Can Supply Chain Flexibility Facilitate Information Sharing?

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Abstract

This paper attempts to provide an explanation for a long-standing observation in supply chain management: while our models typically show that simple contracts cannot induce credible forecast sharing between different parties within the supply chain, why do firms often use them in practice, and exchange information through unverifiable communication (“cheap talk”)? We address this question using a stylized model consisting of a retailer who solicits forecast information from a manufacturer launching a new product. Once information is shared, the retailer decides how much of its budget to invest in procuring inventory of an existing product, and how much to retain as a reserve for the anticipated launch of the manufacturer’s new product. To capture the effect of flexibility on credible forecast sharing, we examine two operational systems: a traditional system, where the retailer must make investment decisions at the beginning of the time horizon, and a flexible system, where the retailer has the option to postpone its procurement decision until learning whether the manufacturer’s product is released. We show that in the traditional system, the manufacturer has an incentive to inflate its forecast, thus, the retailer cannot trust the report. In the flexible system, however, procurement flexibility brings about a situation in which the manufacturer is uncertain about the retailer’s reaction to its report. This uncertainty may induce the manufacturer to report truthfully. Therefore, we show that under complete rationality, firms can employ simple contracts while, at the same time, induce truthful reporting.

Key words: forecast information sharing; new product development; supply chain flexibility; procurement timing

1 Introduction

It is generally accepted that coordination between different levels of a supply chain is critical for the chain to operate effectively (see, for example, Byrnes and Shapiro (1991) and Kurt Salmon Associates (1993)). One of the main mechanisms to achieve such coordination is information sharing between various parties within the supply chain (Cachon (2003) and Lee et al. (2004)). Although the benefits of information sharing as a way to improve the performance of the supply chain is known, the issue of credibility is often a key obstacle in achieving such an objective: when the incentives of the multiple parties are not completely aligned, one party may have an incentive to distort its report to influence the other’s action.
To overcome the credibility issue in information sharing, operations management research has focused on eliciting truthful forecasts through carefully designed and often complex contracts (Cachon and Lariviere (2001) and Özer and Wei (2006)), or through reputation mechanisms (Ren et al. (2010)). While such contracts and mechanisms can be applied in some settings, empirical research suggest that many firms employ simple contracts and share information through nonbinding and unverifiable messages (see, for example, Holmström and Milgrom (1987), Farrell and Rabin (1996), Aviv (2001), Bajari and Tadelis (2001), Holmström et al. (2002), Cohen et al. (2003), and Carroll (2015)).

This discrepancy between theory and practice raises the question: given that simple contracts cannot induce truthful information sharing, why do firms persist in using them and communicate through unverifiable reports? One possible explanation is that supply chain agents are not perfectly rational and are instead behavioral, caring about non-pecuniary factors such as trust and trustworthiness (see Özer et al. (2011)). In this paper, we provide an alternative and complementary explanation. We suggest that, under perfect rationality, if the supply chain entity sending the report is sufficiently uncertain about the receiving firm’s reaction to the report (due to both, the informational uncertainty about the receiver and the supply chain structure being sufficiently flexible for the receiver to have alternative options), it may truthfully share its private information in equilibrium.

We develop a model in which the above issues are formally addressed by considering a supply chain that consists of a budget-constrained retailer and a manufacturer. At the beginning of the time horizon, the manufacturer is in the development stage of producing a new product that will compete with a pre-existing product produced by a third party. Since a new product launch involves many sequential steps (including engineering development and testing, material sourcing, and manufacturing), the manufacturer is uncertain whether he can launch the product in time for the upcoming selling season. Such uncertainties are quite common in practice. For example, Microsoft delayed the release of Xbox from the fall of 2000 to the fall of 2001 since it was not able to acquire the right technology on time (Lee et al. (2006)). Apple’s Lisa project (Cohen et al. (1996)), Intel’s Broadwell processor,1 Airbus A380,2 and Boeing’s 787 Dreamliner3 are other examples where the launch was delayed by several quarters due to development and manufacturing issues. Thus, the manufacturer can only forecast the likelihood of his product being ready for the upcoming selling season. This forecast is the manufacturer’s private information, which he communicates

