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'Too Little' or 'Too Late': The Timing of Supply Chain Demand Collaboration

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Abstract

This study examines the supply chain demand collaboration between a manufacturer and a retailer. We study how the timing of collaboration facilitates production decision of the manufacturer when the information exchanged in the collaboration is asymmetric. We investigate two collaboration mechanisms: ‘Too Little’ and ‘Too Late’, depending on the timing of information sharing between the manufacturer and the retailer. Our research results indicate that early collaboration as in the ‘Too Little’ mechanism leads to a stable production schedule, which decreases the need of production adjustment when production cost information becomes available; whereas a late collaboration as in the ‘Too Late’ mechanism enhances the flexibility of production adjustment when demand information warrants it. In addition, the asymmetric demand information confounds production decisions all the time; the manufacturer has to provide proper incentives to ensure truthful information sharing in collaboration. Information asymmetry might also reduce the difference in production decision between the ‘Too Little’ and ‘Too Late’ collaboration mechanisms. Numerical analysis is further conducted to demonstrate the performance implications of the collaboration mechanisms on the supply chain.

Keywords: supply chain management; incentive contract; asymmetric information; supply chain collaboration; production-planning decision.

JEL Classifications: D81, D82, L14, L24, M11.

1. Introduction

In recent years, there have been several innovations to improve coordination and collaboration among supply chain partners in various industries. In particular, technology-enabled programs have been implemented to improve the availability of information and the efficiency of processes throughout the supply chain. Among these programs, the collaborative planning, forecasting, and replenishment (CPFR) approach is the most comprehensive and commonly adopted one. CPFR is a supply chain framework that includes a set of guidelines for formulating collaborative planning activities among supply chain parties. In essence, it calls for proactive management engagement in aligning goals and business processes, exchanging business information among parties, and coordinating business decisions in distribution and replenishment. CPFR approach is especially beneficial for industries with products that either are highly seasonal or have short life cycles, such as fashion apparels, personal computers and electronics products. In practice, many manufacturers such as Hitachi, Panasonic, Dell, Compaq, Nokia, and major retailers such as BestBuy (Barlas, 2001; Ericson, 2002) have benefited from the adoption of such collaborative solutions. Successful CPFR programs reduce out-of-stocks, improve forecasting accuracy, reduce inventory, improve resource deployment, and facilitate asset utilization (Lehoux et al., 2011; Williams et al. 2014). Ultimately, CPFR provides a company with significant competitive advantages: increases its market share and improves its profitability (Burnette 2010).

However, there are still some major concerns in supply chain collaboration. These concerns have hindered the implementation of CPFR. The high cost of CPFR has limited its adoption in terms of both items and partners (Grocery Manufacturers of America -- GMA, 2002). The collaboration process requires interactions among supply chain organizations at multiple levels—from the executive levels (in aligning goals, objectives, and business processes) to operational levels (in collaborating on forecasting and ordering activities). The high frequency of interactions at operational levels, especially when various products are involved, ties up planning resources and further increases the costs of collaboration. Therefore, it is a practical challenge to develop effective and cost-efficient collaboration solutions.

Given that frequent collaborations are cost-prohibitive, and given that various pieces of information that are useful for supply chain planning are available to different trading partners at different times, it is understandable that timing of collaboration is a big concern in CPFR adoption. From a tactical perspective, the most important types of information that are shared among trading partners are “production plans, inventories and shipping information” and “true demand data” (Matchette and Seikel, 2004). For example, a retailer might share her insights regarding future demand with a manufacturer in return for the manufacturer’s guarantee of supply. However, both production operation and market demand exhibit different degrees of uncertainty to trade partners at different times and make supply chain coordination a very complex task. In particular, if a retailer observes her demand early whereas her supplying manufacturer observes his production costs at a later time, it becomes a puzzle for the supply chain to determine the timing of the collaboration: should the manufacturer collaborate with and commit to the retailer at an early stage, or should the manufacturer delay collaboration until later?

In addition, asymmetry of information is typical in supply-chain collaborations. The inclusion of such information in collaboration solutions inevitably introduces incentives that can distort supply chain decisions (e.g, Cachon and Lariviere, 2001; Chakravarty and Zhang, 2007). Therefore, it is a challenge to maintain the integrity of information in collaboration since parties often have opportunities to manipulate information in order to receive favorable outcomes for themselves. During the collaboration process, business savvy planners and managers tend to rely on their management insights and market specific information when making their decisions (Swaminathan and Tayur, 2003). The very nature of the collaboration framework is therefore subject to the manipulation of information as a result of the ubiquitous existence of differences in objectives and interests among the involved organizations. Indeed, another major reason why firms are reluctant to adopt CPFR is their concern about “trust, verification and acceptance of the results between trading partners” (GMA, 2002). Information asymmetry therefore needs to be evaluated and addressed if trust is to be established in a long-term supply chain collaborative relationship.

The purpose of this study is to investigate the impact of timing on supply-chain decisions regarding demand and production—given the asymmetry of information and the uncertainty of production costs. The study focuses on the establishment of truthful collaboration mechanisms. The specific research questions addressed in the study are:

- How does information asymmetry affect production-planning decisions at different planning stages with different information available?
- How does information asymmetry affect the timing of the production decisions?
- How can production decisions convey incentives to extract truthful information under demand collaboration?

This study addresses the above questions by considering two alternative collaboration mechanisms. The first mechanism focuses on demand forecasting in a scenario whereby a retailer observes her updated demand and is willing to share this information truthfully with a manufacturer (supplier) in return for an early guarantee of production quantity (available for future retailer order) and a financial incentive. Under this mechanism, although a future update of the manufacturer’s production costs might improve the efficiency of supply chain production and distribution, the gains might be lower than the cost required to ‘capture’ this update within the collaboration process. This mechanism operates under the constraints of the production and demand information that is available at the planning stage, and hence is characterized as the ‘Too Little’ mechanism. The second mechanism allows the collaborative planning process to be carried out on the basis of *all* information. In this scenario, because certain information on production costs is available after demand update, waiting for the information to become available delays the lead-time sensitive planning process. This mechanism is therefore characterized as the 'Too Late' mechanism.

By analyzing these two collaboration mechanisms under an *available quantity – transfer* contract form (the contract form or its variant has been considered in Iyer and Bergen 1997, Tsay 1999, Gurnani and Tang 1999, Donohue 2000, Cachon and Lariviere 2001) modelled after the common demand collaboration process, we aim to improve the understanding of timing and information asymmetry on supply chain planning decisions. Numerical analysis is conducted to further demonstrate supply chain performance under different contracts. Some observations of the numerical analysis are reported and managerial implications are discussed.

Our research results include several important aspects. 1) The extent to which production decisions respond to available information during demand collaboration depends on when and how the information is used. 2) Production quantity can be an effective incentive to extract truthful information, depending on information asymmetry. 3) The impact of timing in production decisions is reduced, counter-intuitively, in respect to the information asymmetry in demand collaboration.

2. Literature Review

There is only limited literature that directly addresses demand collaboration issues. However, related studies can be classified into four major streams. The first stream of research has discussed demand collaboration as a forecast-updating process and has quantified the value of collaboration (Aviv, 2001, 2002; Kaminsky and Swaminathan, 2001; Özer et al., 2011). The second stream has investigated general information-sharing issues in supply chains—which can be extended to include demand collaboration with asymmetric information (Lee et al., 1997; Gavirneni et al., 1999; Celikbas et al., 1999; Cachon and Fisher, 2000; Chen et al., 2000; Lee et al., 2000; Raghunathan, 2001). The third stream has applied game theory and agency theory to information truthfulness—such as supply-chain incentive mechanisms (Cachon and Lariviere 1999, 2001; Tsay, 1999; Chakravarty and Zhang, 2007). The fourth stream has studied production–ordering decision in a two-stage production system with multiple demand or cost information updates (Gurnani and Tang, 1999; Donohue, 2000; Barnes-Schuster et al., 2002; Georgiadis and Athanasiou, 2014). There are also other research articles worth specific mentioning. For example, Tan et al. (2007 and 2009) focuses on imperfect advance demand information (ADI). They have developed an expression for the expected cost benefits of imperfect ADI for the myopic problem, revealed the conditions under which imperfect ADI is more valuable, and proposed methods to use imperfect ADI in ordering and rationing decisions. Recently, Özer et al. (2011) have also done interesting work regarding behavioural studies and "cheap talk" in information sharing.

