Working Paper 02-02
The Food Industry Center
University of Minnesota
Printed Copy $22.50

A MODEL OF INFORMATION AND I.T. ADOPTION IN FOOD SUPPLY CHAINS

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March 2002

The Authors have benefited from the insights of Hal Varian, Robert King, and Terry Roe. An earlier version of this paper was presented at the Department of Applied Economics, University of Minnesota.

The work was sponsored by The Food Industry Center, University of Minnesota, 317 Classroom Office Building, 1994 Buford Avenue, St. Paul, Minnesota 55108-6040, USA. The Food Industry Center is an Alfred P. Sloan Foundation Industry Study Center.

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ABSTRACT

Evidence from the Food Supply chain suggests that food retailers often exhibit a reluctance to share information with their suppliers even when this benefits both parties. For example, inventory coordination and reduced costs may be realized by adopting appropriate supply chain management technologies such as cooperative planning, forecasting, and replenishment. This behavior is explained by viewing information as a strategic asset and modeling information exchange and the corresponding adoption of information technologies and analysis as a strategic game, i.e., an economic model where food retailers and their suppliers operate with uncertainty. The game is based on stylized facts from the food industry. Some key results from the game model are: (a) under certain conditions retailers may withhold valuable sales data from suppliers, even if the benefits from supply coordination are reduced; (b) there exists a *revealed* (inferred) equilibrium signal (i.e., suppliers know what orders will be) *even* when sales data are withheld from suppliers; and (c) unanticipated economic slow-downs cause overstocking which harm smaller firms more than larger ones, driving a wedge between them.

This is an attempt to build economic (game-theoretic) models that incorporate the realities of the food supply/demand chain and then to see what behavior the models predict. Such models have been widely used to explain economic behavior and exchange at the agricultural end of the food supply chain and for international trade behavior. This is one of the first applications to the retail/wholesale/manufacture levels in the food delivery chain.

Keywords: information technology, supply chain, IT strategy, food industry

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A Model of Information and IT Adoption in Food Supply Chains

INTRODUCTION

Electronic Commerce is altering the nature and the organization of industries both in the US and globally. The adoption of digital and Internet technology has been credited for an otherwise unexplained increase in productivity in the U.S. during the 1990's. Understanding the nature of the changes and their impact on firms' behavior and industries' structure is crucial for future public policy and corporate strategy. This task is no less critical in the face of recent contraction of the so called "dotcom" market. For example, Porter (2001) suggests that the failure of many dotcoms has been due to adoption of electronic commerce strategies based on unsound business practices. It is therefore crucial to understand *viable* firm strategies and industry structures that are likely to emerge as sustainable in this new digital economy.

This issue is particularly important for the food industry, for several reasons: First, the food industry has been a leader in information technology initiatives for more than 30 years. Secondly, thin profit margins in this industry could render cost-savings from the adoption of electronic commerce significant at the margin. Thirdly, the constantly evolving nature of the food industry, resulting from mergers and acquisitions, can be better understood in light of cost and market advantages made possible through the adoption of information technology (IT). This paper is an effort to understand the implications of the new digital economy for the relationship among firms along the food industry's supply chain. Thus the emphasis is on business to business (B2B), rather than business to consumer (B2C) forms of information exchange. While analytical efforts to understand B2C forms of electronic commerce have been underway for quite some time (e.g, Varian, 1997, 2000) as well as in the food industry in particular (Heim and Sinha, 2001, 2002), similar efforts have been lacking on the B2B segment of the market. This is despite the fact that the B2B segment is predicted to be the most dynamic part of the new digital economy and is estimated to grow from $2.2 trillion in 2003, to $7.4 trillion by 2004 (Rayback, 2000).

In view of the above, the paper's contribution is two-fold: First, it contributes to the understanding of the IT adoption behavior and information sharing of firms in the food industry. Second, based on stylized facts, costs and benefits of information sharing are analyzed in B2B supply chains, using game theory models.

The food industry led the early initiatives with the Uniform Commercial Code (UCC) organization to develop bar codes (Kinsey and Ashman, 2000; Kinsey 2001). This led naturally to scanner technology that is used to compile sales data from consumer purchases. Yet the industry did not exploit the power of this data until recently (Walsh, 1993). In particular, a 1992 initiative known as Efficient Consumer Response (ECR) was meant to take advantage of the power of the Electronic Data Interchange (EDI) technology, making the logistic systems and inventory control more efficient all along the supply chain. This was primarily a defensive strategy to try and meet the competition from efficient large discount retailers. The ECR initiative faltered due to diverse (or no) computer systems in thousands of retail stores that were incompatible with the suppliers computers. Equally important was a reluctance on the part of retailers to share sales data with manufacturers. A later development (1996) known as Collaborative Planning, Forecasting, and Replenishment (CPFR) has many of the same goals as ECR and involves a retailer sharing sales data with a manufacturer (or wholesaler) in real time, often over the Internet, and joining them in inventory replenishment agreements (Kinsey, 2000). Internet technology helps to solve the problems of incompatibility but *does not resolve the trust issue.* Some retailers fear that suppliers who learn about their inventory, sales, and ordering practices may somehow share this information with rivals or otherwise use it in ways that would diminish retailers' profitability (Kinsey and Ashman, 2000). This reluctance has also been reported in Clemons and Row (1993), Progressive Gorcer (1995) and Nakayama, 2000).

In the food supply chain, information is a strategic asset that can determine a firm's comparative advantage, driving the decision of whether or not to adopt information technology. This is true in many industries. For example in banking, strategic considerations were a driving force behind the initial adoption of ATM machines (Thakor, 1999). In the food industry, Nakayama (2000) shows that information exchanges plays a role in the power relationship between supermarkets and their suppliers, impacting their mutual trust and the adoption of information technology among firms. For example, when the food retailer uses EDI for inventory coordination, the supplier has a tighter control of the retailer's mark-up, raising the retailer's costs. This reduces the retailer's incentive to share the point of sales (POS) data with its supplier(s).

The trade-off between the need to share information and the need to protect information is best illustrated in the following question that the retailer asks: "What is the minimum set of information to share with my supply chain partners without risking potential exploitation?" (Lee and Whang, 2000). Gal-Or (1985) showed how information withholding may be a Nash outcome despite its social inefficiency.

The key findings from our theoretical model are consistent with these stylized facts. For example, we find that under certain circumstances a retailer may withhold valuable sales data from its supplier, even if this means reduced coordination of procurements. We also find that there exists a *revealed* equilibrium signal about the market facing the retailer that the supplier can learn, *even* when the retailer withholds sales data from the supplier. Both these findings are consistent with the available evidence. Thus, withholding information, where it might otherwise be learned, points to the possibility of market failure and suggests collaborative industry or industry/regulator outcomes as mutually beneficial in welfare terms. We also find a number of results with respect to firm size. For example we find that the existence of unanticipated slow-downs that lead to overstocking harm smaller firms more than larger ones, driving a wedge between the two. The implications of this result for further industry restructuring cannot be overstated.

We view information as uncertainty reducing and therefore begin with an environment of uncertainty. In this environment, information exchange and IT adoption game occurs between a monopolistic retailer in the product market that is subject to demand and supply uncertainties and a monopolistic supplier that constitutes the retailer's supply source. The supplier may represent a wholesale intermediary, a manufacturer, a processor, or a broker. Our emphasis on market power both on the part of the retailer (*vis-a-vis* consumers) and the supplier (*vis-a-vis* the retailer) underlies the role of demand in modern supply chains. In fact, it has been argued that information conveyed from final demand (consumer) through the supply chain and made possible by scanner data and technology, has fundamentally transformed the food industry from a supply-push model to a demand-pull model (Chase, 2000). For example this process allows for a more complete extraction of consumer surplus from the final demand by allowing for a much greater degree of product differentiation and price discrimination. In other retail markets use of what is known as "Collaborative Filtering,"[1], also used in electronic catalogues, has allowed for the maximum utilization of the information contained in consumer purchasing behavior to predict consumer demand and increase revenue.

The next section develops the basic model. This is followed by a discussion of its applications to the food industry. The fourth section derives the supply chain equilibrium under information sharing. The subsequent section presents information management strategies and the possibility of information withholding, drawing on some summary results from University of Minnesota's Food Industry Center's (2000) survey of supermarkets. This is followed by a discussion of the relation between size and IT adoption strategies. The last section draws concluding remarks and offers possible future extensions.