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1“Exclusive: Intel CEO promises Broadwell PCs on shelves for holidays”. Reuters, May, 2014.
(either truthfully or not) with the retailer. After the communication stage, the retailer faces an investment problem: how much of her budget (“endowment”) to invest in procuring inventory of an existing product in the market (manufactured by a third party) and how much of her budget to retain as a reserve for the anticipated launch of the manufacturer’s product (which has higher yield and/or demand). We focus on analyzing the settings under which the manufacturer has an incentive to truthfully share his private forecast with the retailer. In particular, we examine the role of “cheap talk” (costless, nonbinding, and unverifiable communication) in a sender(manufacturer)-receiver(retailer) game in two operational systems: a traditional system, in which the retailer must make her investment decision at the beginning of the time horizon; and a flexible system, where the retailer has the option to postpone (at a cost) her investment in the existing product until learning whether the manufacturer’s product is released. In both systems, to capture the effect of uncertainty on the manufacturer’s ability to share his forecast, we consider two information structures, one in which the manufacturer has perfect information about the retailer’s endowment, and the other in which the manufacturer is uncertain about it.

We show that in the traditional system, the manufacturer always (regardless of his knowledge of the retailer’s endowment) prefers to report a forecast that is excessively optimistic, so as to induce the retailer to retain a larger cash reserve for the possible release of his product (by investing less in the existing rival product in the market). Anticipating such behavior, the retailer discards the report. Therefore, in the traditional system, information cannot be shared credibly. The incentive of the informed party to provide an excessively optimistic forecast is also recognized in demand forecast sharing models as a key barrier to credible communication (Ren et al. (2010) and Özer et al. (2011)).

In the flexible system, on the contrary, the manufacturer may prefer to send different reports (inflate, deflate, or not alter his report) under different realizations of the retailer’s endowment. This mixture of preferred reports, coupled with the manufacturer’s uncertainty about the retailer’s endowment can, under fairly plausible conditions, result in truthful forecast sharing in equilibrium. Therefore, our model suggests that under complete rationality and in the absence of a complex contract or a reputation mechanism, uncertainty on the part of the reporting firm about the receiver’s reaction to the report, due to the combination of the sender’s informational uncertainty and supply chain flexibility, may result in truthful information sharing between the different tiers within the supply chain.

As a secondary result, we address the observation that manufacturers producing highly unpredictable products often release them through smaller retailers. For example, for the first generation
iPhone, Apple had an exclusive deal with the smallest of the U.S. major wireless communications service providers. Another example is Boeing’s highly ambitious 787 Dreamliner, where the launch customer was a mid-size Japanese airline. Our model provides a possible explanation for why manufacturers with such products may indeed prefer smaller retailers (retailers with lower endowments).

The paper is organized as follows. In Section 2, we review the relevant literature. Section 3 sets out our model in the traditional and flexible systems, and provides benchmark analysis where information is symmetric and complete. Section 4 contains the cheap talk game. A final section concludes the paper. Proofs of the main results appear in the Appendix.

2 Related Literature

Our analysis is related to the literature on strategic information sharing in supply chains, in general, and to the literature on “cheap talk” games in operations management, in particular. Many authors have emphasized the role of information sharing and its effect on improving the efficiency of the supply chain, for example, by better matching demand and supply and alleviating the bullwhip effect, see Chen (2003). While earlier research considered nonstrategic interactions, a more recent stream of research has focused on strategic information sharing: when a party in the supply chain has superior information, it may have an incentive to be strategic in how the information is shared. To enforce credibility, the primary focus has been on designing complex contracts and mechanisms that ensure truthful information sharing, see, e.g., Cachon and Lariviere (2001), Özer and Wei (2006), and Ha and Tong (2008). In practice, however, simple contracts are often used, and the information is usually shared through costless, nonbinding, and unverifiable communication - cheap talk (see Farrell and Rabin (1996), Ren et al. (2010), Özer et al. (2011), and the references mentioned in the introduction). To address this inconsistency between theory and practice, Ren et al. (2010) suggests the use of review or trigger policies with penalties to promote credible information sharing. Shamir and Shin (2014) examine the role of public information sharing within a supply chain that is comprised of an incumbent and an entrant, and suggest that public information sharing by the incumbent is possible when it influences the entrant’s entry decision. Using controlled laboratory experiment, Özer et al. (2011) demonstrate that behavioural factors such as trust and trustworthiness can play a role in sharing demand forecast information.

