normal distribution. Supply fluctuations are likely to be independent of any random demand fluctuations, so $cov(\delta,u) = 0$. The variable q_o is the variable that management wishes to optimize in the presence of uncertainties.

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. For this function, $\pi_b(q_s, q_d{}^f)$ represents the profit for a given supply quantity q_s and final consumer demand $q_d{}^f$, prior to applying the stochastic process operators:

$$E(\pi_b) = \int_{-1}^{1} g(u)du \int_{-1}^{1} \pi_r(q_s, q_d{}^f) f(\delta) d\delta \qquad (1)$$

To evaluate $E(\pi_b)$, it is useful to break it down into situations where supply exceeds demand and vice versa. This enables us to write:

$$E(\pi_b) = P(q_s)q_s \,|_{q_s<q^f{}_d} \cdot prob(q_s < q_d{}^f)$$
$$+P(q_d{}^f)q_d{}^f \,|_{q_s>q_d{}^f} \cdot prob(q_s > q_d{}^f)$$

$$-h(q_s - q_d{}^f)\big|_{q_s > q_d{}^f} \cdot prob(q_s > q_d{}^f) \; -cq_s \tag{2}$$

In this expression, $P(\bullet)$ is the inverse demand function and c is the per unit cost of obtaining the supply of the product from the distributors. This c should be viewed by the reader as a procurement cost, rather than the sum of procurement and holding costs for the supply of the product in inventory. This is an important consideration, since our model might be viewed as double-counting inventory holding costs for over-supply if the unit cost of obtaining the supply of the product were defined otherwise.

For the present analysis, we focus primarily on procurement cost and the economic relationships, rather than the detailed dynamics of inventory management, where the inventory management expertise of others might lead them to model these relationships somewhat differently. The first term expresses the revenue flow when demand exceeds supply so that sales are determined by the availability of supply, q_s. The second term captures the revenue flow when demand is less than supply so that sales are determined by the demand, $q_d{}^f$. One fundamental question that relates both to the second and the third term in Equation (2) is whether price adjustments will be able to clear the markets. If so, then no excess supply problem will arise. The order and pricing decisions will occur before the realization of actual demand and supply, but will be only based on their expectation. As a result, price adjustments may not be adequate to clear the markets.

The possibility of over-supply still remains, however, even though the unit cost c of obtaining the supply does not consider the related costs. Unlike stockouts, over-supply involves accumulation of inventories. Since ours is a one-period model with no inventories carried over to the next period, the excess supply must be disposed of in the same period, or returned to the vendor at a cost to the buyer. Let h be the cost for each unit of excess supply that is held by the buyer, reflecting the unit cost of returning the goods, or the revenue loss per each unit of excess supply due to an *ex post* price mark-down or the related disposal costs. Then there is a revenue loss that is due to this excess supply denoted by $h(q_s - q_d{}^f)$. With this in mind, the subsequent costs of over-supply after procurement become $h(q_s - q_d{}^f)$ if $q_s > q_d{}^f$ (i.e., $u > 0$). This is the last term in Equation (2).

Because both over-supply and erroneous demand forecasts enter into the over-supply term, the buyer bears some responsibility for excess supplies. Depending on the power of the buyer vs. the supplier, the buyer may not accept responsibility for such costs. Thus, excess supply costs may be positive or zero, such that $h \geq 0$.

We compute $E(\pi_b)$ in Equation (2) in two stages. In the first stage, we view q_s as given and integrate over $q_d{}^f$ or over δ to obtain $E(\pi_b(q_s))$. Second, we integrate over q_s (or equivalently u) to obtain $E(\pi_b)$. Note that $0 \leq \delta \leq 1$ for $q_s \geq q_d{}^f$ and $-1 \leq \delta < 0$ for $q_s < q_d{}^f$, and so the first integration yields:

$$\begin{aligned} E(\pi_b(q_s)) = &\int_{-1}^{0} P(q_s) q_s f(\delta) d\delta \\ &+ \int_{0}^{1} P[(q_s(1-\delta)] \cdot q_s(1-\delta) f(\delta) d\delta \\ &- cq_s - h\int_{0}^{1} \delta q_s f(\delta) d\delta \end{aligned} \tag{3}$$

This can be simplified because q_s is given at this stage, and $P(q_s)q_s$ is independent of δ. Since $f(\delta)$ is symmetric in δ and the integral covers half the range of δ, the first integral can be evaluated as $[P(q_s)q_s]/2$. We define the *demand error integral*, $\Omega_\delta \equiv \int_0^1 \delta f(\delta) d\delta$, so the buyer's expected profit is:

$$E(\pi_b(q_s)) = (1/2)P(q_s)q_s + \int_0^1 P[(q_s(1-\delta)] \cdot q_s(1-\delta) f(\delta) d\delta - cq_s - hq_s\Omega_\delta \tag{4}$$

Unanticipated Over-Supply Let Ω_δ represent the mean value of δ, the extent that actual demand falls short of supply, with $\delta > 0$, so that Ω_δ indicates the extent to which there is an over-supply build-up. Also, from $\delta \in (0,1)$, it follows that $\Omega_\delta < 1$. To calculate the value of $E(\pi_b)$ in Equation (2), we proceed with the second stage. This involves integration over q_s, or over the supply variance, u, to yield:

$$E(\pi_b) = \int_{-1}^{1} E(\pi_b(q_s)) g(u) du \tag{5}$$

We can obtain an explicit form of $E(\pi_b)$, which will involve the stochastic parameters δ and u as arguments of the inverse demand functions, $P[q_o(1+u)]$ and $P[q_o(1+u)(1-\delta)]$. Using an approximation method for identifying inverse demand around the order quantity q_o and integrating the results over a density function, the buyer's expected profit becomes:

$$E(\pi_b) \cong (1-\Omega_\delta)P(q_o)q_o - (c + h\Omega_d)q_o + q_o^2 P'(q_o) A(\sigma_u^2, \sigma_\sigma^2, \Omega_\delta) \tag{6}$$

We do not provide the analysis details here. Standard methods of economic analysis and marketing research methods involve the usage of Taylor series expansion as a means to approximate different aspects of the inverse demand function and consumer willingness to pay. When we shift to the use of a linear demand function later in our analysis, this will obviate the need for the use of this technique. The interested reader should see the following useful sources for the background of this technique: Barberá, Hammond & Seidl (1998), Cameron and James (1987), Nistico & Tosato (2002), and Varian (1978).