MODEL

Information is about reducing uncertainty. Thus, to understand firm's incentive regarding the adoption of IT, we must begin by capturing the underlying uncertainty environment. We begin with a simple game that captures the role of information technology in the basic supply chain. As discussed in the Introduction, the game occurs between a monopolistic retailer in the product market that is subject to demand

[1]Collaborating filtering is a methodology that started at the University of Minnesota Carlson School of Management and led to the development of the firm Netperception.com in 1997. It amounts to the statistical use of consumer data, extracted by such methods as Consumer Loyalty programs, to predict individualized consumer purchases and demands.

and supply uncertainties and a monopolistic supplier that constitutes the retailer's supply source.

The game involves two stages. The first stage is a contemporaneous game in which the retailer acts as a monopolist *vis-a-vis* the consumer but a Cournot-follower *vis-a-vis* the supplier, who in turn acts as a Bertrand monopolist (Stackelberg leader) in setting the product's price to the retailer. The second stage involves a sequential game in which the retailer must make long term decisions on costly investments in information technology, based on possible response from the intermediary supplier. This stage is represented in an extensive game form in which we look for subgame perfect equilibrium outcomes.

Stage I Game: Quantity and Pricing Decisions

Retailer: In trying to assess the size of the order to be forwarded to the supplier, the retailer maximizes expected profits. As mentioned, these profits are subject to two sources of uncertainty, demand uncertainty and supply uncertainty. Of crucial importance is the fact that the adverse effects of this uncertainty on expected profits are *asymmetric* with respect to overestimation or underestimation of the demand. This will be seen shortly below.

We begin with demand uncertainty. Demand uncertainty arises from the fact that final sales are subject to stochastic shocks that cannot be predicted so that,

$$q_s - q_d^f = \delta q_s \quad \rightarrow q_d^f = (1-\delta)q_s \quad \text{with} \quad \delta \vee f(0, \sigma_\delta^2), \quad \text{and } \delta \in (-1,1) \qquad (1)$$

where q_d^f is final level of sales (final demand), q_s is the supply received from the supplier, subject to its own uncertainty as described below, and δ is the error in estimating the final demand due to random shocks. To keep the analysis realistic, this error is assumed to be *relative,* i.e., proportional to the magnitude of the supply (thus the term δq_s on the right hand side). The random variable δ is symmetrically distributed with a distribution f that has mean zero and variance σ_δ^2. But to assure that $q_d^f > 0$, δ must be < 1. A convenient way to guarantee this upper bound is to assume that δ has a *truncated* distribution which is also symmetric (such as truncated normal) in the interval $(-1,1)$. Thus, $\delta \in (-1,1)$ as seen in (1).

Next, the uncertainty in the source of supply is depicted in a similar way, but is now relative to a control variable q_o that represents the quantity to be ordered from the supplier. Thus, we write:

$$q_s - q_o = uq_o \quad \rightarrow q_s = (1+u)q_o \quad \text{with} \quad u \vee g(0, \sigma_\delta^2), \ \text{ and } u \in (-1, 1) \qquad (2)$$

where the distribution g is also any symmetric truncated distribution as before. As mentioned, q_o is the (non-stochastic) control variable to be optimized.

The retailer's expected profits $E(\pi_r)$ may now be calculated, as follows:

$$E(\pi_r) = \int_{-1}^{1} E(\pi_r|_{q_s})g(u)du \qquad (3)$$

where, $E(\pi_r|_{q_s})$ in turn is given by,

$$\begin{aligned} E(\pi_r|_{q_s}) &= P(q_s)q_s|_{q_s<q_d^f}.prob(q_s < q_d^f) + P(q_d^f)q_d^f|_{q_s>q_d^f}.prob(q_s > q_d^f) \\ -c_T[q_s.prob(q_s &< q_d^f) + q_s.prob(q_s > q_d^f)] - s(q_s - q_d^f).prob(q_s > q_d^f) \qquad (4) \end{aligned}$$

where $P(.)$ is the inverse demand function, c_T is the *total* unit cost consisting of (a) obtaining the product from the supplier and (b) operational costs of bringing the products to the market (documentation, invoicing, advertisement, etc.); s is unit inventory cost. Equation 4 tells us that expected profits equals the expected revenue from goods sold (first two terms) *less* the expected cost of goods sold. The *asymmetric* nature of the losses show up in two ways. First, if there is a *stock-out* effect, this shows up as *forgone revenue.* In this case $q_s < q_d^f$ so that the revenue is given by what is *actually* sold which is *less* than what the demand is. This is given by $P(q_s)q_s|_{q_s<q_d^f}$ appearing in the first term. When multiplied by the probability of a stock-out $[prob(q_s < q_d^f)]$ one then finds the expected value of this lower revenue level. The second form in which losses show up is if there is an excessive supply of a good relative to the demand ($q_s > q_d^f$). This asymmetry shows up because, unlike the stock-out scenario, in this case we have *inventory costs* that must be added to the cost of procurement. Inventory costs show up as the last term in equation 4, with s denoting the unit inventory cost, $q_s - q_d^f$ denoting the size of the inventory and $prob(q_s < q_d^f)$ denoting the probability of an *over-stock.* Notice also that the second revenue term in (4) is based on *this* probability of over-stock. Here, actual revenue is $P(q_d^f)q_d^f|_{q_s > q_d^f}$ which is based on actual sales (q_d^f) which in this case is *smaller* than the supply of goods. Finally we have the expected procurement cost term itself, shown by the 3rd term in equation 4. Since procurement costs are the same regardless of the whether the amount purchased is too little or to much compared to the demand, the expected procurement is *symmetric* with respect to over-supply or stock-out effects. This is why c_T is factored out in equation 4. But this means that the third term simplifies to $-cq_s$, as seen in equation 5, below.

It should be added that in using s to denote the inventory cost associated with the demand, we have made the implicit assumption that the product is non-perishable so that eventual sales to recover the product's total costs (c_T) are possible and the only loss is storage cost. Moreover, storage costs s may implicitly include time[2].

Expressing the probabilities in (4) in terms of the density function $f(\delta)$ from equation (1), expected profits become:

$$\begin{aligned} E(\pi_r|_{q_s}) &= \int_{-1}^{0} P(q_s)q_s f(\delta)d\delta + \int_{0}^{1} P[(q_s(1-\delta)]q_s(1-\delta)f(\delta)d\delta - \\ &\quad -c_T q_s - s\int_{0}^{1} \delta q_s f(\delta)d\delta \end{aligned} \tag{5}$$

Since q_s is independent of δ, equation (5) can be simplified as:

$$E(\pi_r|_{q_s}) = \frac{1}{2}P(q_s)q_s + \int_{0}^{1} P[(q_s(1-\delta)]q_s(1-\delta)f(\delta)d\delta - c_T q_s - sq_s\Omega_\delta \tag{6}$$

In (6), $\Omega_\delta \equiv \int_0^1 \delta f(\delta)d\delta$, representing the mean value of δ, *conditional* on $\delta > 0$. But from (1) a positive δ represents the size of $q_s - q_d^f$ (in relative terms) or the extent to which demand falls short of the supply of goods. Thus, Ω_δ represents the *average* size of an unanticipated oversupply shock. Since in this sub-range, $\delta \in (0, 1)$, it follows that $\Omega_\delta < 1$. Although Ω_δ is an analytically distinct feature of the distribution $f(\delta)$ it is likely that Ω_δ is positively related to the variance σ_δ^2 so that a

[2] Explicit modeling of time would serve a useful function if products were differentiable based on their storage time before sale. At this point, we focus on a single composite product so that differentiation based on storage time is not relevant to the present analysis.

more widespread distribution involves a larger value of Ω_δ. However, Ω_δ contains a signal value regarding the extent of oversupply while σ_δ^2 is pure white noise.[3]

At this point, expected profits are still conditional on supply. Thus, we use equation (3) to first express expected profits unconditionally, and then use equation (2) to re-express the result in terms of q_o, the retailer's quantity of goods to be ordered up the supply chain. The resulting expression will involve the stochastic parameters δ and u, among other things, that are the arguments of the inverse demand function (e.g., $P[q_o(1+u)]$ or $P[q_o(1+u)(1-\delta)]$) located inside the integrals. Thus, further analysis will involve *Taylor Series* expansion of the inverse demand function, around q_o in order to linearize the function. This expansion is carried out to the second term, then results are integrated over the appropriate density functions, and simplified. Following this process, retailer's expected profits become:

$$E(\pi_r) = (1-\Omega_\delta)P(q_o)q_o - (c_T + s.\Omega_\delta)q_o + q_o^2 P'(q_o)A(\sigma_u^2, \sigma_\delta^2, \Omega_\delta) \tag{7}$$

where $A(\sigma_u^2, \sigma_\delta^2, \Omega_\delta) \equiv [(1-2\Omega_\delta)\sigma_u^2 + \frac{1}{2}\sigma_\delta^2(\sigma_\delta^2 + \sigma_u^2) - \Omega_\delta]$. Notice in (7), that while the supply and demand uncertainty parameters, σ_u^2 and σ_δ^2 affect expected profits adversely, the role of the unanticipated oversupply parameter, Ω_δ, is mixed at this point: On the one hand, it affects expected profits adversely via the revenues and inventory costs (the first two terms); on the other hand, it affects expected profits positively via the slope of inverse demand $P'(q_o)$ (<0)! This observation is tied to the market power of the retail firm. In fact for a competitive firm where demand is horizontal and $P'(q_o) = 0$, the parameter Ω_δ reduces expected profits unambiguously, since the last term vanishes. By contrast, a firm with some market power is able to lower the price in response to excess inventory build-up when supply exceeds final sales ($q_s > q_d^f$, or $\delta > 0$), thus moderating the adverse effect of overestimating the final demand. In summary:

Proposition 1. Market power allows retail firms to better absorb the adverse effect of oversupply shocks, by reducing prices.