Our forecast-sharing game also falls within the class of economic problems known as “cheap talk” models, which originate from Crawford and Sobel’s (1982) analysis of strategic information transmission between an informed sender and an uninformed receiver, where communication is
costless, nonbinding, and unverifiable. Our work differs from the supply chain information sharing literature mentioned above along three broad dimensions. First, unlike the majority of the literature that assume one-sided asymmetric information, we consider a more general information structure: we allow both supply chain parties to possess private information, and permit their information to be correlated. To the best of our knowledge, our paper is the first in this body of literature to consider such an information structure. Second, while many demand forecast sharing models assume that information flows from downstream to upstream, in practice, there are many cases where the upstream firm possess superior information, e.g., large manufacturers such as Apple, Boeing, and Samsung often possess superior information about their proprietary products. This is the case we consider. Note that while the direction of the flow of information may be different, the underlying incentive of the informed party to provide an excessively optimistic report is similar in both cases (to induce the receiver to reserve abundant cash/capacity). Third, and most importantly, we provide an alternative explanation on how in the absence of complex contracts, reputation mechanisms, or behavioral factors, firms within the supply chain may credibly share information.

In the service industry context, Allon et al. (2011) and Allon and Bassamboo (2011b) investigate a service provider (call center) who uses cheap talk (delay announcement) to inform its customers. They show that such communication can increase the profit of the firm and at the same time improve the expected utility of the customers. In a retailer-customer setting, Allon and Bassamboo (2011a) show that when consumers are homogeneous, the retailer cannot influence customer behaviour through cheap talk, and provide conditions when the firm may be able to influence customer behavior in case of heterogenous customers. Our framework differs from these models in that we consider information sharing between different firms within a supply chain whereas they focus on settings in which a service provider transfers real-time information to its customers.

3 The Model

Players: We consider a stylized supply chain consisting of a manufacturer and a retailer. At the beginning of the decision horizon, the manufacturer is in the development stage of producing a new (seasonal) product, “Product N”, that will compete with an existing rival product in the market, “Product E”, manufactured by a third party. Since a new product launch involves many sequential steps (including engineering development and testing, material sourcing, and manufacturing), the manufacturer is uncertain whether he can launch the product in time for the upcoming selling

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season (see the Microsoft, Apple, and Boeing examples provided in the introduction). Thus, he can only forecast the likelihood $\theta$ of the product being ready for release at the start of the selling season, where we assume that $\theta < 1$. The value of $\theta$ is the manufacturer’s private information. Due to the seasonality of the product, we assume that it is not practical for the manufacturer to release a new product in the middle of the selling season.

The retailer is budget-constrained and has an endowment (budget) $b$, which can be fully or partially invested in inventory of the existing product, Product $E$, or retained in the firm as a reserve for the anticipated launch of Product $N$ (which has higher yield and/or demand). We assume that the retailer does not have/want access to external sources of capital. This assumption is supported by the fact that, in practice, there are frictions in the capital market (Harris and Raviv (1991)). The presence of financial constraints are also empirically well documented (see, for example, Whited and Wu (2006)).

The market is characterized by demand uncertainty: the total demand for Product $E$, $D_E$, is a random variable with positive support, strictly increasing cumulative distribution function $F_E(\cdot)$, and density $f_E(\cdot)$. If Product $N$ is released, its demand, $D_N$, is a random variable with positive support, strictly increasing cumulative distribution function $F_N(\cdot)$, and density $f_N(\cdot)$.

The distributions of $D_E$ and $D_N$ are common knowledge.