In this expression, the final term, $A(\bullet)$, represents the *variance of the demand error integral*,

$$A(\sigma_u^2, \sigma_\delta^2, \Omega_\delta) \equiv (1-2\Omega_\delta)\sigma_u^2 + \tfrac{1}{2}\sigma_\delta^2(\sigma_\delta^2 + \sigma_u^2) - \Omega_\delta$$

Finding the optimum order quantity q_o^* requires the concavity of expected profits, $E(\pi_b)$. This imposes a limit on the unanticipated over-supply Ω_δ.

2.2 The Buyer's Optimizing Behavior in the Presence of Linear Demand

We begin by analyzing 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 illustration. The first order condition for optimization yields:

$$\frac{dE(\pi_b)}{dq_o} = 0 \Rightarrow$$

$$q_o^* = \frac{1}{2z} \cdot \frac{(a-c) - (a+h)\Omega_\delta}{(1+\sigma_u^2)(1+\tfrac{1}{2}\sigma_\delta^2 - 2\Omega_\delta)} \tag{7}$$

From the expression for q_o^* presented earlier, we know that the maximum expected profit is:

$$\pi_b^{e*} = \frac{1}{4z} \cdot \frac{[(a-c)-(a+h)\Omega_\delta]^2}{(1+\sigma_u^2)(1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta)} \quad (8)$$

If the buyer is to remain viable in the marketplace, its optimum order size must support positive profit. Since the denominators of Equations (7) and (8) are positive by the concavity of expected profits, the firm will be viable if the numerator in Equation (7) is positive. This means that if the unanticipated over-supply has the upper bound

$$\Omega_\delta < \frac{a-c}{a+h},$$

then we can establish that Ω_δ is limited by the minimum of either

$$\frac{1}{2}(1+\frac{\sigma_\delta^2}{2}) \text{ or } \frac{a-c}{a+h}.$$

In Equations (7) and (8), the supply and demand uncertainties, σ_δ^2 and σ_u^2 affect the expected output and profits adversely, as might be expected, so that

$$\frac{\partial \pi_b^{e*}}{\partial \sigma_\delta^2}, \frac{\partial \pi_b^{e*}}{\partial \sigma_u^2} < 0 \text{ and } \frac{\partial q_o^{e*}}{\partial \sigma_\delta^2}, \frac{\partial q_o^{e*}}{\partial \sigma_u^2} < 0 .$$

However, the effect of the unanticipated over-supply parameter Ω_δ is mixed. The origin of this is found in Equation (6) for expected profits. Ω_δ 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 the unanticipated over-supply Ω_δ will reduce 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 (Buyer's Market Power Proposition): *Buyers that have greater market power with respect to their consumers are better able to absorb the adverse effects of over-supply shocks by reducing their prices than those with little or no market power.*

The net effect of inventory over-supply, as a result, will be negative, $\frac{\partial \pi_b^{e*}}{\partial \Omega_\delta}, \frac{\partial q_o^*}{\partial \Omega_\delta} < 0$, if Ω_δ has an upper bound,

$$\Omega_\delta < \min\{\frac{1}{2}(1+\frac{1}{2}\sigma_u^2), \frac{a-c}{a+h}\} .$$

2.3 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 supplier possesses market power and acts monopolistically. This will be reflected in the extent of the influence it has over the procurement costs, c, that it passes on to the buyer. Supplier profits are then given by:

$$E(\pi_s) = (c_p - v)E(q_s(c)) \quad (9)$$

where v is the unit cost of production, and $q_s = (1+u)\ q_o(c)$ is the supply uncertainty. The function $q_o(c) = \frac{1}{2z} \cdot \frac{(a-c)-(a+h)\Omega_\delta}{(1+\sigma_u^2)(1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta)}$ is determined by Equation (7). Thus, Equation (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 $q_s = (1 + u)\ q_o(c)$ into Equation (9), the supplier's expected profits become:

$$E(\pi_s) = \int_{-1}^{1} (c_p - v) q_o (c_p + c_t)(1+u) g(u) du$$

$$(c_p - v) q_o (c_p + c_t) \qquad (10)$$

The effect of product costs on supplier profits is positive. They can be passed on to the buyer due to $c_p - v$ in Equation (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 Equation (7) and using the relation $c = c_p + c_t$, we can see that balancing these effects means that the supplier charges the buyer via:

$$\frac{dE(\pi_s)}{dc_p} = 0 \quad \Rightarrow$$

$$c_p^* = \frac{1}{2} \cdot [a - c_t - (a+h)\Omega_\delta + v] \qquad (11)$$

An increase in Ω_δ reduces the optimum price by the supplier to the buyer, $\partial c_p^* / \partial \Omega_\delta < 0$. This leads to our second proposition:

Proposition 2 (Procurement Cost and Over-Supply Link Proposition): *The procurement cost that a supplier passes on to a buyer is inversely related to the buyer's over-supply.*

Substituting from Equations (7) and (11) into Equation (10) yields the supplier's expected profits:

$$\pi_s^{e*} = \frac{1}{8z} \cdot \frac{(a - c_t - (a+h)\Omega_\delta - v)^2}{(1+\sigma^2_u)[1 + \frac{1}{2}\sigma^2_\delta - 2\Omega_\delta]} \qquad (12)$$