Optimizing Decision for a Linear Demand: The firm chooses the magni-

[3]Further, note that $\delta^2 < \delta < 1$. It follows that $\int_0^1 \delta^2 f(\delta)d\delta < \int_0^1 \delta f(\delta)d\delta$ or that $(1/2)\sigma_\delta^2 < \Omega_\delta$.

tude of the orders q_o to maximize expected profits. We confine our attention to the case of a linear demand (P''=0) to make the analysis tractable. The first order condition,$\frac{dE(\pi_r)}{dq_o} = 0$, then yields:

$$(1-\Omega_\delta)[P(q_o)+P'(q_o).q_o] + 2A(\sigma_u^2, \sigma_\delta^2, \Omega_\delta).P'(q_o).q_o - (c_T + s\Omega_\delta) = 0 \qquad (8)$$

Concavity of expected profits in q_o implies,

$$\frac{d^2E(\pi_r)}{dq_o^2} < 0 \rightarrow \Omega_\delta < \frac{1}{2} + \frac{1}{4}\sigma_\delta^2 \qquad (9)$$

Thus, in order for a unique profit maximizing point to exist, the magnitude on the oversupply (Ω_δ) (in relative terms) must be limited, given a variance σ_δ^2.

Assuming a linear inverse demand, $P(q_o) = a - bq_o$, optimum order quantity is:

$$q_o^* = \frac{1}{2b}.\frac{(a-c_T)-(a+s)\Omega_\delta}{(1+\sigma_u^2)[1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta]} \qquad (10)$$

and the maximum expected profit is given by:

$$Max\{E(\pi_r)\} \equiv \pi_r^{e*} = \frac{1}{4b}.\frac{[(a-c_T)-(a+s)\Omega_\delta]^2}{(1+\sigma_u^2)[1+\frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta]} \qquad (11)$$

Since the denominator of (10) is positive by (9), a positive value of q_o^* in (10) implies that, $a-c > (a+s)\Omega_s$. Inequality (9) also guarantees that profits in (11) are positive. Notice that in (11) supply and demand uncertainties, σ_u^2 and σ_δ^2, affect optimum orders and profits adversely, i.e.:

$$\frac{\partial \pi_r^{e*}}{\partial \sigma_\delta^2}, \frac{\partial \pi_r^{e*}}{\partial \sigma_u^2} < 0 \qquad (12a)$$

$$\frac{\partial q_o^{e*}}{\partial \sigma_\delta^2}, \frac{\partial q_o^{e*}}{\partial \sigma_u^2} < 0 \qquad (12b)$$

However, the parameter Ω_δ continues to play a dual role in its effect on profits and orders; via the numerator it reduces both, and via the denominator it increases both. As we saw earlier, the latter effect arises from the slope of the inverse demand and is a reflection of the fact that larger firms with market power can absorb the effect of an unanticipated inventory build-up by reducing prices. All of this confirms proposition 1 and the discussion preceding it. However, it is now possible to evaluate the overall net effect of Ω_δ on retailer profits and optimum orders. This effect turns out to depend on the size of Ω_δ. In particular, we find that,

$$\frac{\partial \pi_r^{e*}}{\partial \Omega_\delta}, \frac{\partial q_o^*}{\partial \Omega_\delta} < 0, \text{ if } \Omega_\delta < 1 + \frac{1}{2}\sigma_u^2 - \frac{a - c_T}{a + s} \tag{12c}$$

To summarize these findings:

Proposition 2. Retailers' expected profits and orders are adversely affected by uncertainties in supply and demand, and given some conditions, by unanticipated overstocking.

Supplier: We assume that the supplier is monopolistic *vis-a-vis* the retailer. To analyze supplier behavior, we need to first decompose the unit cost c_T. Let

$$c_T = c + c_o$$

where c is the unit cost that the supplier charges the retailer, and c_o is the operational costs within the retail firm, once the products are received (documentation, advertisement, etc.). Then the supplier profits are given by:

$$E(\pi_s) = (c - v)E(q_s(c_T)) \tag{13}$$

where v is the unit cost of production, and $q_s(c_T) = (1 + u)q_o(c_T)$ by equations (2). The function $q_o(c_T)$ in (13) is given by equation (10), so that in line with a typical Stackelberg Scenario, the supplier observes the retailer's downward sloping demand, as a function of cost of goods c_T. The supplier's expected profits become:

$$E(\pi_s) = \int_{-1}^{1} (c - v)q_o(c + c_o).(1 + u)g(u)du = (c - v)q_o(c + c_o) \tag{14}$$

In other words, the effect of product costs, c, on a large supplier's bottom line is positive to the extent it can be passed onto the retailer ($c - v$ in equation 14) , but negative to the extent that this would trigger an adverse demand response on the part of the retail firm [$q_o(c + c_o)$ in equation 14 with $q_o' < 0$]. We then substitute for $q_o(.) = q_o^*(.)$ from (10), reflecting supplier's Stackelberg behavior. Faced with the conflicting effects of a price increase on its profits, the supplier firm must optimize over c. The result is:

$$\frac{dE(\pi_s)}{dc} = 0 \rightarrow c^* = \frac{1}{2}[a - c_o - (a + s)\Omega_\delta + v] \tag{15}$$

Notice that a rise in Ω_δ reduces c^* charged by the supplier to the retailer, i.e.:

$$\frac{\partial c^*}{\partial \Omega_\delta} < 0 \tag{16}$$

This issue is of key significance to the strategy of IT adoption in the supply chain, especially as it relates to the food industry. The issue will be discussed shortly below.

Substituting from (10) and (15) into (14), we find:

$$Max\{E(\pi_s)\} \equiv \pi_s^{e*} = \frac{1}{4b}.\frac{(a - c_o + v)^2 - [(a+s)\Omega_\delta - \frac{vs}{a+s}]^2 + (\frac{vs}{a+s})^2}{(1+\sigma_u^2)[1 + \frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta]} \tag{17}$$

In equation (17) there are several key issues. First, as in the case of the retail firms, the supplier's profits fall with the uncertainty in the final demand (facing the retailer) and the uncertainty associated with the variance between the supply of goods and retailer's orders:

$$\frac{\partial \pi_s^{e*}}{\partial \sigma_\delta^2}, \frac{\partial \pi_s^{e*}}{\partial \sigma_u^2} < 0 \tag{18}$$

Secondly, the effect of unanticipated oversupply at the level of final sales (Ω_δ) is negative via numerator and positive via denominator. To gauge the overall effect, consider the original equation (14). Differentiating this equation (*when evaluated at the optimum)*, in Ω_δ, the overall effect affect on the supplier profits is adverse:

$$\frac{\partial \pi_s^{e*}}{\partial \Omega_\delta} = \frac{\partial E(\pi_s)}{\partial \Omega_\delta}|_{c^*} = \frac{\partial c^*}{\partial \Omega_\delta} q_o^*(c^* + c_o) + (c^* - v)\frac{\partial q_o^*}{\partial \Omega_\delta}$$

By (16) the first term on the right side of the above equation (the effect of Ω_δ on procurement costs) is negative and by (12c) the second term (effect of Ω_δ on the retail firm's order size) is negative. It follows that under the condition specified in (12c) Ω_δ also adversely affects seller firm's profits:

$$\frac{\partial \pi_s^{e*}}{\partial \Omega_\delta} < 0 \tag{19}$$

For reasons discussed later, this is a key result. It is summarized as follows:

Proposition 3. The supply firms' profits are adversely affected by final demand and procurement uncertainties and by the unanticipated overstocking of the retailer, down the supply chain. Thus, a reduction in these uncertainties and the excess overstock the retailers, improves both the retailers' and the suppliers' profits.