**Remark.** The model can be extended to take into account product substitution, i.e., Product $N$, if released to the market, has a demand cannibalization effect on Product $E$. This can be incorporated into the model by assuming that the demand of Product $E$ has a distribution function $F_E^{RL}(x)$ if Product $N$ is released (not released), where $F_E^{RL}(x) \leq F_E^{NRL}(x), \forall x \geq 0$. For ease of exposition, we ignore such product substitutability. By removing this assumption, our main insights remain unchanged.

**Systems:** To capture the effect of procurement flexibility on credible forecast sharing, we analyze the interaction between the manufacturer and the retailer in two potential operational systems: (i) *Traditional System*, abbreviated $TS$, in which the retailer must decide on her order quantity at the beginning of the time horizon; and (ii) *Flexible System*, abbreviated $FS$, in which the retailer has the option to postpone (at a cost) her ordering decision of Product $E$ until learning whether Product $N$ is released.

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5We ignore any superior demand information since both parties can be endowed with a good demand forecast for Product $N$: the manufacturer may be well informed because of his proprietary information about the product, whereas the retailer can be informed due to her proximity to the consumer market.
3.1 The Traditional System

The timing of events in the traditional system, illustrated in Figure 1, is as follows: at the beginning of the time horizon, the retailer and the manufacturer share information regarding the forecasted likelihood of the release of Product $N$, $\theta$. After the communication stage, the retailer decides on $Q_E$, the order quantity of Product $E$, and the amount of cash reserve $M$ to retain in the firm for the anticipated launch of Product $N$. Then, Product $E$ is procured at wholesale price $w_E$, and if Product $N$ is released, the retailer places her order quantity $Q_N$ at expected wholesale price $w_N$ based on her remaining available cash reserve. Finally, during a finite selling season, the retailer sells Product $E$ at unit price $p_E$, and if Product $N$ is released, it is sold at expected unit price $p_N$. Without loss of generality, we ignore the possible salvage value of leftover inventory at the end of the selling season, which can be easily incorporated at the cost of extra parameters, but without any additional insights. Moreover, for ease of exposition, and without loss of generality, we normalize the risk-free interest rate to zero, i.e., the retailer does not make any profit by hoarding cash and not investing in either Product $E$ or Product $N$ (if released).

**Traditional System Benchmark (Full Information Sharing):** As stated above, given the manufacturer’s report of $\theta$, the retailer seeks to choose the order quantity of Product $E$, $Q_E$, her cash reserve, $M = b - w_E Q_E$, and the order quantity of Product $N$ (if released), $Q_N$, to maximize her overall expected profit. Assume that the manufacturer truthfully reports his forecast of $\theta$ (this assumption is relaxed in Section 4). Let $Q = \{Q_E, Q_N\}$ denote a vector of order quantities. Then,
the retailer’s problem can be formulated as follows (throughout the paper, subscript \( r \) and \( m \) denote the retailer’s and manufacturer’s parameters, respectively):

\[
\max_{Q,M} \Pi_r^{TS}(Q, M, \theta, b) = \Pi_E^{TS}(Q_E) + \theta \Pi_N^{TS}(Q_N)
\]

\[
s.t. \quad w_E Q_E + M = b, \quad w_N Q_N \leq M,
\]

where \( \Pi_E^{TS}(Q_E) = p_E \mathbb{E}[\min(Q_E, D_E)] - w_E Q_E \) is the retailer’s expected profit when she places an order of \( Q_E \), and \( \Pi_N^{TS}(Q_N) = p_N \mathbb{E}[\min(Q_N, D_N)] - w_N Q_N \) is her expected profit from procuring inventory of Product \( N \) (if released to the market). The first constraint is the budget constraint, while the second constraint ensures that the total investment in Product \( N \) does not exceed the cash reserve.

Given the retailer’s cash reserve, and the expected per unit production cost of Product \( N \), \( c \), the manufacturer’s profit if he releases Product \( N \) is:

\[
\Pi_m(Q_N) = (w_N - c) Q_N.
\]

It is obvious that if Product \( N \) is not released, the manufacturer’s profit is 0.