This expression raises a number of issues. First, supplier profits fall when the buyer faces uncertainty in final demand, the supply of goods and the buyer's orders. This is related to the second derivatives, $\frac{\partial \pi_s^{e*}}{\partial \sigma_\delta^2}, \frac{\partial \pi_s^{e*}}{\partial \sigma_u^2} < 0$. We can see that the buyer and supplier benefit from a reduction in the market variance as well as improved coordination between orders and deliveries. Second, the effect of unanticipated over-supply at the level of final sales to the consumer shows up in different ways. It shows up negatively through the numerator and positively via the denominator. To gauge the effect, we consider the expression for the supplier's expected profit E(π_s) from Equation (10). Differentiating this when it is evaluated at the optimum in Ω_δ gives:

$$\frac{\partial \pi_s^{e*}}{\partial \Omega_\delta} = \frac{\partial E(\pi_s)}{\partial \Omega_\delta}$$

$$= \frac{\partial c_p^*}{\partial \Omega_\delta} q_o^* (c_p + c_t) + (c_p^* - v) \frac{\partial q_o^*}{\partial \Omega_\delta} \qquad (13)$$

With $\frac{\partial c_p^*}{\partial \Omega_\delta} < 0$, an increase in Ω_δ reduces the optimal price charged by the supplier based on the first term in Equation (13). The second term, $\frac{\partial q_o^*}{\partial \Omega_\delta} < 0$, suggests that the effect of Ω_δ on the buyer's order size is negative, so long as $\Omega_\delta < \min[\frac{1}{2}(1 + \frac{1}{2}\sigma_u^2), \frac{a-c}{a+h}]$ holds. This enables us to conclude that Ω_δ also adversely affects the supplier's profits via $\frac{\partial \pi_s^{e*}}{\partial \Omega_\delta} < 0$. We state this result in the following proposition:

Proposition 3 (Uncertainty Reduction-Profitability Link Proposition): *The supplier'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 over-supply of the buyer will improve both the buyer and the supplier's profits.*

Interpretation This finding explains how recent inventory build-ups among large retail firms (e.g., Hewlett-Packard, Dell, Best Buy, Macy's – and more tragically with the problems of Circuit City), led by the slowdown in consumer spending and diminishing availability of short-term corporate financing, reverberated through the supply chain, causing a general slowdown and a decline in firm profits. Combining our Procurement Cost and Over-Supply Link Proposition, and the inequality, $\frac{\partial c_p^*}{\partial \Omega_\delta} < 0$, we are able to obtain an explanation for why firms may be concerned about the consequences of adopting IT to support sharing information.

A decline in unanticipated over-supply possibly due to asymmetric and 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 demand via a decline in the value of unanticipated over-supply tends to improve the supplier's profits. This is a key finding in our research that is echoed by the earlier work of Seidman & 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, as Riggins and his colleagues have argued (Riggins, Kriebel & Mukhopadhyay 1994, 1995, Riggins & Mukhopadhyay 1999), through the use of such approaches as CPFR and vendor-managed inventory. Sharing inventory data reduces supply uncertainties, and benefits the buyer and the supplier (Nakayama 2000).

Next, let us consider the perspectives of the buyer and supplier in other settings. Although they may be able to gain from sharing information, there are still ways in which they will be in conflict. In our model, procurement costs play the role that creates this conflict. 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 main question for strategy, 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 supplier. We next will expand on the initial model to incorporate the buyer's aversion to the potentially damaging loss associated with sharing information.

3. Analysis of Information Sharing

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.

The difference in time between the sequential decisions means that the buyer may act strategically with respect to its supplier – even as it acts myopically with respect to the prices and quantities it faces. In our model, the

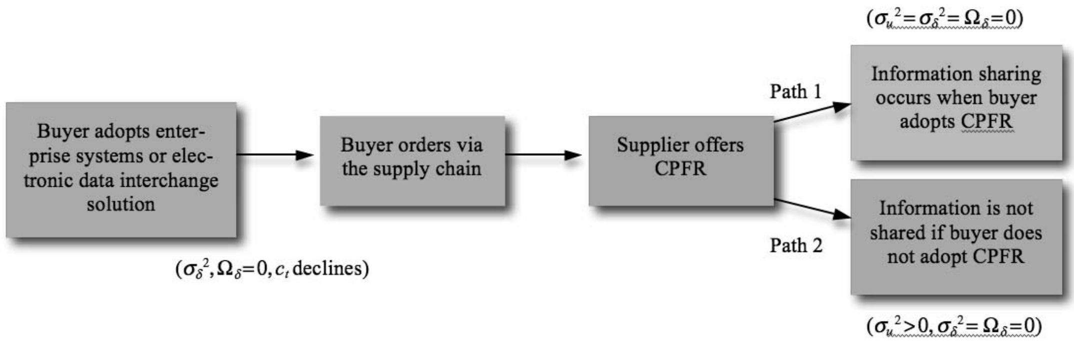

Figure 1 A sequential game theory model for CPFR information sharing

Note: Adopting CPFR permits the buyer to drive the value of the demand error integral Ω_δ to 0, but the operational costs of matching orders to demand remain. Path 1 is the *information sharing strategy path*, and results in a specific long-run expected profit for the buyer. Path 2 is the *information withholding strategy path* for the buyer. The long-run expected profit for this decision is different. Along Path 1, the information that the buyer and the supplier have is the same. Along Path 2 though, the buyer decides to procure without sharing its private information about final demand with the supplier. The result is that the supplier and buyer will have asymmetric information.

buyer observes the dependence of procurement costs, c_p, on unanticipated over-supply, Ω_δ The buyer's profits are found by substituting the supplier's cost Equation (11) into the buyer's profit Equation (8), as follows:

$$\pi_b^{e*} = \frac{1}{4z} \cdot \frac{[(a - c_p^{\ *} - c_t) - (a+h)\Omega_\delta]^2}{(1+\sigma_u^{\ 2})(1+\frac{1}{2}\sigma_\delta^{\ 2} - 2\Omega_\delta)}\bigg|_{c_p^{\ *}}$$

$$= \frac{1}{2} \cdot [a - c_t - (a+h)\Omega_\delta + v] \qquad (14)$$

3.1 Strategy Decision Opportunities for the Buyer

This analysis leads to several strategic decision-making opportunities for the buyer. The most interesting one is where the buyer has the incentive to use information on final consumer demand (e.g., from POS data) to raise its own profits, but to withhold information from its supplier, adversely affecting the supplier's profits. An available alternative for 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. This includes the critical parameters of firm size, investment cost, 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 σ_δ^2, and the unanticipated over-supply Ω_δ, 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_t, to decline. As a result, it is able to forecast demand more effectively, reducing uncertainty. This causes the variance of the demand error forecast σ_δ^2, and the unanticipated over-supply Ω_δ to fall.