In the first stream of research noted above, Aviv (2001) defined collaborative forecasting as the centralization of forecasting information and processes. The forecast-updating process includes a series of updates on demand information that become available to each individual supply chain member. They find that the value of collaborative forecasting is mainly driven by the uniqueness of each supply chain partner's demand information. Aviv (2002) examined collaborative planning in supply chains with three different degrees of collaboration—at the levels of demand, inventory, and policy. Kaminsky and Swaminathan (2001) considered a model to capture forecast evolution and integrate it with capacitated production planning for a product with terminal demand. Zhu and Thonemann (2004) analyzed the effects of sharing information on future demand in a supply chain of a single retailer and multiple identical customers with correlated demands and imperfect information. They found that it was often optimal to share demand information with some, but not all, customers. Williams et al. (2014) prescribed a forecasting approach which simultaneously uses both retailer order history and POS data to predict retailer orders for suppliers. However, in the above studies, the asymmetric nature of the information shared in the collaboration and its impact on supply chain decisions have not been examined, despite the importance of sharing private information in supply chain collaboration as explained in recent works such as Cachon and Lariviere (2001), Cachon and Netissine (2004), and Chakravarty and Zhang (2007).

In the second stream of literature mentioned above, information sharing provides a broad foundation for supply chain collaboration. Lee et al. (1997) examined the so-called 'bullwhip effect' in supply chains, and suggested information sharing and related supply chain programs to reduce this effect. Follow-up studies attempted to quantify the value of information sharing and yielded mixed results. Some demonstrated that information sharing has significant benefits, particularly when demands over time are highly correlated (Lee et al., 2000; Chen et al., 2000; Gavirneni et al., 1999), whereas others showed little value when the entire order history is used in forecasting (Raghunathan, 2001; Aviv, 2002). Based on simulations, Cachon and Fisher (2000) showed insignificant savings from information sharing. They argued that the true value of information sharing might come from the supply chain programs that it enables. Miyaoka and Hausman (2004) found that frequent updates of demand might not necessarily be beneficial to a supply chain—because of the ensuing 'bullwhip effects'. Agrawal et al (2009) showed that the lead time reduction is more beneficial in comparison with the sharing of information in terms of reduction in the bullwhip effect phenomenon.

In the third stream of literature noted above, buyers' intentions, as reflected in demand forecasts, are typically not verifiable or enforceable. Terwiesch et al. (2005) found that, in practice, suppliers penalize buyers for unreliable forecasts by providing lower service levels, whereas buyers penalize suppliers with inflated forecasts (non-truth-telling). The design of incentive compatible contracts has thus become an important research area. Cachon and Lariviere (1999) studied supply chain allocation rules to induce truth telling under asymmetric demand information. Tsay (1999) examined how capacity and purchase commitment through a quantity flexibility contract can facilitate truth telling in supply chain collaboration. Cachon and Lariviere (2001) studied supply contracts featuring a manufacturer using demand forecast information to influence suppliers' decisions on capacity. In a screening problem setting, Burnetas et al. (2007) examined how and how well a supplier could use different forms of quantity discount contract to influence the stock ordering decisions of a retailer with asymmetric demand information. Chakravarty and Zhang (2007) studied the lateral collaboration between two firms in a supply chain with contingent capacity, and found that incentive contracts could improve the system efficiency through closer-to-first-best capacity investment and rule out the possible capacity overinvestment. Kim and Netessine (2013) investigated how information asymmetry and procurement contracting strategies interact to influence the supply chain parties' incentives to collaborate. Yua and Gohb (2014) investigated the twin effects of supply chain visibility and supply chain risk on supply chain performance. The supply chain visibility was linked to the capability of sharing timely and accurate information on exogenous demand, quantity and location of inventory, transport related cost, and other logistics activities throughout an entire supply chain.

The fourth stream of research shares similar timing, and production-ordering decisions to our model. Donohue (2000) focused on wholesale and return-price contracts in coordinating the supply chain with two production modes. Gurnani and Tang (1999) addressed ordering decisions from the perspective of a single retailer without the supply chain effects when there were multiple forecast updates and uncertain cost information. Barnes-Schuster et al. (2002) also examined a buyer–supplier system with two production periods and correlated demands, but focused on how to use options to coordinate such a system. Dettenbach and Thonemann (2014) provided the approaches that are necessary to implement inventory control policies that utilize real time yield information. Their results can also be used to estimate the cost saving that can be achieved by using real time yield information. Georgiadis and Athanasiou (2014) investigated long-term demand-driven capacity planning policies in the reverse channel of closed-loop supply chains (CLSCs) with remanufacturing, under high capacity acquisition cost coupled with uncertainty in actual demand, sales patterns, quality and timing of end-of-use product returns.

This research extends the work on the fourth stream of literature although we also have borrowed ideas from other streams of literature. Our research uses a Newsvendor-like model involving ordering, production and pricing decisions similar to the models used by Donohue (2000), Gurnani and Tang (1999), Eppen and Iyer (1997), and Iyer and Bergen (1997). In our study, a two-stage supply-chain decision model similar to those of Gurnani and Tang (1999) and Donohue (2000) is formulated. In addition, we consider uncertain demand and allowance made for production quantity to increase over time with an uncertain cost. This research extends the work of Gurnani and Tang (1999) by establishing a supply chain model with separate decisions made by supply chain partners regarding information shared under collaboration and production quantities. Unlike the model in Donohue (2000), which considered a price contract with certain cost and no information asymmetry, our incentive mechanism model provides close examination on the impact of the asymmetric information prevalent in supply chain information exchange.

This research contributes to the literature as follows: First, we focus on how asymmetric demand information drives supply chain management decision; in particular, we formulate an incentive mechanism to extract truthful demand information via collaboration, and examine the impact of such information on key supply-chain decisions (such as production quantities). Second, we discuss how the lagging lead-time between uncertain production-cost information and asymmetric demand information influences the timing of production decisions. Third, our incentive-based contract allows information issues to be addressed under supply chain collaboration. In addition, the demand information shared in our model is asymmetric in nature.

3. Demand Collaboration Model

We begin our model setup by introducing the CPFR process between a manufacturer and a retailer. The CPFR framework highlights shared objectives and business plans at strategic level. At operational level, it includes collaborations in: (i) demand-forecasting; (ii) order-forecasting; and (iii) order-execution. In collaborating with respect to *demand forecasting*, parties generate and share demand forecasts on the basis of historical sale information and their particular market conditions. Collaboration at this level allows the supply chain to capture demand information, such as upcoming local promotions, which is not present in the sale history. In collaborating with respect to *order forecasting*, the parties share order-forecasts on the basis of their historical ordering data as well as local costs, production capacity and distribution capacity. Collaboration is needed because ordering decisions are made on the basis of both uncertain demand information and uncertain cost information. Notably, the uncertain demand information is considered as private—only the retailer observes it.

In this research, we study the CPFR process in a supply chain with one manufacturer and one retailer. The retailer purchases a single product from the manufacturer at a price of w and then sells it to the market at a price of p ($p>w$); the retailer incurs an underage unit cost of l if there is unsatisfied demand. On the other hand, the manufacturer incurs an overage cost of h_m if he has any leftover inventory but no underage cost for any unsatisfied retailer order.

Similar to existing literature such as Gal-Or (1991) and Armstrong (1999), we consider the planning cycle which includes three time periods: at time 1, the retailer observes the market and forecasts the demand; she may or may not share the market information with the manufacturer. At time 2, the manufacturer observes the production costs; at time 3, demand is realized, the retailer places order with the manufacturer, contract is executed. In this research, we consider two collaborative mechanisms. In the mechanism characterized as 'Too Little', the manufacturer and the retailer collaborate at time 1 (demand forecast) when only the demand information is available to the retailer; whereas, in the mechanism designated as ‘Too Late’, they collaborate at time 2 (order forecast) when both demand information and cost information are available. Indeed, the ‘Too Little’ mechanism is a limited-information contract that uses the exchanged information earlier to take advantage of lower production cost. The ‘Too Late’ mechanism, however, has the full information about demand and cost, but has to make a late and probably more costly adjustment based on the information. Figure 1 illustrates the CPFR process.

(Insert Figure 1 around here)

We denote t_1 and $\hat{t}_1$ as the observed market demand information and reported demand information by the retailer at time 1 respectively. Note that $\hat{t}_1 = t_1$ represents the situation the retailer tells truth to the manufacturer at time 1. We assume t_1 follows a distribution $f_1(t_1)$ with $t_1 \in [\underline{\alpha}, \overline{\alpha}]$ and $E(t_1) = \mu$. The retailer’s final demand is realized at time 3; we denoted it as t_3 and assume $t_3 = t_1 + \xi$ where ξ is a random disturbance with zero mean and probability density function $f_3(\xi)$, and $t_3 \in [\underline{\theta}, \overline{\theta}]$. Therefore, $f_3(t_3 | t_1) = f_3(t_3 - t_1) = f_3(\xi)$ and $E(t_3 | t_1) = t_1$. It is assumed that both $f_1(t_1)$ and $f_3(\xi)$ fall into the class of distribution functions characterized by non-decreasing hazard rate (NDHR)—such as uniform, normal, negative exponential, logistic, or Gamma distributions (Fudenberg and Tirole, 1991).