As a benchmark, we next derive the retailer’s optimal decision in the traditional system, assuming that the manufacturer truthfully reveals his forecast. To avoid trivial solutions, throughout the paper we assume that the retailer’s endowment is not sufficient to procure the optimal unconstrained order quantities of both products, but is sufficient to procure the optimal unconstrained order quantities of any single product (either Product \( E \) or Product \( N \)). Proposition 1 characterizes the retailer’s optimal decision in the traditional system under truthful information exchange.

**Proposition 1.** Assume the manufacturer truthfully reports his forecast of \( \theta \). In the traditional system:

(a) The optimal order quantity of Product \( E \), \( Q_{E}^{TS^*} \), is the unique solution to the following first-order condition:

\[
p_E (1 - F_E(Q_{E}^{TS^*})) - w_E - \theta \frac{w_E}{w_N} (p_N (1 - F_N(\frac{\frac{b - w_E Q_{E}^{TS^*}}{w_N}}w_N)) - w_N) = 0.
\]

(b) The retailer’s optimal cash reserve is \( M_{TS^*} = [b - w_E Q_{E}^{TS^*}]^+ \), and her optimal order quantity of Product \( N \) (if released) is \( Q_{N}^{TS^*} = \frac{M_{TS^*}}{w_N} \).

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\(^{6}\)Note that an equivalent optimization problem would maximize the retailer’s total expected cash holding:

\[
p_E \mathbb{E}[\min(Q_E, D_E)] + \theta p_N \mathbb{E}[\min(Q_N, D_N)] + (1 - \theta) M.
\]
(c) Comparative statics: the table below indicates the changes to the values of columns as row parameters increases; “+” indicates an increase and “-” a decrease, e.g., a “-” in the \( (\theta, Q_{TS}^{*}) \) cell means \( \frac{\partial Q_{TS}^{*}}{\partial \theta} < 0 \).

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<thead>
<tr>
<th>( \theta ) increase</th>
<th>( Q_{TS}^{*} ) change</th>
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<td>( \theta ) increase</td>
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Parts (a) and (b) of the proposition demonstrate that in the traditional system, there exist a unique optimal order quantity of Product \( E \) and a unique optimal cash reserve. The comparative statics presented in part (c) shows that the retailer’s optimal cash reserve is increasing in \( \theta \) (resulting in the optimal order quantity of Product \( N \) (if released) to be increasing in \( \theta \)), whereas the optimal order quantity of Product \( E \) is decreasing in \( \theta \). Moreover, as the retailer’s budget increases, both optimal order quantities \( (Q_{E}^{*}, Q_{N}^{*}) \) and the cash reserve \( (M^{*}) \) increase. From Proposition 1, we derive the following result.

**Corollary 1.** In the traditional system, the manufacturer’s profit \( (\Pi_{m}) \) is increasing in \( M_{TS}^{*} \), \( \theta \), and \( b \).

This corollary links the manufacturer’s profit with the retailer’s cash reserve and the likelihood of the release of his product. It shows that the manufacturer’s profit increases when either the retailer’s cash reserve or the likelihood of the release of his product increase. The intuition behind this result is that an increase in \( \theta \) increases the retailer’s cash reserve, thus, she has more cash on hand for the possible release of Product \( N \), which results in an increase in the manufacturer’s profit. This result will be used extensively in Section 4.

### 3.2 Flexible System

In the flexible system, the retailer has the option to postpone her procurement decision of Product \( E \) until after learning whether Product \( N \) is released. Specifically, she has the option to procure inventory of Product \( E \) at one of two times: early (where she is still uncertain whether Product \( N \) will be released) or late (when her uncertainty about the release of Product \( N \) is eliminated). If the retailer decides to postpone her procurement decision, she must purchase Product \( E \) at a higher per unit cost \( w_{E}^{*} > w_{E} \). The higher cost is due to expedited manufacturing and shipping expenses. Note that similar to Swinney et al. (2011), Anupindi and Jiang (2008) and Van Mieghem and Dada (1999), we are assuming that the retailer is not able to place multiple orders of Product \( E \), i.e., she must decide between early or late procurement, but cannot split her order between both.
Retailer: (if not postpone) Decide order quantity of Product $E (Q_E)$, and cash buffer ($M$), given $\theta$.