To keep our initial analysis simple, we also will assume that demand-related uncertainty is eliminated, so that the demand error forecast, σ_δ^2, and the anticipated over-supply Ω_δ will be equal to zero. The drop in demand 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 information sharing is a reduction in supply uncertainties in supply chain coordination, so that σ_u^2 also goes to zero.

Buyer and Supplier Impacts Although the supplier benefits, the buyer faces trade-offs. The buyer benefits from supply and demand uncertainty reduction. But sharing final demand information increases a 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, Kriebel & Mukhopadhyay (1994), and Seidmann & Sundarajan (1998) have shown the rationale for 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 it will not share the most sensitive market data.

3.2 Buyer Adoption of Supplier's CPFR: Information Sharing and Final Demand

The buyer's profits with respect to the dependence of procurement costs c_p on the unanticipated over-supply Ω_δ was presented in Equation (14). The buyer's strategy alternatives are based on evaluating the associated profit stream under different informational schemes. We will evaluate *long-run net 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 information sharing through CPFR, the supply and demand error variances are eliminated, as shown by Path 1. When this is the case, the buyer's profit function becomes:

$$\pi_b^{e*}\big|_{\text{info sharing}}$$
$$= \pi_b^{e*}(\Omega_\delta = 0, \sigma_\delta^2 = 0, \sigma_u^2 = 0, c_t' < c_t)$$
$$= \frac{1}{16z}(a - c_t' - v)^2 \qquad (15)$$

The buyer's long-run net profit Γ_1 is its equilibrium profit from Equation (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, the long-run profit for Path 1 for the buyer is:

$$\Gamma_1 = \frac{1}{16z}(a - c_t' - v)^2 - r(F_1 + F_2) \qquad (16)$$

3.3 When the Buyer Rejects the Supplier's Offer of CPFR: Asymmetric Information on Customer Demand

This case, described by Path 2, is interesting to analyze because it can explain the observed IT investment behavior. Supply chain buyers tend to under-invest in IT that promotes information sharing because they are concerned about trust and supplier opportunism, as discussed by Doney & Cannon (1997). Another issue has to do with the potential difficulties associated with the bargaining outcomes that may result from conflicts that arise related to the surpluses that the buyer and the seller create from their joint investments (Clemons & Kleindorfer 1992, Han, Kauffman & Nault 2008). Bargaining power is known to be a driver of willingness to invest in IT solutions. This issue has been significant in the food industry, for example. Kinsey & Ashman (2000) have pointed out that this may be why market leaders have adopted product bar codes and scanner technologies that lag behind present day e-procurement and information-driven inventory replenishment practices.

Why is this? We need to recognize why information is a strategic asset for the firm, and why it should be guarded and withheld when the competitive circumstances warrant it. Consider $\frac{dE(\pi_s)}{dc_p} = 0$ and $\frac{\partial c_p^*}{\partial \Omega_\delta} < 0$. The unit cost of procurement c_p rises for the buyer as a result of smaller values of the demand forecasting error integral Ω_δ representing a reduction in unanticipated over-supply. Improved information to the supplier as a result of CPFR 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. The buyer, as a result, may find it beneficial to withhold sales information from the supplier, foregoing the benefits of CPFR for inventory coordination with the supplier. This way, the value of Ω_δ^s will stay the same.

Although the supplier remains uncertain about the state of the buyer's final consumer demand, the buyer still can estimate 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 means it will be different from the supplier's, an *information asymmetry*. The buyer's profits under this strategy can be evaluated by gauging the maximum expected value of the buyer's equilibrium profits in Equation (14). We distinguish between the information uncertainty experienced by the buyer, Ω_δ^b and $(\sigma_\delta^b)^2$, from that of the supplier, Ω_δ^s and $(\sigma_\delta^s)^2$. In the maximization of the buyer's expected profits in Equation (8), the *buyer's information effect* enters directly, but the *supplier's information effect* operates only via the unit cost parameter, c_p^*. Consistent with full information sharing, we present the buyer's expected profits for no information sharing based on Equation (14), via the relation:

$$\pi_b^{e*}\Big|_{\text{no info sharing}} = \frac{[(a-c_p^*-c_t')-(a+h)\Omega_\delta{}^b]^2}{4z(1+\sigma_u{}^2)(1+\frac{1}{2}(\sigma_\delta{}^b)^2-2\Omega_\delta{}^b)}\Bigg| \{c_p^* = \frac{a-c_t'-(a+h)\Omega_\delta{}^s+v}{2}, \Omega_\delta{}^b=0, (\sigma_\delta{}^b)^2=0, c_t'<c_t\} \qquad (17)$$

The supplier perceives a demand error integral Ω_δ^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 Equation (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 Equation (17), we assume that the buyer has access to full information about final consumer demand, which it withholds from the supplier. This is the essential information asymmetry. So $\Omega_\delta^b = (\sigma_\delta^b)^2 = 0$, while Ω_δ^s and $(\sigma_\delta^s)^2 > 0$. The long-run profit from the asymmetric information strategy, Γ_2, is:

$$\Gamma_2 = \frac{[(a-c_t'-v)+(a+h)\Omega^s{}_\delta]^2}{16z(1+\sigma_u{}^2)} - r(F_1+F_2) \qquad (18)$$

So, it appears that the long-run expected profit for the buyer, Γ_2, rises with Ω_δ^s.