APPLICATION TO THE FOOD INDUSTRY

Suppose the retail firm adopts a strategy (technology) to predict, analyze and forecast final demand. In food industry this could be done by adopting Product Analysis or Category Management practices. These practices make use of POS data, obtained from scanner technology, to better gauge and predict final demand. In our model, this would lead to a reduction in σ_δ^2 and Ω_δ. The retailer's adoption of such practices would also raise supplier profits, per equations (18) and (19), giving the supplier the incentive to learn the retailer's information. The supplier could do so by adopting a collaborative data management practices with the retailer such as CPFR.

However, sharing its market data with the supplier raises retailer's unit product costs per equation (16). In fact, Nakayama (2000) finds that the food retailer's upstream adoption of EDI for inventory coordination (which approximates the concept of CPFR here) results in a tighter control of the retailer's mark-up by the supplier, in effect raising the retailer's costs. This would reduce retailer's incentive to share the POS data with the supplier. Faced with this reticence, the supplier may provide the retailer with additional incentives to join in the CPFR technology. One such incentive, as Nakayama finds, is the suppliers' provision of "incremental value added services"(e.g., analysis and assistance in sales and marketing, providing product information, coordination in shipping and delivery, etc.), thereby reducing the uncertainties associated with supply. In fact, such a sharing would increase retailer's profits per inequality 12a (second inequality), as we have seen.

Yet, a retailer may choose to act strategically *vis-a-vis* the supplier in the *signal space.* A retailer of this kind would be able to *observe* the dependence of costs on Ω_δ. Such a retailer would then have an incentive to use POS data to raise his own profits (via 12a-first inequality, and 12c) but to *withhold* information from the supplier to keep the part of product's cost attributable to supplier (c) down, *even when this means less supply and inventory coordination* (higher σ_u^2). This suggests one explanation of the lack of "trust" in the contract between the supplier and the retailer, that has often been cited in the food industry and was discussed in the Introduction.

It turns out, as we shall see in the further development of the model, that even under theses circumstances, the supplier is able to extract some information from the retailer, based on the latter's quantity of orders from to the supplier. This theoretical result is supported by evidence in the food industry. Thus Nakayama (2000, p. 198) states,"...suppliers obtain more accurate and timely information on product sales and on their partner's operational status through such EDI transaction sets as purchase orders and product activity." Thus, in equilibrium, the there will be some information spillover even under this asymmetric information scheme. However, we shall see that the equilibrium size of this signal may still not match the full information scheme. This finding has interesting industry-wide implications. For example, it would provide an incentive to the supplier to downwardly integrate as is the case with wholesalers SuperValu and Nash Finch who have acquired a larger number of retail food stores. The supplier's quest to access the retailer's valuable POS and inventory data (via retailer's internal use of EDI), may be equally matched by the retailer's efforts to protect such information. One way to achieve this that would be for the retailer to vertically integrate upward, developing its own sources of supplies. This is exemplified by Wal-Mart, Kroger and other large chains that have developed their own-warehousing capabilities, known as self-distribution retail chains.

Finally, note that since the supplier has some market power, the component of the unit cost (c) that it charges the retailer must exceed the product's cost of production (v) to allow for a positive "mark-up". But this provides another incentive, other than information protection, for the retailer to internalize "excess" costs, reinforcing the pattern of upward vertical integration. However, this would only occur for self-distributing food retailers in which the warehousing capabilities already exist. In this paper we ignore this possibility.

The next section analyzes supply chain equilibrium with an information sharing schemes, using this as a benchmark against the signaling games and the asymmetric information schemes discussed later.

EQUILIBRIUM UNDER INFORMATION SHARING

Equilibrium in the supply-chain model just described arises from substituting the cost function (15) into the retailer's expected profits (11). Since a component of costs are set by the supplier, the underlying assumption here is that the parameter Ω_δ in equation (11), which the supplier observes, is the same as that which the retailer experiences. Thus, this is a full information equilibrium. Let Π_r^E denote retailer's expected profits under this information sharing equilibrium. Then,

$$\Pi_r^E = \pi_r^{e*}(c = \frac{a - c_o - (a+s)\Omega_\delta + v}{2}) \tag{20}$$

where π_r^{e*} is given by equation 11. This yields:

$$\Pi_r^E(\Omega_\delta, \sigma_\delta^2, \sigma_u^2) = \frac{1}{16b}.\frac{[(a - c_o - v) - (a+s)\Omega_\delta]^2}{(1+\sigma_u^2)[1 + \frac{1}{2}\sigma_\delta^2 - 2\Omega_\delta]} \tag{21}$$

Equation (21) prepares the groundwork for a retailer who wishes to act *strategically* in the signal space based on the *realization* that the supplier price c depends on its knowledge of the final demand (via Ω_δ). For now, however, we treat (21) as the aggregate equilibrium solution with full information and establish some key properties of (21). First, as can be seen, the effects of supply and demand uncertainties (σ_u^2 and σ_δ^2) on equilibrium profits are adverse as before (see inequalities in 12a). The effect of oversupply shock, Ω_δ, however, needs to be re-examined due to the dependence of costs (c) on Ω_δ (equation 20). In particular, we find:

$$\frac{\partial \Pi_r^E}{\partial \Omega_\delta} < 0, \text{ if } \Omega_\delta < 1 + \frac{1}{2}\sigma_u^2 - \frac{a - c_o - v}{a+s} \tag{12c'}$$

Condition in (12c') is nearly identical to (12c) with the total product cost c_T in (12c), being replaced by the sum of the unit production costs v and the retailers unit operating costs c_o. As in (12c), (12c') tells us that a positive overstock shock adversely impacts retailers' profits, as long as the shock has some reasonable upper bound.

Firm Size and inventory build-up

One interesting question to ask is: how does an overstock shock (Ω_δ) affect large and small firms in equilibrium? To answer this question let both firms face demands with same slope (b) but $a_l > a_s$ where a_l and a_s are the vertical intercept for large and small firms respectively, representing the scale of the market. From (21) we find:

$$\frac{\Pi_r^E(a_l)}{\Pi_r^E(a_{s)}} = [\frac{(a_l - c_o - v) - (a_l + s)\Omega_\delta}{(a_s - c_o - v) - (a_s + s)\Omega_\delta}]^2 \tag{22}$$

from which we find the following informative result:

$$sign\{\frac{\partial[\frac{\Pi_r^E(a_l)}{\Pi_r^E(a_s)}]}{\partial\Omega_\delta}\} = sign\{(a_l - a_s)(c_o + v + s)\} > 0 \tag{23}$$

Equation (23) tells us that an overstock shock creates a profitability gap between small and large firms, in favor of the large ones:

Proposition 4: Although overstocking adversely affects profits, unanticipated slowdowns that lead to unanticipated overstocking harm smaller firms more than larger ones, driving a wedge between the two. The greater are the unit production and inventory costs, the larger is the gap between the two types of firms due to overstocking.

STAGE II GAME: INFORMATION MANAGEMENT STRATEGIES

Strategies for adopting IT involve information sharing between parties with the goal of inventory management and minimization of supply disruptions. Yet, information is often the retailer's strategic asset and the concern that information may be used against him/her may temper the desire to adopt IT. This trade-off is best illustrated in the following question that the retailer asks: "What is the minimum set of information to share with my supply chain partners without risking potential exploitation?" (Lee and Whang, 2000). Furthermore, an overview of the literature on how and why firms adopt certain types of IT over others, leads one to the conclusion that the process of adoption of IT is at least in part the result of strategic decisions. This issue is clear in Nakayama's (2000) study of the food industry in which the retailer-supplier *power* relationship is at the core of the retailer's decision to adopt EDI. Thus, based on his survey of grocery stores, Nakayama finds that "there is evidence that power shifts towards suppliers with EDI links." (Nakayama, 2000, p. 208). In others industries (e.g., banking) similar considerations have been raised, as was discussed before. Formal game approaches have been utilized in other contexts to study strategic considerations of IT adoption by firms (cf. Dewan, et. al. 2000).