We define q_j and c_j for $j = 1, 2$, as the cumulative production quantity and production cost of the manufacturer at time *j*. The manufacturer observes the production cost at time 2 as $c_2 \in \{c_2^L, c_2^H\}$ with the probabilities of $1\text{-}\beta$ and β for c_2^L and c_2^H respectively. Common causes of uncertain production cost include machine downtime, quality and yield issues (Hu et al., 2005; Wang and Gerchak, 1996), raw material price changes (Gurnani & Tang, 1999), uncertain currency exchange rates in a global supply chain (Kogut and Kulatilaka, 1994; Dasu and Li, 1997), labour strikes that could temporarily affect labour availability and production capacity (GM’s cost uncertainty as discussed in McCracken and Hawkins, 2006), oil price hikes, etc. (Spinler and Huchzermeier, 2006; Parlar and Perry, 1996). In this paper, we assume, in accordance with Gurnani and Tang (1999), that $c_2^H > c_1$, $c_2^L < c_1$. Therefore, the marginal production cost at time 2 for any unit above the initial quantity q_1 can be lower than the initial cost c_1. However, $\overline{c}_2 = (1-\beta)c_2^L + \beta c_2^H > c_1$, indicating that expected production cost increases over time.

A menu contract in *available quantity – transfer* form $\{q_2(\hat{t}_1), T(\hat{t}_1)\}$ is used between the manufacturer and the retailer. That is, if the retailer collaborates with the manufacturer by reporting her demand information as $\hat{t}_1$, the manufacturer will make a *cumulative* production quantity q_2 available at time 2. After all production-quantity adjustments are made, the manufacturer compensates the retailer with a transferred payment *T* for the information provided by the retailer. The profit of the manufacturer and the profit of the retailer of a planning cycle are denoted as π^m and π^r respectively. We use "*a*" to denote the *available* production quantity achieved through earlier collaboration— $a = q_2^i(\hat{t}_1)$ (*i*=*H*,*L*) and $a = q_2(\hat{t}_1)$ for the 'Too Late' and 'Too Little' mechanisms respectively. Define *Q* as the actual order quantity of the retailer. The objective function for the retailer at time 3 is then

$$\max_Q \pi^r[Q \mid (t_3, a \mid \hat{t}_1), \hat{t}_1] = \pi_o^r[Q \mid (t_3, a \mid \hat{t}_1)] + T(\hat{t}_1) \tag{1}$$

Subject to: $$\pi_o^r[Q \mid (t_3, a \mid \hat{t}_1)] = \begin{Bmatrix} pt_3 - wQ - h(Q - t_3), & if \ \ Q \geq t_3 \\ (p-w)Q - l(t_3 - Q), & if \ \ Q \leq t_3 \end{Bmatrix} \ \& \ Q \leq a \, . \tag{2}$$

$\pi_o^r[Q \mid (t_3, a \mid \hat{t}_1)]$ is the original profit of the retailer at time 3 without the transferred payment from the manufacturer to the retailer. Naturally, the retailer orders the optimal quantity, $Q^* = Q^*(t_3, a) = \min(t_3, a)$, which leads to $\max_Q \pi^r[Q \mid (t_3, a \mid \hat{t}_1), \hat{t}_1] = \pi^r[Q^*, \hat{t}_1]$ and

$\pi^r[Q^*, \hat{t}_1] = \pi_o^r(Q^*) + T(\hat{t}_1)$, where

$$\pi_o^r(Q^*) = \begin{Bmatrix} (p-w)t_3, & if \ \ a \geq t_3 \\ (p-w)a - l(t_3 - a), & if \ \ a \leq t_3 \end{Bmatrix}. \tag{3}$$

Note that $\pi_o^r(Q^*)$ is piece-wise linear, simply-concave and non-decreasing function with respect to *a*, whether $a = q_2^i(\hat{t}_1)$ or $a = q_2(\hat{t}_1)$ for given $\hat{t}$. This nature of $\pi_o^r(Q^*)$ also explains why without a proper incentive contract, the retailer always has motivation to keep the demand information private in order to inflate her purchase intention and gain assurance of supply from the manufacturer. Since the manufacturer's profit function π^m is in quite different formats in the two collaboration mechanisms, we will introduce them in the following two subsections separately.

3.1 The 'Too Little' Mechanism

The 'Too Little' mechanism works as the following:

- At time 1, the retailer observes her market condition information t_1 (mean demand); the manufacturer offers a menu $\{q_2(\hat{t}_1), T(\hat{t}_1)\}$ without observing the production cost. The retailer either accepts or rejects the manufacturer's offer. If the retailer accepts the offer, the retailer's demand information is reported to the manufacturer as $\hat{t}_1$. Then the manufacturer determines his initial production quantity $q_1(\hat{t}_1)$ at a cost of c_1 per unit that is known to both parties. If the retailer rejects the contract, she gets the (normalized) zero profit.

- At time 2, the manufacturer observes the production cost c_2 and can choose to increase his production quantity at the cost of c_2 per unit.
- At time 3, as the market demand is realized, the retailer places an actual order Q with the manufacturer. The contract is executed, and profits are realized to both parties.

In this mechanism, the manufacturer chooses the contract terms $\{q_2(t_1), T(t_1)\}$ and collaborates with the retailer at time 1 to maximize his expected profit of π^m, even if the second-period production cost information c_2 is not yet known. The objective function for the manufacturer is then

$$\max_{\{q_1, q_2, T\}} E_{t_3, c_2} \pi^m \{q_2(t_1), T(t_1)\} \quad (4)$$

Subject to:

$$E_{t_3} \pi^r (Q^*(t_3, q_2(t_1)), t_1 \mid t_1) \geq E_{t_3} \pi^r (Q^*(t_3, q_2(\hat{t}_1)), \hat{t}_1 \mid t_1) \quad (5)$$

$$E_{t_3} \pi^r (Q^*(t_3, q_2(t_1)), t_1 \mid t_1) \geq 0 \quad (6)$$

$$q_2(t_1) - q_1(t_1) \geq 0. \quad (7)$$

Note that $\pi^m(q_2(t_1), T(t_1) \mid t_1) = \pi_o^m(q_2(t_1) \mid t_1) - T(t_1)$, and

$$\pi_o^m(q_2(t_1) \mid t_1) = w \min(t_3, q_2(t_1)) - c_1 q_1 - c_2 \left[q_2(t_1) - q_1 \right] - h_m(q_2(t_1) - \min(t_3, q_2(t_1)))$$
$$= (w + h_m) \min(t_3, q_2(t_1)) - (c_1 + h_m) q_2(t_1) - (c_2 - c_1) \left[q_2(t_1) - q_1 \right]. \quad (8)$$

Here constraint (5) is the *Incentive Compatibility* (*IC*) constraint, which ensures the retailer's truth-telling behavior. This constraint is important because it establishes trust-based collaboration between supply chain partners and maintains integrity of information used in production and distribution planning (Cachon and Lariviere, 1999; Bolton and Dewatripont, 2005). Mechanisms that satisfy this constraint are so-called "implementable" mechanisms. Constraint (6) is the retailer's *Individual Rationality* (*IR*) constraint, which guarantees the retailer's participation in the collaboration. The *IR* constraint is normalized to zero, which means that the retailer needs a non-negative profit to agree to the mechanism. Constraint (7) assures that the production quantity is adjustable only upwards, given that the initial production resources have already been tied up at time 1.

3.2 The 'Too Late' Mechanism

The "Too Late" mechanism works as follows:

- At time 1, the retailer and manufacturer do not engage in collaboration. The retailer observes her market demand information t_1. The manufacturer determines his initial production quantity q_1.

- At time 2, the manufacturer observes his cost, $c_2 \in \{c_2^L, c_2^H\}$. The manufacturer then offers an incentive contract $\{q_2^L(t_1), T^L(t_1)\}$ or $\{q_2^H(t_1), T^H(t_1)\}$ to the retailer according to the observed cost. If the retailer agrees with the contract, she will collaborate by sharing information $\hat{t}_1$; and the manufacturer may need to adjust his production quantity to $q_2^i(\hat{t}_1)$ where $i = H, L$. If the retailer rejects the contract, she obtains zero profit in return.
- At time 3, as the market demand is realized, the retailer places an actual order Q with the manufacturer. The contract is executed and profits are realized to both parties.