Proposition 4 (Buyer's Information Withholding Proposition): *The effect of a buyer's strategy to achieve information asymmetry by withholding proprietary market information from its supplier is to increase the buyer's profits.*

Compared to the information sharing strategy payoff in Equation (15), the price paid for the buyer's refusal to share information is supply uncertainty and poor procurement coordination.

4. Analysis of Asymmetric Demand Information Sharing Related to Customer Demand

Before we can examine what the outcome of the information sharing will be for the supplier and the buyer, it is appropriate to more carefully explore the nature of the information that they possess. We next discuss what determines the equilibrium value of the demand error integral for the supplier $\Omega_\delta{}^s$, and further examine what is involved to analyze the tradeoffs.

4.1. The Case of Multiple Equilibria under Asymmetric Information on Demand

There is a key aspect of the asymmetric information exchange between the buyer and the supplier. 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. The market equilibrium between the buyer and the supplier arises if expectations are realized: the expected quantity of orders forecasted by the supplier matches the *certainty equivalence level* of the orders by the buyer. This equality comes from applying the expression for the optimal order quantity,

$$q_o^* = \frac{1}{2z} \cdot \frac{(a-c)-(a+h)\Omega_\delta}{(1+\sigma_u^{\ 2})(1+\frac{1}{2}\sigma_\delta^{\ 2} - 2\Omega_\delta)},$$

to yield:

$$q_s^* \,\big|_{\text{order quantity expected by supplier}} = q_b^* \,\big|_{\text{order quantity received from buyer}}$$

$$\to \frac{1}{2z} \cdot \frac{(a-c_t'-c_p(\Omega_\delta^s)-(a+h)\Omega_\delta^s}{(1+\sigma_u^{\ 2})(1+\frac{1}{2}(\sigma_\delta^s)^2 - 2\Omega_\delta^s)}$$

$$= \frac{1}{2z} \cdot \frac{(a-c_t'-c_p(\Omega_\delta^s)-(a+h)\Omega_\delta^b}{(1+\sigma_u^{\ 2})(1+\frac{1}{2}(\sigma_\delta^b)^2 - 2\Omega_\delta^b)} \qquad (19)$$

The unit cost, c, in q_0^*, depends on the demand error integral of the supplier Ω_δ^s as in Equation (17). Yet $c_p(\Omega_\delta^s)$ shows up to both parties in the same way. Why? The supplier has access only to information it receives, and the buyer knows this to be the case for the supplier. So although the supplier acts strategically in terms of its choice of the supply quantity, the buyer can act strategically on its own with respect to the signals that it exchanges. The buyer will decide based only on its own information Ω_δ^b and $(\sigma_\delta^b)^2$.

To evaluate the buyer's profits, we assume that the buyer has access to full information about final consumer demand, which it withholds from the supplier. As a result, $\Omega_\delta^{\ b} = (\sigma_\delta^{\ b})^2 = 0$ for the buyer, while Ω_δ^s and $(\sigma_\delta^s)^2 > 0$ for the supplier. Equation (19) has two roots, $(\Omega_\delta^{\ s*})_1 = 0$ and $(\Omega_\delta^{\ s*})_2 = \dfrac{2}{2-\alpha} - \dfrac{a-c_t'-v}{a+h} > 0$. The second root is always positive. The first term is greater than 1, while the second term is less than 1. Just one corresponds to complete information. The parameter $\alpha < 1$ is characteristic of the underlying density function, where we have assumed $1/2(\sigma_\delta^{\ s})^2 = \alpha\,\Omega_\delta^s$, with $\alpha < 1$. This assumption is based on the definitions of

$$\Omega_\delta \equiv \int_0^1 \delta f(\delta) d\delta\,, \sigma_\delta^{\ 2} \equiv \int_{-1}^1 \delta^2 f(\delta) d\delta\,,$$

and $\delta^2 < \delta < 1$.

With an increase in information asymmetry $\Omega_\delta^{\ s}$ due to information that the buyer withholds from the supplier, the quantity ordered by the buyer rises and, if $1/(2-\alpha) > (a - c_t' - v) / (a + h)$, the quantity expected by the supplier falls. This occurs with a discontinuity at $1/(2-\alpha)$. The result that order quantity expected by the supplier should decrease with greater informational asymmetry is a realistic result and holds when h (the "penalty" for carrying excess supply) is large enough to satisfy the above inequality. We therefore confine our attention to when this condition is satisfied, as it yields a more realistic outcome. The most interesting aspect of this result, however, is that the same condition guarantees that the second root of Equation (19), $(\Omega_\delta^{\ s*})_2$ is the right of discontinuity $(\Omega_\delta^{\ s*})_2 > 1/(2-\alpha)$, This is depicted in Figure 2.

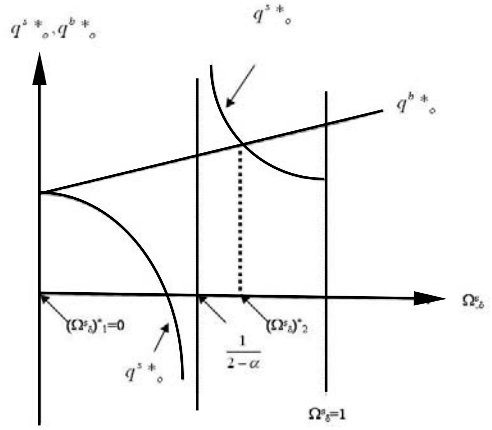

Figure 2 Determination of information sharing equilibria in supply chain management setting

This means that the discontinuity creates *multiple separating equilibria*. It follows that the initial level of informational asymmetry determines which equilibrium value of Ω_δ^s is reached. This is an instance of *path dependency*. We now discuss in greater detail how this initial level of informational asymmetry determines which path the system follows.