We carry this analysis further. This is done by viewing the retailer's choice of IT technologies as the outcome of a sequential game between the retailer and the supplier. The underlying assumption is that quantity-pricing decisions have a shorter time horizon than IT decisions. Thus, we can model the quantity-pricing strategies contemporaneously, but the IT strategies must have a sequential dimension.

We base our stylized facts for modeling of the information game on the result of the annual report from the University of Minnesota's Food Industry Center's (2000) study of 344 supermarket stores. This is shown in Table 1. We assume that the food retailer already has scanner technology, as almost all supermarkets now carry this basic technology. Beyond this, the retailer has a set of choices: First it may or may not use traditional EDI data (first row in table 1) to manage document exchange. Second, even when it uses traditional EDI, the retailer has a choice to advance EDI to Electronically Assisted Receiving (EAR) (second row) or to the point of Scanning Data for Automatic Inventory Refill (SDAIR) (fourth row) which may be viewed as a type of CPFR. It is interesting to note from row 3 that many retailers use the data for the analysis of the market and category management. For our modeling purposes this amounts to a reduction in the values of σ_δ^2 and Ω_δ associated with an improved forecasting ability. This information is of critical value to the retailer as well as to its upstream supplier (the wholesaler, distributor, manufacturer, processor, or broker) who would like to use it to better streamline and manage its inventory. To the extent that this would also lead to reduction in "noise" on the orders from retailer to the supplier (reduction in σ_u^2), both the retailer and its upstream supplier would benefit. But the retailer would have to relinquish valuable information for this purpose. This leads to the question of whether retailer is willing to *share* this information with the upstream supplier. It is reasonable to assume that in table 1, only the fourth row (SDAIR), which is some form of CPFR, allows for this information sharing possibility.

Table 1

The subgame perfect equilibria arises from the retailer's choice of the most profitable strategy, given the supplier's response to each strategy. These strategies are presented in Figure 1. Each strategy is analyzed below:

Figure 1

Strategy 1. EDI/EAR plus Category Management

This is path 1 in Figure 1. When the food retailer adopts EDI/EAR for internal use, its cost of handling the products declines (c_o falls). Additionally, adopting Product Analysis and Category Management facilitates retailer's demand forecasts and reduces demand uncertainties. Thus, σ_δ^2 and Ω_δ fall. (For simplicity we assume σ_δ^2 and Ω_δ fall to zero). This increases retailer profits (inequality 12c). But it also increases supplier profits (first inequality in 18 and inequality 19). Thus, supplier has the incentive to induce the retailer to share this information. Evidence suggests that in the food industry one such incentive is the supplier's subsidizing of the retailer's use of EDI-based technologies such as CPFR[4]. For our model, we assume that this technology is provided to the retailer at no cost. In addition, CPFR entails the added incentive to the retailer that the supplier shares its inventory and order data with the retailer. This has the effect of better procurement coordination, i.e., σ_u^2 falls (we assume σ_u^2 falls to zero). Evidence for this behavior in the food sector is also found in Nakayama. Despite these incentives, however, the retailer's adoption of CPFR may nonetheless *increase* the cost of procuring the goods from the supplier as is seen from inequality (16), $\partial c^*/\partial \Omega_\delta < 0$. In the food industry, Nakayama finds evidence for this as the supplier is now able to exercise greater control over the retailer's mark-ups and promotions, in effect raising the retailer's costs. For this reason, the retailer may accept or reject the supplier's initiative:

Response Strategy 1.1. Retailer accepts CPFR: Information Sharing Game: In this case, supply error variance is eliminated to both parties ($\sigma_u^2 = 0$). This is Path 1.1 in Figure 1 and amounts to *information sharing* since $\Omega_\delta = 0, \sigma_\delta^2 = 0$ for both parties. The retailer's gains from this decision are its equilibrium profits in (21), adjusted for the (flow) cost $r(F_1 + F_2)$ of financing the technologies, where r is the rate of interest, F_1 is the fixed costs of EDI, and F_2 is the cost involved in product

[4]Nakayama speaks of EDI technology offered by the supplier. In our analysis this is equivalent to CPFR since we refer to EDI for the simpler document transfer technology.

analysis/category management. This yields:

$$\text{Net Gain of Strategy 1.1} \equiv \Gamma_{1.1} = \Pi_r^E(\Omega_\delta = 0, \sigma_\delta^2 = 0, \sigma_u^2 = 0, c_o' < c_o) - r(F_1 + F_2)$$
$$= \frac{1}{16b}(a - c_o' - v)^2 - r(F_1 + F_2) \quad (24)$$

Response Strategy 1.2: Retailer rejects CPFR: Asymmetric Information Game: This case, described by Path 1.2 in the figure, is the most interesting case to analyze, both analytically and because it explains why retailers may choose to withhold valuable sales data from the suppliers. Consider equations (15) and (16) where the unit cost of procurement (c^*) may rise to the retailer. A retailer acting strategically in the *signal space* would observe the dependence of costs on the information available to the supplier. Analytically, this means that the retailer realizes that the a more informed supplier, while contributing to the lower inventory costs, is also better able to use its market power over the retailer to set prices to the retailer (via the dependence of c^*on Ω_δ in equation 15). In that case, the retailer may find it beneficial to withhold sales information from the supplier, by keeping procurement costs c^* low, while it can estimate its own final demand without uncertainty by analyzing its own POS data with Category Management. In this case, the retailer would reject CPFR, thus foregoing the benefits of CPFR in terms of inventory coordination with the supplier (σ_u^2 remains positive). The fact that information available to the retailer is now *distinct* from the supplier's information points to an *asymmetric* information exchange between the supplier and the retailer. The retailer's profits under this strategy arise from evaluating equilibrium profits in equation (11), taking special care to distinguish the information available to the retailer (which we call $\Omega_\delta^r$and σ_δ^{r2}), with that available to the supplier (which we call Ω_δ^s). In (11) the own-information effect enters directly, but the information effects from the supplier operates via costs (eqn. 15). Thus, we have,

$$\text{Net Gain of Strategy 1.2} \equiv \Gamma_{1.2} = \pi_r^{e*}(\Omega_\delta^r = \sigma_\delta^{r2} = 0, c_o' < c_o, c = \frac{a - (a+s)\Omega_\delta^s + v}{2})$$
$$-r(F_1 + F_2) = \frac{1}{16b} \cdot \frac{[(a - c_o' - v) + (a+s)\Omega_\delta^s]^2}{(1 + \sigma_u^2)} - r(F_1 + F_2) \quad (25)$$

In (25) supply error variance σ_u^2 remains positive while costs of operation fall from c_o

to $c_o^{'} < c_o$ due to the use of EDI/EAR. Also, $\Omega_\delta^r = \sigma_\delta^{r2} = 0$ denote the information gain to the retailer but not the supplier, who perceives a positive overstock value of $\Omega_\delta^s > 0$. Since $\partial\Gamma_{1.2}/\partial\Omega_\delta^s > 0$ we have,

Proposition 5: The effect of a retailer withholding sensitive market data from its supplier is to increase the retailer's profits, all else equal.

Of course, all else may not be the same since, compared to the information sharing strategy (equation 24), the price to be paid for the retailer's refusal to share information is the supply uncertainty, σ_u^2. The next subsection determines the equilibrium value of Ω_δ^s and further examines this trade-off.

Equilibrium Signal with Asymmetric Information

A key and surprising finding in this asymmetric information exchange turns out to be that despite the retailer's withholding sensitive final demand data from the supplier, the latter will in fact *extract* some information based on the equilibrium size of the orders. To see this, note that market equilibrium is attained if an *expectation realization* condition is satisfied, namely,

$$\begin{aligned} q_o^*|_{\text{perceived by supplier}} &= q_o^*|_{\text{ordered by retailer}} \Longrightarrow \\ \frac{1}{2b}.\frac{a - c_o^{'} - c(\Omega_\delta^s) - (a+s)\Omega_\delta^s}{(1+\sigma_u^{s2})[1+\frac{1}{2}\sigma_\delta^{s2} - 2\Omega_\delta^s]} &= \frac{1}{4b}\frac{a - c_o^{'} - c(\Omega_\delta^s) - (a+s)\Omega_\delta^r}{(1+\sigma_u^{r2})[1+\frac{1}{2}\sigma_\delta^{r2} - 2\Omega_\delta^r]} \end{aligned} \tag{26}$$

where we have applied the optimum quantity equation (10) to write (26). Recalling that the unit cost c_T in (10) consists of two components, $c_o^{'} + c$, the component c is expressed in terms of the cost function $c(\Omega_\delta^s)$ in (15). That $c(\Omega_\delta^s)$ shows up to both parties in the same way is because, on the one hand, the supplier has access only to the information contained in Ω_δ^s and, on the other, the retailer is aware of this fact. This suggests that while the supplier acted strategically in the quantity space it is the retailer that acts strategically in the signal space. Beyond that, the retail firm operates on its own information set, given by Ω_δ^r.