Under this mechanism, the collaboration occurs at time 2 when the production cost information $c_2 \in \{c_2^L, c_2^H\}$ is realized. Once the retailer shares demand information, the manufacturer has the information on both demand and cost. The additional information improves the manufacturer's planning efficiency; however, waiting for such information to be revealed delays the production process. The manufacturer in this case begins production at time 1 since producing the full contract quantity at a later time might prove too costly. In other words, a manufacturer adopting the 'Too Late' mechanism might lose the opportunity to take full advantage of the lower production cost at time 1. The manufacturer's problem is then:

$$\max_{\{q_1\}} E_{t_1, c_2, t_3} \pi^m = \beta \Pi_m^L(q_1) + (1-\beta)\Pi_m^H(q_1), \tag{9}$$

where $\Pi_m^i(q_1) = \max_{\{q_2^i, T^i\}} E_{t_1, t_3} \pi^m(q_2^i(t_1), T^i(t_1) \big| t_1, c_2^i)$, $i = H, L$.

Subject to

$$E_{t_3} \pi^r(Q^*(t_3, q_2^i(t_1)), t_1 \mid t_1) \geq E_{t_3} \pi^r(Q^*(t_3, q_2^i(\hat{t}_1)), \hat{t}_1 \mid t_1), \ i = H, L. \tag{10}$$

$$E_{t_3} \pi^r(Q^*(t_3, q_2^i(t_1)), t_1 \mid t_1) \geq 0, \ i = H, L. \tag{11}$$

$$q_2^i(t_1) - q_1 \geq 0, \ i = H, L. \tag{12}$$

Similarly to the 'Too Little' mechanism, the *IC* constraint in (10) in the 'Too Late' mechanism guarantees the retailer to tell truth at time 2 when the collaboration takes place. The *IR* constraint in (11) ensures the retailer's participation with a non-negative profit. Note that although the collaboration is implemented at time 2, the manufacturer could choose to produce a certain amount at time 1, and then adjust to the optimal production level $q_2^i(\hat{t}_1)$ $i = H, L$ determined by the contract at time 2.

4. Model Development and Discussion

Previous studies on demand collaboration tended to assume that forecasts of demand are verifiable public information, which is freely shared (referred to as 'Full Information'). Our model focuses on the situation in which demand information is private in nature (referred to as 'Asymmetric Information' here). Thus, a comparison between the optimal solutions in the 'Full Information' and

'Asymmetric Information' situations in both "Too Little" and "Too Late" mechanisms under the *available quantity-transfer* contract form would be interesting and revealing to those companies considering supply chain collaboration. Note that the use of 'Full Information' and 'Asymmetric Information' does not imply any structural differences in the supply chain. It merely reflects the fact that asymmetric information often distorts supply chain decisions from their optimal forms. All proofs in the paper are provided in the online Technical Appendix, which can be downloaded at the end of the paper.

4.1. The 'Full Information' Solutions

Lemma 1. *In the 'Full Information' situation, under the 'Too Little' mechanism, the manufacturer should produce all contract quantity at time 1, and makes no additional production at time 2:*

$$\tilde{q}_1(t_1) = \tilde{q}_2(t_1) = \{q_2 \mid F_3(q_2 \mid t_1) = 1 - (h_m + c_1)/(p + l + h_m)\}\ .\blacksquare$$

Note that the production quantities at time 1 and time 2 only depend on the final demand distribution, and the retailer's and the manufacturer's costs parameters. In the 'Too Little' mechanism, because neither party has prior information (at time 1) about the production cost at time 2, the contract total production quantity at time 2 reflects the manufacturer's own expected cost. In other words, at time 1, the manufacturer produces a quantity that is equivalent to the reported demand level from the retailer *plus* a 'safety' stock amount (based on his time 1 production cost). Even though the manufacturer has the option to change the production quantity at time 2, he has to abide by the agreement to provide the total quantity because the contract is signed at time 1. Realizing that the expected production cost at time 2 will be greater than the production cost at time 1, the manufacturer would rather produce the total contracted quantity at time 1, and makes no production adjustment at time 2.

Lemma 2. *In the 'Full Information' situation, under the 'Too Late' mechanism,*

(1) *if* $t_1 < \tilde{t}_1^i(\tilde{q}_1)$, *the manufacturer produces all contract quantity at time 1 and makes no additional production at time 2:* $\tilde{q}_2^i(t_1) = \tilde{q}_1$, $i = H, L$;

(2) *if* $t_1 > \tilde{t}_1^i(\tilde{q}_1)$, *the manufacturer should make additional production at time 2:*

$$\tilde{q}_2^i(t_1) = \{q_2^i \mid F_3(q_2^i \mid t_1) = 1 - (h_m + c_2^i)/(p + l + h_m)\} > \tilde{q}_1\ ,\ i = H, L\ .\blacksquare$$

In the 'Too Late' mechanism, collaboration takes place at time 2 while the production of quantity q_1 starts at time 1. In anticipation of better demand information available at time 2, the manufacturer chooses an optimal production quantity at time 1, $\tilde{q}_1$. For given $\tilde{q}_1$, we define $\tilde{t}_1^i(\tilde{q}_1)$ as the particular t_1 value at which the quantity $\tilde{q}_1$ is optimal because $(p + l + h_m)\left[1 - F_3(\tilde{q}_1 \mid \tilde{t}_1^i)\right] - h_m - c_2^i = 0$. Therefore, the manufacturer considers $\tilde{t}_1^i(\tilde{q}_1)$ as the threshold value for given $\tilde{q}_1$. If the observed demand information is beyond the threshold value, $t_1 > \tilde{t}_1^i(\tilde{q}_1)$, the manufacturer produces extra units at time 2 and agrees to supply the retailer a total available quantity, $\tilde{q}_2^i$, which is higher than his initial production $\tilde{q}_1$ for both cost types, c_2^L and c_2^H. However, if the observed demand is below the threshold value, $t_1 < \tilde{t}_1^i(\tilde{q}_1)$, there will be no production adjustment at time 2 (similar to the 'Too Little' case). It is obvious that the threshold value $\tilde{t}_1^i(\tilde{q}_1)$ increases with $\tilde{q}_1$ —implying a larger t_1 range of no-production-adjustment at time 2 for a higher $\tilde{q}_1$. In contrast, for a given $\tilde{q}_1$, the threshold value $\tilde{t}_1^i(\tilde{q}_1)$ also increases with respect to the time 2 production cost c_2^i.

Note that our results for the 'Full Information' situation, especially in the 'Too Late' mechanism, are consistent with the results of Gurnani and Tang (1999), particularly in the special case with perfect information. In Gurnani and Tang (1999), their results call for ordering (producing) at time 1, and then ordering more at time 2 if the new (perfect) demand information is above a certain threshold value.

4.2 The 'Asymmetric Information' Solutions

In the 'Asymmetric Information' situation, to solve the *available quantity-transfer* contract problems under both 'Too Little' and 'Too Late' mechanisms, we first derive the conditions under which the 'Too Little' and 'Too Late' mechanisms are implementable from the retailer *IC* constraints. The manufacturer's optimal decisions regarding production quantities over time are then generated.

Lemma 3. *The 'Too Little' mechanism is implementable if $q_2(t_1)$ is increasing with respective to t_1; the 'Too Late' mechanism is implementable if $q_2^i(t_1)$ is increasing with respective to t_1, $i = H, L$.* ■

This lemma indicates that, for the retailer to reveal her demand information truthfully, the manufacturer needs to structure the total available quantity and the transfer appropriately. Specifically, we derive the following proposition from Lemma 3 to discuss the relationship between the total production quantity and the transfer value.

Proposition 1. *To induce truth-telling, in the situation that the demand value observed by the retailer t_1 is low, the manufacturer should determine a lower product quantity but provide the retailer a higher transfer value than those in the situation that the demand value observed by the retailer t_1 is high.* ■

Notably, transfer should be higher in the low-demand case to reduce the retailer's needs to exaggerate in the future. Without a proper transfer payment, the retailer's propensity to over-claim is much higher in the low observed-demand situation than in the high observed-demand situation. A transfer that is decreasing with demand claim, but matching with the increase in production quantity can counteract the retailer's propensity to exaggerate and establish a 'truth-telling balance'.