4.2. Information Convergence in Supply Chain Signaling

Our model is an example of a *signaling model* (Spence 1973). The supply chain buyer's behavior carries an unintended signal about the expected state of its final consumer demand through the orders it places. Suppose the buyer begins with an initial level of market uncertainty corresponding to the mean unanticipated over-supply Ω_δ^o. The buyer's actions reveal some information about the market to the supplier, so the level of uncertainty to the supplier, Ω_δ^s, will decline from its original level of Ω_δ^o. This is the idea of *information convergence.* But where will the final equilibrium occur? The answer depends on the relative size of Ω_δ^o compared to the point where the discontinuity occurs: $1/(2-\alpha)$. There are three scenarios:

- **Scenario A (Low Demand Uncertainty):** *Initial consumer demand uncertainty is low, with* $(\Omega_\delta^{s*})_1 = 0 < \Omega_\delta^o < 1/(2-\alpha) < (\Omega_\delta^{s*})_2$. *So* $(\Omega_\delta^{s*})_1 = 0$ *will be binding and the supplier's inference will lead to full information convergence.*
- **Scenario B (Medium Demand Uncertainty):** *Initial consumer demand uncertainty is moderate, with* $(\Omega_\delta^{s*})_1 = 0 < 1/(2-\alpha) < \Omega_\delta^o < (\Omega_\delta^{s*})_2$. $1/(2\text{-}\alpha)$ *will be binding and the supplier's inference about the changes in the unanticipated over-supply also will lead to information convergence.*
- **Scenario C (High Demand Uncertainty):** *Initial consumer demand uncertainty is large, with* $(\Omega_\delta^{s*})_1 = 0 < 1/(2-\alpha) < (\Omega_\delta^{s*})_2 < \Omega_\delta^o$. $(\Omega_\delta^{s*})_2$ *will be binding and the supplier's inference will converge to this point.*

There actually is a sub-scenario that we consider related to Scenario A also. This other scenario will occur when h is sufficiently small so that the second root will be negative, and only the first root will make sense. This is the *full information root*. In this case, only full information will hold regardless of the size of Ω_δ^o. (We thank an anonymous reviewer for pointing this out.)

Due to the discontinuity in supplier profits, the information convergence will be towards either $(\Omega_\delta^{s*})_1$ or $(\Omega_\delta^{s*})_2$. This will depend on the value of Ω_δ^o. This permits us to assert our next proposition:

Proposition 5 (Inferred Equilibrium Proposition): *If consumer demand uncertainty is low, then supplier inference from the buyer's orders leads to an equilibrium with full information (Scenario A and its related sub-scenario). If demand uncertainty is moderate then supplier inference leads to an equilibrium so the supplier faces some uncertainty (Scenario B). With higher uncertainty, supplier inference leads to an equilibrium with even greater uncertainty (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 on the part of the buyer will be more harmful in markets that have high levels of uncertainty about final demand. Yet, the high degree of demand uncertainty may yield higher a higher payoff to the buyer when it exploits its private information, leading it to implement a strategy of withholding information. Under this circumstance, the learning of the supplier about the final demand will not develop as far or become complete.

4.3. Strategy Dominance and Information Convergence

When should the buyer switch strategies though? Will it be worthwhile to do this? Let us consider the profit streams of the buyer under the *information sharing strategy* and the *information withholding strategy* associated with Γ_1 in Equation (16) and Γ_2 in Equation (18). The relative profitability of the strategies is a function of market uncertainty. This is reflected in the value of the demand error integral Ω_δ. So we need to study the values of Ω_δ to characterize when making a switch is appropriate. The two profit functions Γ_1 and Γ_2 will be equal at some value of the demand error integral which we call Ω_δ^T. This threshold value T of market uncertainty for switching IT strategies can be represented by the following function:

$$\Omega_\delta{}^T = \frac{[(1+\sigma_u{}^2)^{1/2} - 1][a - c_t' - v]}{a+h} \qquad (20)$$

When we compare Ω_δ^T with the second root $(\Omega_\delta^{s*})_2$ solution to the certainty equivalence expression in Equation (19), we find that three outcomes are possible. They develop depending on the positions of two information parameters: the initial market uncertainty Ω_δ^o and the switching uncertainty Ω_δ^T. and the profit advantage of withholding information, three outcomes are possible: the strategic value of the information withholding vanishes or is reversed, or its relative margin diminishes but it remains dominant. We distinguish three demand scenarios again.

With *low demand uncertainty*, $\Omega_\delta^o < \Omega_\delta^T$ (Scenario A), the information sharing strategy always dominates: $\Gamma_2\ (\Omega_\delta^o) < \Gamma_1$. For *medium demand uncertainty*, $1/(2-\alpha) > \Omega_\delta{}^o > \Omega_\delta^T$ information is initially withheld as $\Gamma_2\ (\Omega_\delta{}^o) > \Gamma_1$, but the information withholding payoff for the buyer will dissipate in the long run, due to information leakage to the supplier. There is *full information convergence*. This means that the system converges to $(\Omega_\delta^{s*})_1 = 0$, because $\Omega_\delta{}^o$ is on the same side as $(\Omega_\delta^{s*})_1$ 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, that is, $\Gamma_2\ ((\Omega_\delta^{s*})_1) < \Gamma_1$. Finally, with *high demand uncertainty*, $\Omega_\delta^o > \max[\Omega_\delta^T, (\Omega_\delta^{s*})_2] > 1/(2-\alpha)$ so that $\Gamma_2\ (\Omega_\delta^o) > \Gamma_1$. Once again, information will be withheld, but probably will be leaked over time.