We can then solve (26) to determine the equilibrium size of Ω_δ^s. First note that since the retailer has adopted the necessary strategy (Category Management) to eliminate market uncertainty, $\sigma_\delta^r = \Omega_\delta^r = 0$ in (26). Additionally, we need to relate the supplier's perceived uncertainty parameter, σ_δ^s to its perceived mean oversupply parameter Ω_δ^s. Recall from footnote (3) that $(1/2)\sigma_\delta^2 < \Omega_\delta$. Thus we can write,

$$(1/2)\sigma_\delta^{s2} = \alpha\Omega_\delta^s \tag{27}$$

where α is any positive parameter (<1). For example, α may be a characteristic of the underlying density function such as the "noise-to-signal ratio". We then substitute for σ_δ^{s2} from equation (27) in terms of Ω_δ^s. Solving the resulting equation for Ω_δ^s, yields two equilibrium solutions:

$$(\Omega_\delta^s)_1^* = 0, \;\; (\Omega_\delta^s)_2^* = \frac{2}{2-\alpha} - \frac{a - c_o' - v}{a+s} \tag{28}$$

It can be easily shown that for the second solution to exist, we must have:

$$2 - \alpha > \frac{a - c_o' - v}{a+s}$$

But this condition is always satisfied since $2-\alpha > 1 > \frac{a-c_o'-v}{a+s}$. Moreover, $(\Omega_\delta^s)_2^* > \frac{1}{2-\alpha}$ where $\frac{1}{2-\alpha}$ marks a discontinuity for $q_o^*|_{\text{perceived by supplier}}$, i.e., the left side of (26). The two equilibria $(\Omega_\delta^s)_1^*$ and $(\Omega_\delta^s)_2^*$ are separated by this discontinuity. Which information state does the system tend to? It is clear that this depends on the initial level of informational asymmetry. In particular,

Proposition 6. If market uncertainty is sufficiently low that $\Omega_\delta^o < 1/(2-\alpha)$, *then supplier inference from expected orders leads to a "revealed equilibrium" consistent with full information [*$(\Omega_\delta^s)_1^* = 0$*] If market uncertainty is sufficiently high that* $\Omega_\delta^o > 1/(2-\alpha)$, *then supplier inference from expected orders leads to a "revealed equilibrium" such that some residual uncertainty remains facing the supplier [*$(\Omega_\delta^s)_2^* > 0$*].*

The existence of a revealed equilibrium that emerges from supplier inference based on orders from the retailer seems consistent with the evidence in the food industry, as reported by Nakayama (2000, p. 198).

Comparing Strategies 1.1 and 1.2

Suppose the retailer begins with an initial level of market uncertainty with a corresponding level of mean oversupply of Ω_δ^o. Then, adopting strategy 1 eliminates this uncertainty entirely regardless of the level of initial uncertainty. This is shown by the flat line in Figure 2, representing $\Gamma_{1.1}$ in (24). Retailer's gain under strategy 1.2 is shown by the upward sloping curve representing $\Gamma_{1.2}$ in (25). The intersection of the two defines a threshold value of say, $\bar{\Omega}_\delta$, given by equating (24) and (25):

$$\bar{\Omega}_\delta = \frac{[(1+\sigma_u^2)^{1/2} - 1](a - c_o' - v)}{a+s} \tag{29}$$

Comparing this value with the positive equilibrium $(\Omega_\delta^s)_2^*$ in (28) one finds that the positive equilibrium may fall to the right or the left of the intersection value of $\bar{\Omega}_\delta$. Thus the two information equilibria fall either on both sides of the intersection $[(\Omega_\delta^s)_2^* > \bar{\Omega}_\delta > (\Omega_\delta^s)_1^*]$ or on the left of the intersection $[\bar{\Omega}_\delta > (\Omega_\delta^s)_2^* > (\Omega_\delta^s)_1^*]$. Now, depending on both the initial information about the demand (thus the value of Ω_δ^o) and whether $\bar{\Omega}_\delta$ separates the two equilibria or not, one can find convergence to full information $(\Omega_\delta^s)_1^*$, (Figure 2-Case 1) or to improved information but not full information $(\Omega_\delta^s)_2^*$ (Figure 2-Case 2). Moreover, from Figure 2 we can see that when both equilibria lie on the left of the intersection, regardless of the position of Ω_δ^o the *information sharing strategy 1.1 dominates* as the information withholding strategy leads to information convergence that occurs in the range where $\Gamma_{1.1} > \Gamma_{1.2}$. On the other hand, when the two equilibria fall on either side of the intersection, the position of Ω_δ^o matters. For initially high levels of market uncertainty corresponding to $\Omega_\delta^o > (\Omega_\delta^s)_2^* > \bar{\Omega}_\delta$ convergence is to $(\Omega_\delta^s)_2^*$ and occurs in the range where $\Gamma_{1.2} > \Gamma_{1.1}$ (Figure 2-Case 3). Thus, *information withholding strategy dominates.* For lower levels of uncertainty such that $\Omega_\delta^o < \bar{\Omega}_\delta$, convergence occurs to $(\Omega_\delta^s)_1^* = 0$, which is in the range where $\Gamma_{1.1} > \Gamma_{1.2}$ (not shown in the figure), so that again *information sharing dominates.* In short, unless $\Omega_\delta^o > (\Omega_\delta^s)_2^* > \bar{\Omega}_\delta$, information sharing strategy dominates. Moreover, since (by comparing 28 and 29),

$$(\Omega_\delta^s)_2^* \;\mathsf{R}\; \bar{\Omega}_\delta \text{ as, } (1+\sigma_u^2)^{1/2} \;\mathsf{Q}\; \frac{\frac{2}{2-\alpha}}{\frac{a-c_o'-v}{a+s}} \tag{30}$$

the condition that $(\Omega_\delta^s)_2^* \;\mathsf{R}\; \bar{\Omega}_\delta$ is guaranteed only if there is a low supply uncertainty σ_u^2. This condition is needed together with high initial demand uncertainty (and thus high Ω_δ^o) to lead to information withholding as a dominant and sustained strategy, otherwise information sharing strategy dominates. In summary,

Figure 2

Proposition 7: A retail firm that uses internal EDI and category management practices but chooses not to share market (POS) data with its supplier, will have an initial profit advantage over a similar firm that shares its POS data with the supplier. But as the value of the information withheld diminishes (supplier infers the market facing the retailer), the information withholding strategy may no longer pay unless demand uncertainty is high and supply uncertainty is low.

Strategy 2: Category Management, but no EDI/EAR: Asymmetric Information Again

This is path 2 in Figure 1. Evidence from Table 1 suggests that at least in the case of single food store and small grocery chains (2-10 stores), the majority of stores use category management, but few use EDI or Electronic Receiving. In the absence of the basic EDI/EAR infrastructure the supplier is not likely to have the incentive to provide the retailer with CPFR tools since that technology is predicated on basic EDI structure for intra-firm use. As a result, the structure of this game is one of asymmetric information similar to case 1.2. The only difference with 1.1 arises from the treatment of the costs: the absence of EDI or electronic receiving implies that operation costs c_o remain unchanged and that fixed costs entail category management costs (F_2) only:

$$\begin{aligned}\text{Net Gain under Strategy 2} \quad &\equiv \quad \Gamma_2 = \pi_r^{e*}(\Omega_\delta^r = \sigma_\delta^{r2} = 0, c_o, c = \frac{a-(a+s)\Omega_\delta^w + v}{2}) \\ -rF_2 \quad &= \quad \frac{1}{16b}.\frac{[(a-c_o-v)+(a+s)\Omega_\delta^w]^2}{(1+\sigma_u^2)} - rF_2 \qquad (31)\end{aligned}$$

Comparing Strategy 2 with 1.1 and 1.2

First, in comparing the profitability of strategy 2 above with 1.2 (eqn. 25) we note that strategy 2 entails smaller fixed cost (F_2 versus $F_1 + F_2$) but a larger procurement cost owning to the loss of efficiency when EDI or EAR are not used (c_o versus $c_o^{'}$). Therefore the overall profitability of strategy 2 may be larger or smaller than 1, depending on the size of fixed and operational costs. Specifically,

$$\Gamma_2 > \Gamma_{1.2} \text{ for } F_1 \text{ large or } (c_o - c_o^{'}) \text{ small}$$
$$\Gamma_2 < \Gamma_{1.2} \text{ for } F_1 \text{ small or } (c_o - c_o^{'}) \text{ large} \tag{32}$$