Proposition 2. *In the 'Asymmetric Information' situation, under the 'Too Little' mechanism, the optimal quantities at time 1 and time 2,* q_1^* *and* q_2^* *are equal (* $q_1^* = q_2^*$*) and can be obtained by solving*

$$(p+l+h_m)\left[1-F_3\,(q_2^*\,|\,t_1\,)\right] = h_m + c_1 + \Delta(q_2^*\big|t_1\,),$$

where $\Delta(q_2\left|t_1\right.) = (p-w+l)\,f_3(q_2\left|t_1\right.)(1-F_1(t_1))/\,f_1(t_1\,) > 0$.■

This proposition shows that in the 'Asymmetric Information' situation, the optimal production quantity at time 2 depends not only on the cost parameters as in the 'Full Information' solutions, but also on the retailer's demand information distribution $f_1(t_1\,)$. To provide the retailer with an incentive to share her demand information truthfully at time 1, the manufacturer needs to take into account the retailer's cost and profit potential when determining his manufacturing production quantity at time 2. In particular, according to Proposition 1, the manufacturer needs to structure his transfer value with regard to the final quantity available to the retailer to elicit the truthful demand information from the retailer. The transfer value scheduled under the 'Asymmetric Information' situation, in turn, distorts the manufacturer's profit potential under the 'Full Information' situation.

Note that the manufacturer's decision with respect to the production quantity at time 1, q_1^*, is simply the final product quantity available after time 2 since no additional production is needed at time 2. This is because the manufacturer, while making a decision with t_1 at time 1, does not have the cost information at time 2. Because the cost is expected to increase, the manufacturer should not adjust at time 2.

Proposition 3. *In the 'Asymmetric Information' situation, under the 'Too Late' mechanism,*

(1) if $t_1 < t_1^i(\hat{q}_1^*)$, $q_2^i(t_1) = \hat{q}_1^*$, $i = H, L$;

(2) if $t_1 > t_1^i(\hat{q}_1^*)$, $q_2^i(t_1) > \hat{q}_1^*$, $i = H, L$,

where $q_2^i(t_1)$ *can be obtained by solving* $(p+l+h_m)\left[1-F_3\,(q_2^i\,|\,t_1\,)\right] = h_m + c_2^i + \Delta(q_2^i\big|t_1\,)$.■

In the above proposition, we further denote the optimal production quantity at time 1 as $\hat{q}_1^*$.

Similar to the 'Full Information' situation, $t_1^i(\hat{q}_1^*)$ is used to denote the threshold value of t_1 for which the pre-determined quantity $\hat{q}_1^*$ is most suitable so that

$$(p+l+h_m)\left[1-F_3\,(\hat{q}_1^*\,|\,t_1\,)\right] = h_m + c_2^i + \Delta(\hat{q}_1^*\big|t_1\,).$$

The 'Asymmetric Information' threshold value $t_1^i(\hat{q}_1^*)$ is different from that of the 'Full Information' situation, $\tilde{t}_1^i(\tilde{q}_1)$, even for the same production quantity at time 1 —$t_1^i(q_1) > \tilde{t}_1^i(q_1)$. It should be noted that $t_1^i(\hat{q}_1^*)$ still increases with $\hat{q}_1^*$ and c_2^i.

Proposition 3 shows how the contract is segmented based on both demand types and cost types. In the 'Too Late' mechanism, collaboration is implemented at time 2 when the production-cost information is revealed, thus the optimal choices regarding quantities are dependent on the type of time 2 production cost $c_2^i, i = H, L$. When the demand information observed by the retailer and communicated to the manufacturer via collaboration at time 2 is less than the threshold level $t_1^i(\hat{q}_1^*)$ (depending on the cost type c_2^i), the manufacturer produces no additional quantity beyond what he begins at time 1. In fact, in this situation, the observed demand information is so low that no change in production at time 2 is justified. However, when the observed demand information at time 1 exceeds $t_1^i(\hat{q}_1^*)$, the manufacturer chooses a total production quantity at time 2 that is greater than the initial production quantity at time 1—based on the realized production cost at time 2 and the retailer's claimed demand information. Because the initial production quantity is determined in expectation of demand and production cost, when the observed demand at time 2 is large enough, for a given 'High' or 'Low' cost, the manufacturer would rather increase his production quantity.

4.3 The Impact of Information Asymmetry on Supply Chain Collaboration Decisions

By comparing the solutions of the two mechanisms under the two different situations, 'Full Information' situation and 'Asymmetric Information' situation, we can find the impact of information asymmetry on supply-chain collaboration decisions.

Proposition 4. *For the 'Too Little' mechanism, the production quantity in the 'Full Information' situation is always higher than that in the 'Asymmetric Information' situation:*

$\tilde{q}_1(\bullet) = \tilde{q}_2(\bullet) > q_1^*(\bullet) = q_2^*(\bullet)$. ■

(Insert Figure 2 around here)

(Note that Figures 2-4 are based on the same parameter values used in Figures 5-6 as the numerical examples of this paper. The specific values are listed in the first paragraph of section 5.)

The result in Proposition 4 indicates that demand information asymmetry plays an important role in determining the degree of distortion in production quantities in the 'Too Little' mechanism. In the situation of 'Asymmetric Information', since the manufacturer needs to compensate the retailer for sharing her demand information (using transfer out of the manufacturer's own profit), he has to carefully evaluate the level of the information asymmetry. As we have proved in the Appendix, higher level of the information asymmetry will result in larger difference between the optimal production quantities under the 'Full Information' situation and under the 'Asymmetric Information' situation.

Therefore, the manufacturer needs to provide higher transfer value (because the retailer's propensity to exaggerate in absence of such a transfer tends to be high in low observed–demand situation) while he takes advantage of such low-demand information to produce a total quantity much less than what he would have had to produce if the demand information were public. In contrast, when a high demand value is observed by the retailer, and the manufacturer finds it beneficial to reduce his transfer substantially while producing a total quantity closer to, although still less than, what he would have done if the demand information were public.

***Proposition 5**. For the 'Too Late' mechanism, when $t_1 > t_1^i(\hat{q}_1^*)$ and $t_1 > \tilde{t}_1^i(\tilde{q}_1)$, the total production quantity in the 'Full Information' situation is always higher than that in the 'Asymmetric Information' situation.* ■

(Insert Figure 3 around here)

This proposition indicates that collaboration at a late stage provides the manufacturer more opportunities to 'fine-tune' his total production quantity—according to both the specific cost type observed and the demand information revealed. Under the 'Asymmetric Information' situation (compared with the 'Full Information' situation), for a pre-determined q_1, there is a wider range of low demand value for which the manufacturer is not willing to produce additional amount at time 2. This is supported by the fact that $t_1^i(q_1) > \tilde{t}_1^i(q_1)$. In other words, the threshold value for a given q_1 is higher in the 'Asymmetric Information' situation than in the 'Full Information' situation. This phenomenon suggests that, in the 'Asymmetric Information' situation, in order to elicit truthful private demand information from the retailer, the manufacturer has to sacrifice more planning efficiency (compared with the 'Full Information') when the reported demand is low. However, once the reported demand is above both threshold values, the 'Asymmetric Information' contract provides a more responsive total production quantity.

On the other hand, because $t_1^L(q_1) < t_1^H(q_1)$, the manufacturer is willing to adjust his total production quantity within a wider range when observing a low production cost. In the 'Asymmetric Information' situation, the manufacturer is more willing to use transfer to compensate the retailer for her truthful sharing of demand information under the Low-cost type than under the High-cost type. This characteristic is especially salient when the retailer's observed demand is low. Furthermore, for either cost type, the transfer value is more sensitive to the total production quantity in the low-demand range than in the high-demand range. However, if this sensitivity is high enough for the initial production quantity, the initial production quantity $\hat{q}_1^*$ in the 'Asymmetric Information' situation is lower than that in the 'Full Information' situation, as indicated in the following result:

***Corollary 1**: For the 'Too Late' mechanism, $\tilde{q}_1 > \hat{q}_1^*$.* ■

This result shows that the manufacturer is more conservative in the 'Asymmetric Information' than 'Full Information' in producing the initial quantity due to the transfer payment required to induce the truthful information under the 'Too Late' mechanism. Thus, the initial production quantity in the 'Full Information' situation is higher. As explained above, the positive hazard rate difference highlights the need for a sensitive transfer in the 'Asymmetric Information' situation to induce truth telling of the retailer. A large and dominant range of such a sensitive transfer in the 'Asymmetric Information' situation distorts the manufacturer's profit potential and makes him less willing to produce more products initially (compared with in the 'Full Information' situation).