Unlike Scenario B though, the *information leakage* to the supplier will be incomplete or partial because the discontinuity $1/(2-\alpha)$ prevents Ω_δ^s from ever falling to the level of $(\Omega_\delta^{s*})_1 = 0$. Instead, it will settle at $(\Omega_\delta^{s*})_2 > 0$. With some residual information payoff for the buyer, was the buyer's initial decision to withhold information correct in retrospect? The answer depends on whether the value of $(\Omega_\delta^{s*})_2$ to which the system settles is less or more than the threshold Ω_δ^T. Suppose $(\Omega_\delta^{s*})_2 < \Omega_\delta^T$. Then the buyer will be worse off – so that $\Gamma_2 (\Omega_\delta^{s^*})_2 < \Gamma_1$ – despite some residual information payoff opportunity that remains, reversing the buyer's initial information advantage. Next, suppose $(\Omega_\delta^{s^*})_2 > \Omega_\delta^T$. Then the buyer will still be better off, as suggested by $\Gamma_2 (\Omega_\delta^{s^*})_2 > \Gamma_1$. It will be the case that the buyer will maintain an information initial advantage, based on $\Gamma_2 (\Omega_\delta^{s^*})_2 < \Gamma_1$. Again, see Figure 2 for a representation of these results. The answer depends on whether the value of $(\Omega_\delta^{s^*})_2$ to which the system settles is less or more than the threshold Ω_δ^T. Suppose $(\Omega_\delta^{s^*})_2 < \Omega_\delta^T$. Then the buyer will be worse off – so that $\Gamma_2 (\Omega_\delta^{s^*})_2 < \Gamma_1$ – despite some residual information payoff opportunity that remains, reversing the buyer's initial information advantage. Next, suppose $(\Omega_\delta^{s^*})_2 > \Omega_\delta^T$. Then the buyer will still be better off, as suggested by $\Gamma_2 (\Omega_\delta^{s^*})_2 > \Gamma_1$. It also will be the case that the buyer will maintain an information initial advantage, based on $\Gamma_2 (\Omega_\delta^{s^*})_2 < \Gamma_1$.

When the buyer withholds information, it will capture greater profits initially. Due to inference on the part of the supplier though, a new level of equilibrium profit will result that makes the information withholding strategy an inferior outcome for the buyer, in comparison to the outcome it would have achieved had it 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. The benefits of the information withholding strategy vanish due to learning by the supplier. Thus, we further assert:

Proposition 6 (Buyer's Feasible Strategies Proposition): *An information sharing strategy or an information withholding strategy may be feasible strategies for the buyer. In some circumstances though, an information withholding strategy locks the buyer into path-dependent lower long-run profit due to information leakage that occurs, enabling the supplier to learn more about the value of final demand.*

5. 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 leading firms such as Dell, Home Depot, Wal-Mart, Target, Best Buy and the like. To examine how a firm's strategy for information sharing ought to be formulated for the case of a single buyer and many suppliers, we now will extend our preceding analysis.

5.1. Modeling Extension

We begin by assuming that there are i identical suppliers indexed by i = 1,…, I. Supplier i's expected profit is given by:

$$E(\pi_s^{\ i}) = E[c_p(q_o^{\ *})q_s^{\ i}] - vE(q_s^{\ i})\ ,\ i = 1,\ \ldots,\ I \tag{21}$$

Here, $q_s^{\ i} = (1 + u_i)q_0^{\ i}$ 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 can only exert a limited degree of market power. For example, it may be possible for a supplier to supply the single large buyer with a unique product that is not offered by others. This is likely to be the case only rarely though. We will show that the incentive for information withholding by the buyer will diminish when there are many suppliers. Assuming the same symmetry assumptions on the distribution of u_i as we did earlier, the total order size from the buyer to all suppliers is still given by Equation (7). Breaking down total unit cost in Equation (7) into procurement cost, c_p, and transaction cost, c_t, the cost can be stated as:

$$q_o^* = \frac{1}{2z} \cdot \frac{(a - c_p - c_T) - (a+h)\Omega_\delta}{[1+\sigma_u^2](1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta)}$$

$$\equiv V - W; c_p \Rightarrow c_p(q_o^*) = \frac{1}{W}(V - q_o^*) \quad (22)$$

Here $V \equiv \frac{1}{2z} \cdot \frac{(a - c_T) - (a+h)\Omega_\delta}{[1+\sigma_u^2](1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta)}$ and $W \equiv -\frac{1}{2z} \cdot \frac{1}{[1+\sigma_u^2](1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta)}$ 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:

$$c_p^* = \frac{1}{I+1} . \frac{V}{W} + \frac{I}{I+1}\nu$$

$$= \frac{1}{I+1}[(a - c_T) - (a+h)\Omega_\delta] + \frac{I}{I+1}\nu \quad (23)$$

5.2. Supplier Competition Reduce Opportunistic Behavior

We note several interesting aspects of Equation (23). When there is just one supplier, Equation (23) reduces to Equation (11), verifying the consistency of the main results. As there are more and more suppliers though, the size of the mark-up over the manufacturing cost v falls. In fact, when the number of suppliers becomes very large, c_p^* will approach v. The suppliers become fully competitive as a result. Further note that the impact of information about the buyer's market on the supplier's ability to charge c_p^* becomes more limited, the larger is the number of suppliers. This conclusion is based on $\partial \,|\, \partial c_p^* / \partial \Omega_\delta \,|\, \partial I < 0$. This suggests our next proposition:

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

5.3. Buyer's Profits under Information Sharing with Many Suppliers

The buyer's profits are found by substituting procurement costs c_p^* from Equation (23) into the buyer's profit in Equation (8) from before to yield:

$$\pi_b^{e*} = \frac{1}{4z} \cdot (\frac{I}{I+1})^2$$

$$\cdot \frac{[(a - c_T - \nu) - (a+s)\Omega_\delta]^2}{(1+\sigma_u^2)(1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta)} \quad (24)$$

An interesting result from Equation (24) is that $\partial \pi_b^{e*} / \partial I > 0$. This means that the more suppliers there are, the larger will be the buyer's profits. This result arises from the dampening effect of the larger number of suppliers on procurement costs, c_p^*. But because the adverse effects of information sharing on the buyer are also more limited with a larger number of suppliers, it must follow that the buyers are now more willing to invest in IT to support information sharing with their numerous suppliers. We saw this before with $|\partial c_p^* / \partial \Omega_\delta|$.

The suppliers also will be less reticent to withhold information.