The fact that strategy 2 may sometimes be more profitable than strategy 1.2 raises the possibility that it may be even more profitable than strategy 1.1. To examine this possibility, we evaluate Γ_2 at $\Omega_\delta^s = 0$, i.e., when the supplier learns full information about market demand. This provides a lower bound for Γ_2. We then compare this lower bound (which is also one of the its equilibrium values), to Γ_1. It follows that,

$$\Gamma_2(\Omega_\delta^s = 0) \ \mathsf{T} \ \Gamma_{1.1} \text{ for } F_1 \ \mathsf{T} \ F_1^* \tag{33}$$

where F_1^* is the critical value of the fixed cost of EDI, associated with the equality of the two profit streams, given by:

$$F_1^* = \frac{1}{r}[(a - c_o' - v)^2 - \frac{(a - c_o - v)^2}{(1 + \sigma_u^2)}] \tag{34}$$

This is depicted in Figure 3. From this figure it is clear that when the fixed cost of EDI is sufficiently high, it is possible for the asymmetric information strategy to dominate the information sharing strategy, even when the information is fully revealed to the supplier. This result can be summarized as follows:

Figure 3

Proposition 8: If the cost of EDI is high, a retail firm that adopts only *category management (but not EDI) and chooses to* withhold *market (POS) data from its supplier, can maintain a profit advantage over a similar firm that shares its POS data with the supplier, even as the value of the information withheld diminishes (i.e., as supplier infers the market facing the retailer).*

The preponderance of retail firms in the food sector that just adopt category management (see Table 1), combined with the evidence (cited earlier) on a lack of trust in information sharing in this sector, are consistent with Proposition 8, and suggest that the fixed cost of EDI may in fact be substantial at least for food retailers that operate in smaller scale. This issue is taken up in the next sub-section. First, however, we consider briefly the retail firm's remaining strategy, which is not to adopt any IT strategies at all.

Strategy 3: No EDI/EAR or Category Management

This is the "reference" or the "base" strategy. In this case all uncertainty parameters are non-zero and equation 21 itself provides the profit term. This equation is also depicted in Figure 3, by the curve Γ_3. As seen this curve is downward sloping because informational advantages of the firm over its supplier are now removed from the model, so that increased uncertainty reduces firm profits. It is possible that this strategy could be the dominant one if the fixed costs F_1 and F_2 associated with other IT strategies are prohibitively high, the operating cost advantage associated with the EDI strategy (c_o' relative to c_o) is small, or the degree of market uncertainty and the associated overstock values are small.

Firm Size and IT Adoption

One immediate result that follows from the above equations is that firm size (determined by the quantity of orders) influences the likelihood of which strategies it is likely to adopt. This is because profits under these strategies must exceed the threshold of fixed costs and this is more likely for larger firms. To see this we need to relate firm level of quantity ordered (which measures the size) to firm profits (which measures effordability of fixed IT costs). From equations (10) and (11) we find this relation to be:

$$q_o^* = \frac{2r\pi_r^*}{a - c_T - (a+s)\Omega_\delta} \tag{35}$$

Setting the profit flow in (35) to the financing cost of IT, then, any strategy with a fixed cost F is viable if,

$$q_o^* \geq \frac{2rF}{a - c_T - (a+s)\Omega_\delta} \equiv G(F) \tag{36}$$

where $G(F)$ is linear and increasing function of F as seen in (36). Now consider the three strategies discussed above. Recall that the fixed costs associated with the three strategies are, $F_1 + F_2$, F_2 and zero for strategies 1, 2 and 3, respectively.

It follows that firms that are too small ($q_o^* < G(F_2)$) cannot afford to adopt any technology (strategy 3), medium size firms ($G(F_2) < q_o^* < G(F_1 + F_2)$) will be able to afford technologies needed only for efficient category management (strategy 2), and large firms ($q_o^* > G(F_1 + F_2)$) will be able to afford category management as well as EDI/EAR technologies (Strategy 1). Thus,

Proposition 9: Firm size determines the feasibility of adopting any form of information technology, in that smaller firms may not be able to cover the fixed costs of such technologies and will not adopt them, intermediate size firms can adopt a limited form of the technology and only the largest firms can adopt the costliest technology.

This result is roughly consistent with what we find in the literature and particularly with the findings reported in the University of Minnesota's Food Center Report (2000) on its survey of grocery stores nationwide.

CONCLUDING REMARKS

This paper develops an optimization model that explains the adoption of information technology by retail firms along the supply chain. It focuses on (a) the uncertainty environment underlying the decision to adopt IT and (b) the strategic dimension of IT adoption decisions from the view point of withholding or sharing information. We find that information reduces procurement and demand uncertainties, reducing costs to all parties and raising profitability. This is consistent with observations in the retail food industry. But we are also able to explain why food retailers tend to withhold sales data from their suppliers, as has been observed in the food industry. Further, we determine the circumstances that this is likely to occur, adding to the predictive value of this research. We also determine that there exists a *revealed* equilibrium signal about the market facing the retailer that the supplier can infer, *even* when the retailer withholds sales data from the supplier. The notion that some information may be inferred by the supplier is also consistent with some of the observed patterns in the food industry (see the text). The existence of information withholding behavior, where it might otherwise be learned, points to possible market failure and suggests collaborative industry or industry/regulator outcomes as mutually beneficial.

The model is suited to the stylized facts of the food industry where distributors (suppliers) have market power over retailer (buyers), and so information withholding takes place to counter this supplier's market power. However, studies have shown (e.g., Dai and Kauffman, 2001) that even when market power is on the side of the buyer, and sellers are numerous, as in buyer-initiated supply chains (e.g., Dell Computers, Sears and Wal-Mart), the question of information loss is crucial. Our model, starting with basic profit maximizing principles can be extended to address these types of markets as well. It offers a rigorous basis for such extensions.

Another contribution of this paper is that by modeling market demand uncertainty we are able to measure "unanticipated overstocks." This allows us to trace the effects of market uncertainty on small and large firms. By finding that increased uncertainty favors larger firms over smaller ones, the paper provides a basis for explaining industry restructuring. Also we can ask: How is the IT adoption decision of firms influenced by the specter of an unanticipated inventory accumulation in the face of current economic slow down?

One of the next steps is to test the propositions with empirical evidence and to extend the models to cases where retailers and wholesalers are vertically integrated. There should be little difference from the models herein. However, one difference may be that it would be the store chain headquarters (which owns their own distribution centers) that chooses to share sales data with manufacturers. Among the predictions of the model for example is that one would expect that manufacturers will ascertain their buyers' sales from historical data.

One option that has not been considered here because it is not as critical to the food industry, but is much more important in other industries, is the adoption of the technology that allows the independent retailer to take advantage of the B2B exchanges directly. However, even this option may be rising in its significance for the food sector (see for example Shulman, 2000) which has lagged considerably behind the manufacturing sector in this respect. Thus for example, food retailers may join an B2B exchange such as Transora using standardized protocol set by UCCNET (Shulman, 2000). However, adopting this option involves trade-offs as well. On the one hand, the retailer is able to secure the least costly procurement of supplies by directly purchasing from the producer(s), rather than warehousing intermediaries. On the other hand, the absence of contractual supplier-retailer relationships and certainly the absence of inventory coordination through EDI strategies implies that supply uncertainties σ_u^2 *cannot* be eliminated. In fact two studies, one by Dai and Kauffman (2002) and the other by Kauffman and Mohtadi (2002), argue precisely this point: i.e., that the risk versus cost trade-offs are the distinguishing features of the internet based B2B procurement systems versus the traditional EDI systems. This persistence of supply uncertainties, as opposed to EDI based systems in fact characterizes much of the food industry because of the perishable nature of the products.

It should also be added that other characteristics of the food industry, *perishability* and *high product variety* can easily be incorporated into our model. Perishability affects s or the storage cost; product variety affects b or the slope of the demand, to the extent that it increases product substitutions.

Finally, network effects may be present as well. Such effects have been studied extensively since the pathbreaking work of Katz and Shapiro (1994) (see for example, Economides, 1996), and even applied to electronic commerce (MacKie-Mason, Shenker and Varian, 1996). Network effects may tend to counter the reluctance to adopt information technology due to trust issues, since they would raise the opportunity cost of non-participation to the retailers who do not participate. With network effects included one would expect that larger firms (chains) would share more data, and that even smaller chains will begin to share sales data with their suppliers as they realize the benefits of network effects over concerns about trust.