Proposition 6*: The total production quantity available for retailer orders at time 2 varies between the two mechanisms. Specifically,*

(1) $q_2^L > q_2^* > q_2^H$ *for* $t_1 \geq t_1^H(\hat{q}_1^*) > t_1^L(\hat{q}_1^*)$ *;*

(2) $q_2^L > q_2^*$ *and* $q_2^L > q_2^H = \hat{q}_1^*$*, for* $t_1^H(\hat{q}_1^*) > t_1 \geq t_1^L(\hat{q}_1^*)$ *;*

(3) $q_2^L = q_2^H > q_2^*$ *for* $t_1^H(\hat{q}_1^*) > t_1^L(\hat{q}_1^*) > t_1$. ■

This proposition indicates that the total production quantity at time 2 under the 'Too Late' mechanism when the type of cost is Low, q_2^L, is always greater than the quantity under the 'Too Little' mechanism, q_2^*. However, the total production quantity under the 'Too Late' mechanism when the type of cost is High, q_2^H, is greater than the quantity under the 'Too Little' mechanism, q_2^*, only if the demand information is sufficiently low, for example, $t_1 < t_1^L$. When type of cost is 'High' and the demand is sufficiently high $t_1 > t_1^H(\hat{q}_1^*)$, the total quantity under the 'Too Little' mechanism, is greater than the quantity under the 'Too Late' mechanism, $q_2^* > q_2^H$. The reason is the inflexibility of production under the 'Too Little' mechanism—the manufacturer maintains the production quantity decided at time 1 without adjustment at time 2 (because of the earlier contract promise to the retailer). This is because the manufacturer has to make a production decision without knowing the future type of production cost, which is expected to be higher than the production cost at time 1.

More generally, the 'Too Little' mechanism allows the manufacturer to be appropriately responsive to the retailer's demand information when producing his initial production quantity. However, the 'Too Little's' mechanism, in which the manufacturer promises a total quantity to the retailer before knowing the later cost type, discourages the manufacturer from adjusting his total production quantity at time 2. Thus, the manufacturer's initial quantity can be responsive to the complete range of demand information, but the contract inflexibility is reflected in exclusion of more updated cost information. In contrast, the 'Too Late' mechanism allows the manufacturer to wait for both the cost and demand information to be available before committing to the retailer, thus providing the manufacturer with more leverage. However, the lack of demand and cost information at time 1 puts the manufacturer at disadvantage—in expectation of both cost types and both demand types, the manufacturer has to produce an initial quantity that might become inefficient if the demand level reported by the retailer turns out to be lower than a threshold value. Thus, relative to the 'Too Little' mechanism, the 'Too Late' mechanism might conceivably provide value to the manufacturer if the Low-cost type occurs with a good chance and if the demand is above a certain threshold value.

(Insert Figure 4 around here)

Proposition 7*. When* $t_1 > \max[t_1^i(\hat{q}_1^*), \tilde{t}_1^i(\tilde{q}_1)]$*, and* $f_3^{'}(q_2 \,|\, t_1) \leq 0$ for $q_2 > q_2^H(\bullet)$,

$$\left[F_3\,(q_2^*(\bullet)\,|\,t_1) - F_3\,(q_2^i(\bullet)\,|\,t_1)\right] \leq \left[F_3\,(\tilde{q}_2(\bullet)\,|\,t_1) - F_3\,(\tilde{q}_2^i(\bullet)\,|\,t_1)\right].\blacksquare$$

This proposition suggests that the percentile difference of the final production between 'Too Little' and 'Too Late' is smaller in the 'Asymmetric Information' situation than in the 'Full Information' situation when t_1 is sufficiently high. In other words, when the observed demand information is sufficiently high, the two mechanisms become closer under the 'Asymmetric Information' than under the 'Full Information' situation. The existence of asymmetric information and the necessary incentives for truthfully sharing of such information have a strong impact on the production plans—once the additional transfer payment is included to allow effective incorporation of the information. The presence of such transfer payment in the 'Asymmetric Information' situation actually decreases the difference in production quantity between the two mechanisms, and actually diminishes the manufacturer's interest in producing cost-sensitive quantities.

The condition $f_3^{'}(q_2 \,|\, t_1) \leq 0$ for $q_2 > q_2^H(\bullet)$ indicates that the optimal production quantity in each contract happens on the flat or downward-sloping side of the probability density function, a common situation for distributions such as normal distribution or beta distribution with appropriate cost parameters. This happens because $q_2 > q_2^H(\bullet)$ usually provides some safety stock beyond the expected demand t_1. For uniform distribution, $f_3^{'}(q_2 \,|\, t_1) = 0$, and thus the percentile difference in the final production quantities between 'Too Little' and 'Too Late' in the 'Asymmetric Information' situation is the same as that in the 'Full Information' situation. In summary, we have the following observations for the *available quantity–transfer* contract.

- A comparison of the 'Full Information' and 'Asymmetric Information' solutions demonstrates that information asymmetry and the timing of information exchanges have a significant impact on the manufacturer's production decisions. The extent of such impact is associated with the extent to which the retailer's truth-telling behavior depends on the nature of the demand distributions over time (final market demand distribution $f_3\,(t_3\,|\,t_1)$ and demand information distribution $f_1\,(t_1)$ respectively).

- A comparison of the production quantities under the two mechanisms shows that the responsiveness of production quantity decision differs according to when and what information is available. The timing of collaboration has a significant impact on how production decisions are made in the planning process.
- Production decisions can be used to motivate demand collaboration, especially when the demand is in the relative high range. Such decisions are effective because of the demand information asymmetry and the transfer payment involved. Additional monetary compensation does sometimes reduce distortions of the production plans. Production decisions are adjusted only on exceptions—when demand information exceeds certain predefined levels. Information asymmetry reduces the effect of timing on production decisions. In other words, in order to incorporate the asymmetric information under demand collaboration, the manufacturer expects a reduced impact of his choice of collaboration and production timing on his production quantities.

5. Supply Chain Performance: A numeric Example

In this section, we adopt Uniform distribution to develop optimal supply chain profits under both the 'Too Little' and the 'Too Late' mechanisms. The parameters used in our numerical example are w = 45; h_m = 15; l = 50; c_1 = 20; c_2^L = 17; c_2^H = 25; β = 0.51; p = 80; μ = 200; α = 50; θ = 80, e.g. $[\underline{\alpha},\overline{\alpha}]=[\mu-\alpha,\mu+\alpha]=[150,250]$ and $[\underline{\theta},\overline{\theta}]=[t_1-80,t_1+80]$.

(Insert Figure 5 around here)

Given the above parameters, Figure 5 shows how the supply chain profit changes with the market demand condition (t_1) under both collaboration mechanisms. In particular, Figure 5 indicates that the 'Too Little' mechanism has a higher profit than the 'Too Late' mechanism once the mean demand t_1 is above certain level. When the mean demand t_1 is low, the manufacturer should produce more quantity under the 'Too Late' mechanism than under the 'Too Little' mechanism ($\hat{q}_1^* > q_1^*$). The optimal quantity prepared early under the 'Too Late' mechanism allows the supply chain to avoid the potentially large amount of lost sale and transfer payment to elicit retailer's truth-telling, even though the manufacturer has to produce more and thus incur higher cost initially. The main trade-off in the 'Too Late' mechanism is the trade-off between the lower lost sale and transfer payment, and the higher initial production cost resulting from the larger quantity $\hat{q}_1^*$. However, as the mean demand t_1 increases to above a certain level, the manufacturer needs to further adjust his production quantity under the 'Too Late' mechanism in response to mean demand t_1, to the extent that the increase in the production cost dominates the benefits, leading to a higher cost under the 'Too Late' mechanism than that under the 'Too Little' mechanism.

(Insert Figure 6 around here)

Figure 6 shows how the expected supply chain profit changes with the probability of high cost, β. Note that $\underline{\beta} = (c_1 - c_2^L)/(c_2^H - c_2^L)$ in Figure 6 represents the lower bound of β, such that $\overline{c}_2 = (1-\beta)c_2^L + \beta c_2^H > c_1$. Figure 6 illustrates that (1) under the 'Too Little' mechanism, the total supply chain profit does not change with β; (2) under the 'Too Late' mechanism, the total supply chain profit decreases with β. It is interesting to notice that when β is significantly low (the high cost is much unlikely to happen), the supply chain profit under the 'Too Late' mechanism outperforms the supply chain profit under the 'Too Little' mechanism. This is because the 'Too Little' mechanism is more rigid when β is smaller and does not allow adjustment at time 2. On the other hand, as β gets larger (high cost becomes more likely to happen), the benefit of being able to adjust production quantity at a later time diminishes against the production cost committed early under the 'Too Little' mechanism.