To check this, we recalculated the net gains functions, Γ_1 and Γ_2, under the information sharing and withholding strategies. The net gains from information sharing can be obtained by setting σ_u^2 and Ω_δ in Equation (24) to zero, and then subtracting the fixed costs of technology, F_1 and F_2. This yields:

$$\Gamma_1 = \frac{1}{4z}\cdot\left(\frac{I}{I+1}\right)^2\cdot(a-c_T-v)^2 - r(F_1+F_2) \tag{25}$$

Note that $\partial\,\Gamma_1/\partial I > 0$, so the buyers gain more from information sharing strategies when there are many suppliers. This leads to our penultimate proposition:

Proposition 8 (Buyer's Information Sharing Strategy with Many Suppliers): *Buyers facing a large number of suppliers will be more willing to share sensitive market data with them; their gain from information sharing is greater with many suppliers.*

Evidence of aggressive inter-organizational supply chain integration and information sharing practices by firms like Wal-Mart with its numerous suppliers gives real-world support for our finding (Yao, Evers & Dresner 2007).

To explore how the number of suppliers that the buyer faces may influence the selection of an information withholding strategy, we need to recalculate the net gains from withholding information that would permit the supplier to have a better idea of what the final demand will be. To do this, we follow the procedure outlined previously relative to Equation (18) of distinguishing between the buyer's and the supplier's information. The result is:

$$\Gamma_2 = \frac{1}{4z}\cdot\frac{\left[\frac{I}{I+1}(a-c_t'-v)+\frac{1}{I+1}(a+s)\Omega^s{}_\delta\right]^2}{(1+\sigma_u{}^2)} - r(F_1+F_2) \tag{26}$$

Consistent with our prior finding for one supplier, this expression reduces to Equation (18) when there is just one supplier. An interesting result emerges through the interpretation of the numerator of this expression. We observe that as the number of suppliers rises, the first term increases while the second term falls. 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 Equation (25). The second term, however, is unique to the strategy of withholding information, since it multiplies the demand error integral $\Omega_\delta{}^s$. Since the value of this term declines with more suppliers, we see that the retailer's gains from implementing the strategy of withholding strategy also declines as the number of its suppliers increase. Why? With a larger number of suppliers, the aggregate potential for opportunism declines, thus reducing a buyer's gain from protecting itself against such opportunism. We summarize this finding in our final proposition:

Proposition 9 (Buyer's Information Withholding Strategy with Many Suppliers): *Buyers facing a large number of suppliers will be less willing to withhold sensitive data on final market demand from them; as their gain from such a strategy will be diminished in the presence of many suppliers.*

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

	Number of Suppliers: Fewer	Number of Suppliers: More
Higher Buyer's Willingness to Share Information		Buyers will be more willing to share information
Lower Buyer's Willingness to Share Information	Buyers will be less willing to share information	

Figure 3 Buyer's willingness to share information relative to the 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 the buyer end – as in electronics or microprocessor chip-making – is where more information sharing will occur. But industries where there is concentration at the supplier end – such as steel, consumer goods or food – may face greater hurdles to engender information sharing between supply chain partners. Within each industry there may be variations among supply chains in terms of the concentration of supply and demand. The evidence that we observed in the food industry, for example, suggests buyers at the end of large supply chains are more apt to invest in IT to support information sharing than buyers associated with smaller supply chains (King, Wolfson & Seltzer 2002).

6. Conclusion

New technologies permit supply chain strategies that contribute 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? To what extent does information signaling lead to potentially unintended outcomes?

We explored this question using a game-theoretic signaling model that emphasizes buyer uncertainty with respect to final consumer demand in a supply chain setting. We found circumstances where information sharing and information withholding might take place, depending on the degree of initial uncertainty about market demand. Our most interesting result is that a buyer that finds information withholding to be efficient initially also may find itself locked into a less efficient outcome in the long run. This occurs as the upstream firms along the supply chain are able to infer the buyer's private information about demand patterns for what it sells to consumers. This *signaling mechanism* becomes operative through orders that a buyer places with the supplier. Ordering patterns permit the supplier to infer information about the final demand that the buyer is likely to face, permitting the supplier to potentially engage in profit-maximizing opportunistic behavior, as Sinha (2000) and Agrawal & Pak (2001) foresaw.

Our results are consistent with some of the findings in prior research, especially Cachon & Fisher (2000) and Radhakrshnan & Srindi (2008). Their general theoretical perspective is supply chain partners should only share information when the buyer and supplier are no worse off by exchanging information. We also learned that the industry structure of procurement is likely to be a critical determinant of whether an information sharing strategy is effective for the firm. The more suppliers there are around a buyer, the more willing a buyer should be to make IT investments to support information sharing in supply chain operations.

We also developed a basis for why the observed information sharing strategy choices may be path-dependent for the buyer – something we believe has unexpected "surprise value" in our efforts to create new knowledge. Our interpretation of how the buyer's decision about which strategy to adopt is predicated on the idea that adoption is not forced and that information is shared with no dishonesty or inaccuracies (Cachon & Lariviere 2001). By withholding all shared information except procurement orders, the supplier will be unable to know more than the buyer's ordering behavior – which constitutes a set of signals – can communicate about customer demand.

We note the following limitations of the current analysis. First, the generality of our findings is limited by the linear demand structure that we have chosen to implement. 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. This is not our expertise, and so we leave it to others to tackle this aspect of the problem, on the basis of our present results. 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 the first-tier suppliers' strategic opportunism, as the distance increases across the supply chain from the buyer to the primary supplier to the secondary and the tertiary supplier, etc. The strategic benefits associated with the use of the buyer's demand information can only be exploited once by one supplier, or in multiple pieces by a number of the tiered suppliers. However, this kind of information exploitation by one supplier will diminish the available strategic gains that are possible for others, and hence, it will also tend to dampen any other supplier's interest in being opportunistic. In this respect, our intuition is in harmony with the findings of Clemons & Hitt (2004) and Han, Kauffman & Nault (2004), who have explained and documented the importance of building interorganizational relationships that balance the benefits of collaboration for different kinds of business forecasting and risk management, with the potential for strategic opportunism that is always at hand.

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