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Table 1

IT Adoption Practices by Retailers in Food Supply Chains*

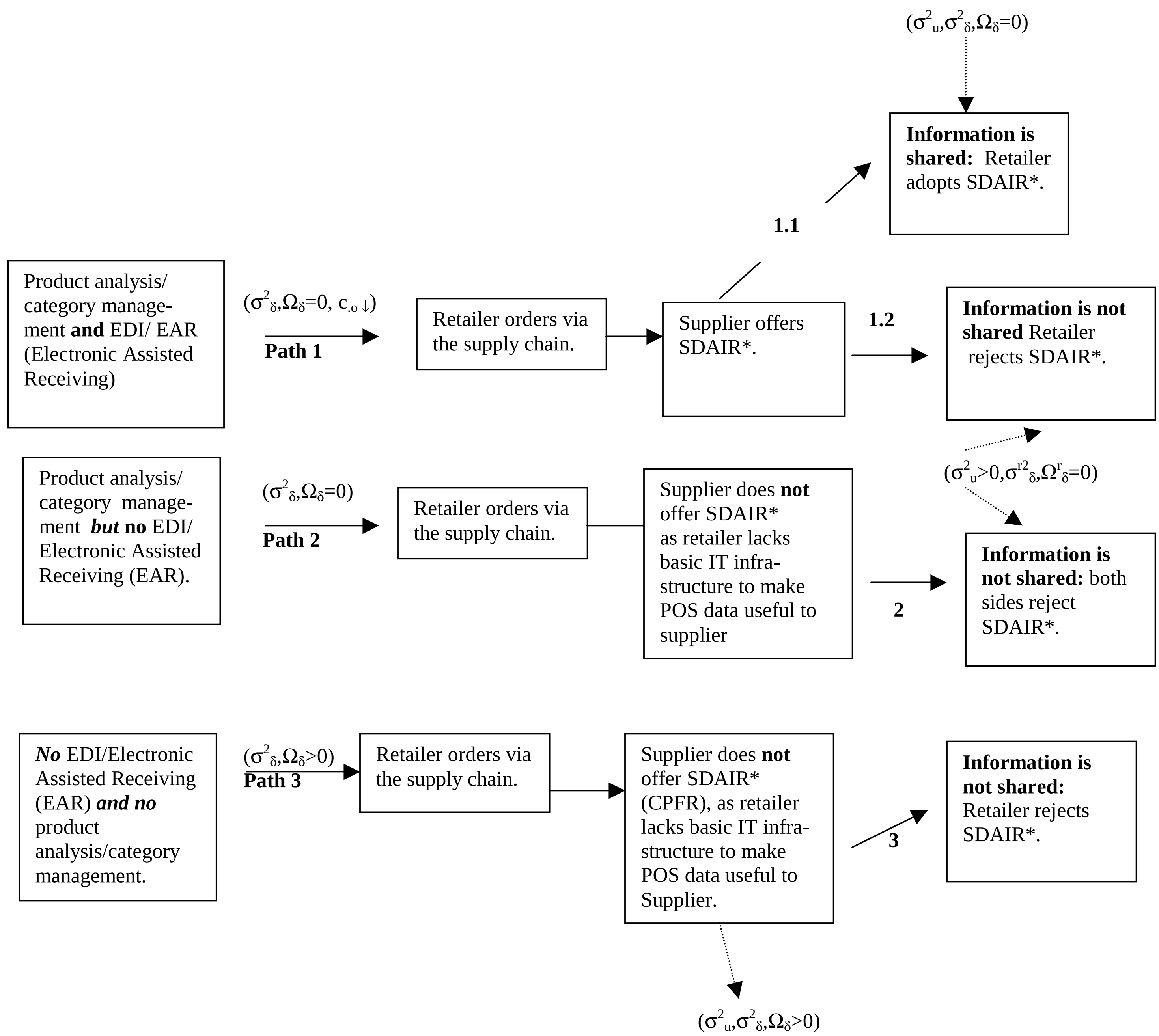
Percentage of Stores Adopting Different IT Practices

	Firm Size by the Number of Stores:				
	Single Stores	2-10 Stores	11-30 Stores	31-60 Stores	>60 Stores
Electronic Data Interchange (EDI)	19%	24%	37%	38%	48%
Electronic Assisted Receiving (EAR)	28%	37%	56%	65%	78%
Product Movement Analysis/ Category Management	81%	75%	77%	88%	90%
Sanning Data for Automatic Inventory Refill (SDAIR)	5%	1%	6%	4%	25%

*Souce: Extracted from The "2000 Supermarket Panel Annual Report," by The Retail Food Industry Center (now the Food Industry Center) at the University of Minnesota.

Figure 1

An Extensive Game Representation for Information Sharing /IT Strategies of Retailers in Food Supply Chains



*SDAIR =Scanner Data for Automatic Inventory Refill. This is assumed to be a segment of CPFR. Also see the text and Table 1.

Figure 2: A comparison of Information sharing Information Withholding Strategies

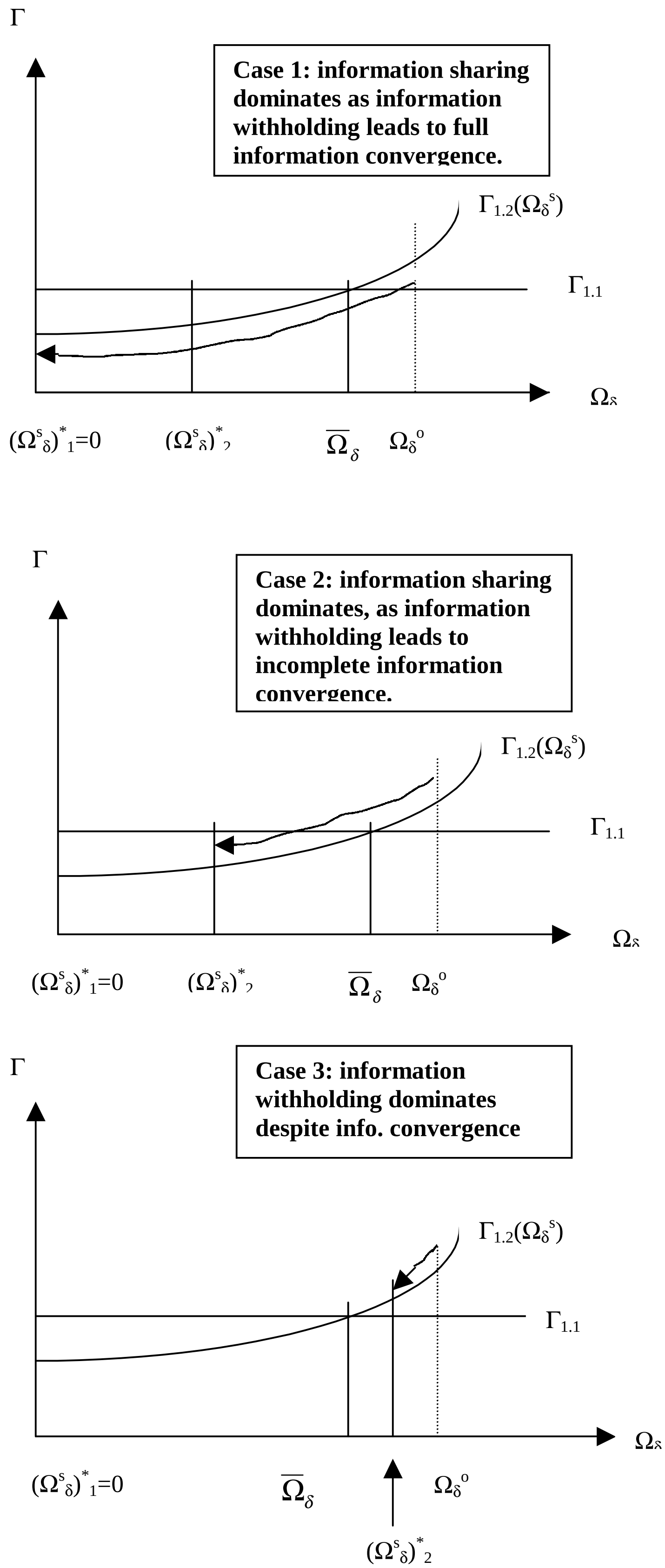


Figure 3: Information withholding may dominate without EDI adoption