In conclusion, our numeric analysis clearly indicates that (1) supply chain profitability under the two mechanisms changes with different market and production information; (2) a strong market signal and/or a more likely high future cost discourages the implementation of the 'Too Late' mechanism; (3) potential increase in production cost makes the 'Too Late' mechanism much less attractive compared with the 'Too Little' mechanism.

6. Discussion and Conclusions

This study has established a supply-chain model, based on CPFR, to investigate two alternative collaboration mechanisms under conditions of asymmetric information. The two alternative collaboration mechanisms are: (i) collaborating early with limited information; and (ii) collaborating late with more information but potentially higher costs. These two supply-chain incentive mechanisms incorporate the asymmetric nature of the information exchanged in collaboration. In this research, we focus on the production quantity decisions made by the supply chain in response to the asymmetric information. This approach captures the behavioural aspects of collaboration management. The timing of information realization (and its utilization) has been studied in terms of its cost implications and its effectiveness in ensuring truthful information sharing in collaboration.

We find that both the nature of the asymmetric information and the timing of the collaboration have significant effects on supply chain decisions. Specifically, (1) early collaboration (as illustrated in the 'Too Little' mechanism) leads to a stable production schedule without a later adjustment when more information becomes available; whereas late collaboration (as illustrated in the 'Too Late' mechanism) allows a flexible production adjustment when the observed demand signal is sufficiently high to justify the cost increase. (2) Under the 'Too Little' mechanism, the supply chain will produce less under asymmetric information if the demand distributions allow the collaboration mechanism to induce truthful information sharing through a monetary compensation. This usually happens when the retailer's observed-demand is relatively low. (3) Under the 'Too Late' mechanism, securing truthful demand information from the retailer leads to a smaller production adjustment when a monetary transfer is more effective than production quantity in capturing the information; a larger adjustment in production quantity will be needed when quantity is more effective under certain demand characteristics (usually the relatively high demand range). (4) The total production quantities under the two mechanisms differ according to the initial demand observation—a sufficiently small observed-demand at time 1 leads to a 'Too Little' initial production quantity that is smaller than the quantity under the 'Too Late' mechanism regardless of the cost type at time 2. (5) The existence of asymmetric information reduces the differences between the final production quantities under the two mechanisms, when the observed-demand is sufficiently high so that production quantities need to be adjusted.

With regard to supply chain performance, numerical study reveals that 'Too Little' or 'Too Late' mechanism does not always dominate one another under the *available quantity-transfer* contracts. However, 'Too Little' mechanism tends to be more profitable when the mean of the demand information is high, or when the probability of High cost type is high. The 'Too Late' would be preferred when the opposite condition is true.

In summary, this research contributes to the literature on supply chain collaboration by providing insights into how the timing of collaboration facilitates supply chain production decisions when the information exchanged is asymmetric. The study has shown that both the 'Too Little' and the 'Too Late' mechanisms are sensitive to the asymmetric nature of the information. More importantly, in the relatively low demand range, the presence of asymmetric information might actually cause the supply chain decisions to be more stable in the 'Too Late' mechanism than in the 'Too Little' mechanism. This result has significant implications for supply chain managers and provides support to exception-based control mechanisms suggested by CPFR. Although the purpose of supply chain collaboration is to extract as much information as possible to improve supply chain planning and management, a well-designed collaboration solution does not necessarily lead to more volatile requirements of production capacity. Whereas a less flexible production schedule inevitably affects costs elsewhere (for example, in distribution, transportation, and inventories), it can also serve as an incentive instrument to protect the integrity of the information-sharing process. Therefore, the expectation of that collaboration should result in a more responsive supply chain should be mitigated, in some cases, by the need to safeguard the truthfulness of the information and the stability of lower cost production.

Supply chain managers should also note that the timing of the collaboration could be quite significant—depending on the nature of the information being shared and utilized in the planning process. Although the stylized nature of this study might mean that this result cannot be directly used to build supply chain collaboration solutions, the implications of the finding might be helpful in the design of better collaboration processes. Furthermore, other forms of contracting can be applied to customize collaboration and to increase the responsiveness and flexibility of supply chain decisions.

Supply-chain collaboration is a ‘two-way street’ that requires a long-term perspective and trust-based relationships among supply-chain partners. We have shown that, by providing incentives (in production quantities and monetary compensation), downstream supply chain behavior can be controlled. It could be argued that upstream behavior can cause similar problems, if not more so, because upstream partner have more opportunities to manipulate information. A direct extension of this research would therefore be to consider a situation in which the manufacturer also has private information. Being an informed principal, the manufacturer then would be able to take advantage of his signaling capability to neutralize the privately informed retailer’s position. Numerous industry reports have indicated such complicated situations hinder further implementation of CPFR. Extending our current research into this area should provide a more comprehensive understanding of supply chain collaboration.

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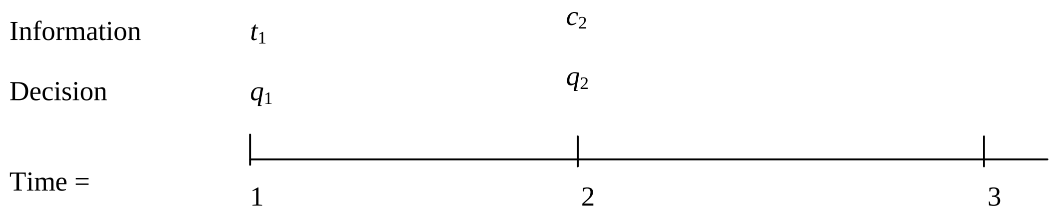

Figure 1. Information and Event Sequence under “Too Little” and “Too Late”

“Too Little”: collaboration takes place at Time = 1 and the manufacturer arranges for production, q_1, without knowing c_2.

“Too Late”: collaboration takes place at Time = 2 and the manufacturer arranges for production, q_1, at Time = 1 without knowing t_1 and c_2.

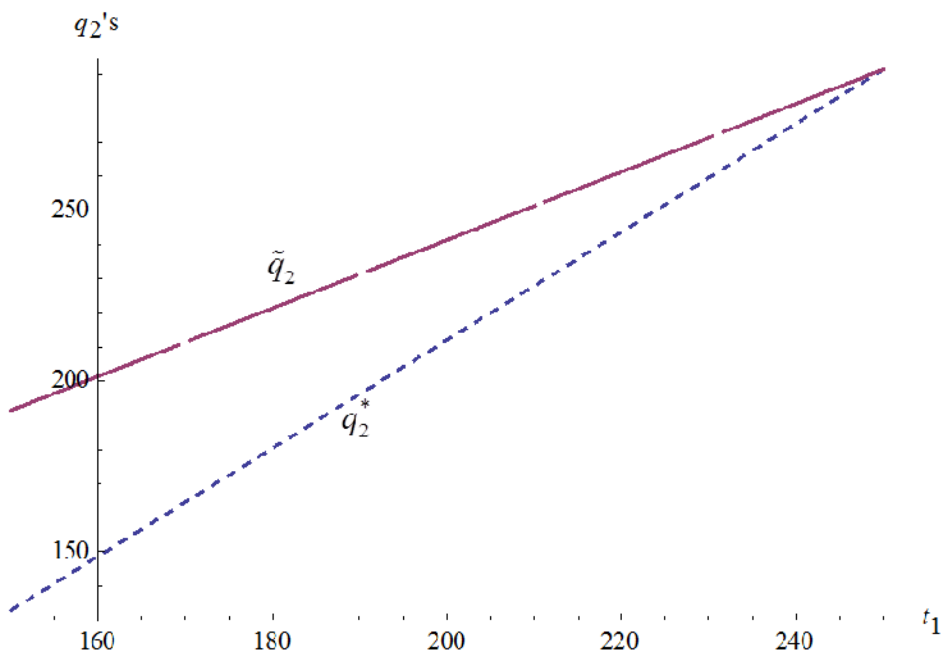

Figure 2: Illustrated Difference between Full Information (First Best) and Asymmetric Information (Second Best) in the Too Little Case

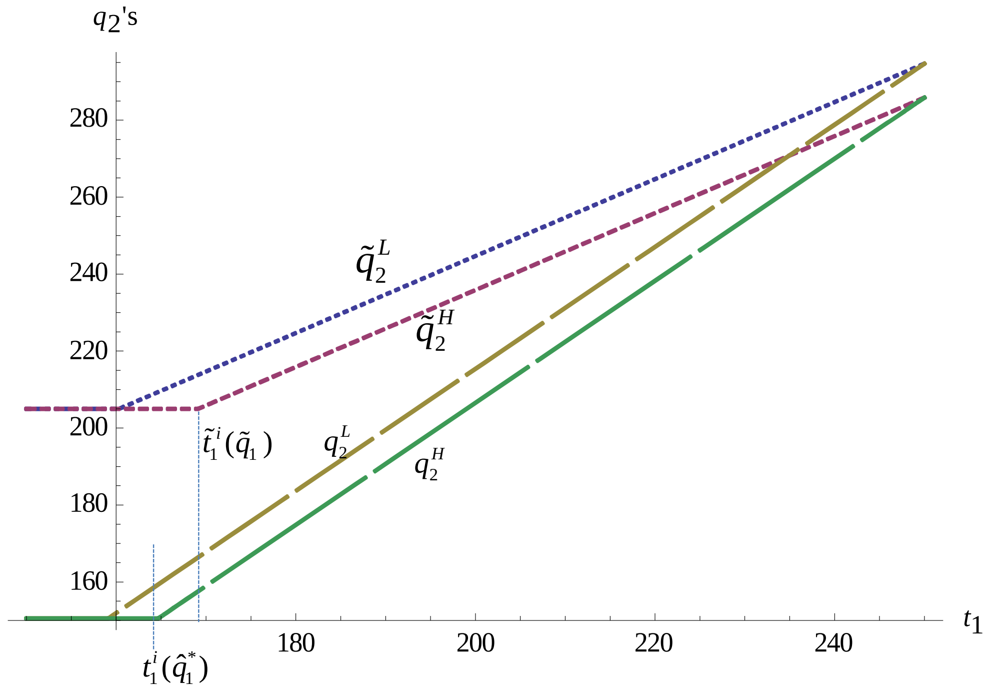

Figure 3: Illustrated Difference between 'Full Information' and 'Asymmetric Information' in the 'Too Late' Mechanism

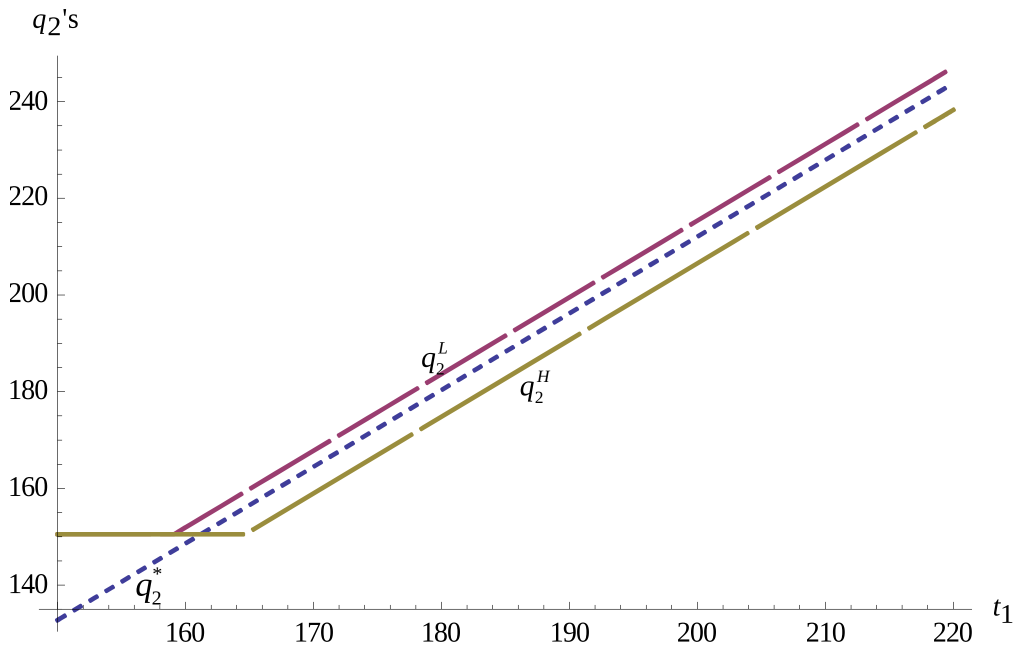

Figure 4: Illustrated Difference between 'Too Little' and 'Too Late' Mechanisms in Asymmetric Information Situation

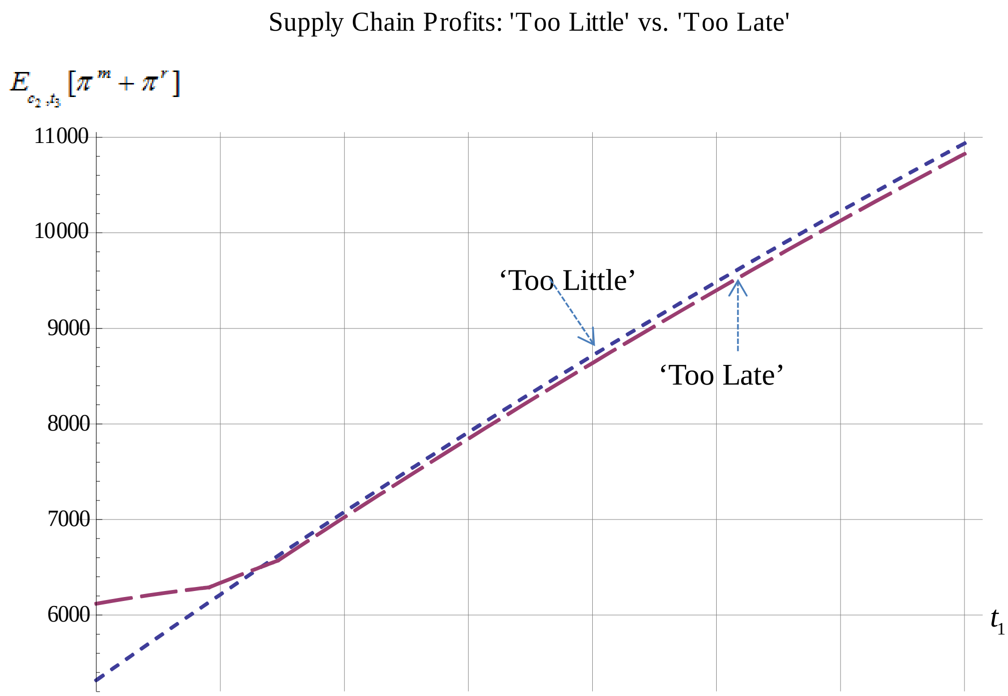

Figure 5: Illustrated Performance Difference between 'Too Little' and 'Too Late' mechanisms in Asymmetric Information situation with respect to t_1

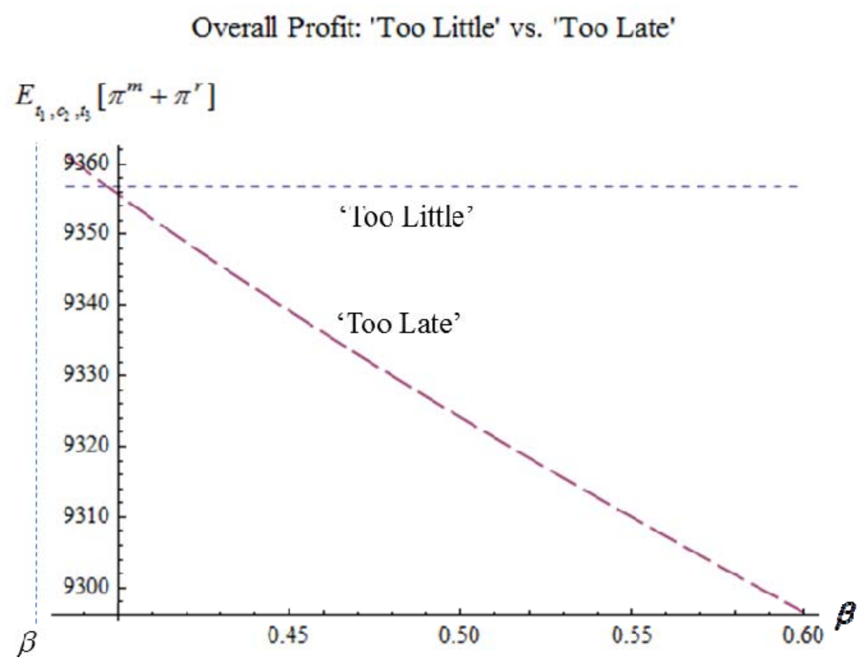

Figure 6: Illustrated Performance Difference between 'Too Little' and 'Too Late' Mechanisms in Asymmetric Information with respect to β