Retailer: (if postpone) Decide order quantity of Product $E (Q_E)$, and order quantity of Product $N (Q_N)$ (if released), given $b$.

Retailer: Make postponement decision.

Retailer: (if not postpone) Decide order quantity of Product $E (Q_E)$, and cash buffer ($M$), given $\theta$.

Retailer: Receive the product(s) and selling season starts.

Retailer: Salvage leftover inventory (at zero value).

Figure 2: Sequence of Events in the Flexible System

This assumption is reasonable when the fixed production/capacity/procurement cost of Product $E$ is high enough. The sequence of events in the flexible system, depicted in Figure 2, differs from that of the traditional system since after the information sharing stage, the retailer also faces an investment timing decision for Product $E$.

Flexible System Benchmark (Full Information Sharing): Assume that the manufacturer truthfully reports his forecast of $\theta$. If the retailer decides not to postpone her procurement decision, her optimal expected profit, $\Pi_{r}^{NPOS^{*}}$, is equal to that of the traditional system. Specifically, given $\theta$, her optimal expected profit for the early procurement case is:

$$\Pi_{r}^{NPOS^{*}} = \Pi_{r}^{TS^{*}} = \Pi_{r}^{TS}(Q^{TS^{*}}, M^{TS^{*}}, \theta, b)$$

If she decides to postpone, the following two outcomes must be considered:

(I) Product $N$ is released ($RL$): in this case, the retailer optimally allocates her endowment to procure both products (note that she must procure Product $E$ at cost per unit $w^r_E$). Therefore, her optimal expected profit, $\Pi_{r}^{RL^{*}}$, is the solution to:

$$\max_{Q=(Q_E, Q_N)} \Pi_{r}^{RL}(Q, b) = p_E\mathbb{E}[\min(Q_E, D_E)] - w^r_E Q_E + p_N \mathbb{E}[\min(Q_N, D_N)] - w_N Q_N$$

s.t. $w^r_E Q_E + w_N Q_N \leq b$.
By comparing the above profit to the retailer’s profit in the traditional system we see that: the per unit cost of Product $E$ increases, while the uncertainty about the release of Product $N$ disappears (i.e., $\Pi_{RL}^{T*} = \Pi_{TS}^{T*}|_{w_E=w_E^*, \theta=1}$).

(II) Product $N$ is not released (NRL): in this case, the retailer only procures inventory of Product $E$ at higher cost $w_E^\tau$. Therefore, her optimal expected profit, $\Pi_{NRL}^{T*}$, is the solution to:

$$\max_{Q_E} \Pi_{NRL}^{T*} (Q_E, b) = p_E E[\min(Q_E, D_E)] - w_E^\tau Q_E$$

\[ \text{s.t. } w_E^\tau Q_E \leq b, \]

Note that $\Pi_{NRL}^{T*} = \Pi_{TS}^{T*}|_{w_E=w_E^*, \theta=0}$.

From (I) and (II), and given the manufacturer’s report of $\theta$, the retailer’s optimal expected profit if she postpones her procurement decision is:

$$\Pi_{POS}^{T*} = \theta \Pi_{RL}^{T*} + (1 - \theta) \Pi_{NRL}^{T*}.$$ 

Thus, when the retailer is deciding whether or not to postpone her procurement decision, she must compare the optimal expected profit from not postponing, $\Pi_{NPOS}^{T*} = \Pi_{TS}^{T*}$, with the optimal expected profit from postponing, $\Pi_{POS}^{T*}$. Specifically, the retailer’s optimal expected profit in the flexible system (assuming a truthful report of $\theta$) is:

$$\Pi_{FS}^{T*} = \max\{\Pi_{NPOS}^{T*}, \Pi_{POS}^{T*}\}.$$ 

The following proposition provides the details of the retailer’s optimal investment timing and procurement decisions in the flexible system, assuming that the manufacturer truthfully reports his forecast.

**Proposition 2.** Assume the manufacturer truthfully reports his forecast of $\theta$. In the flexible system, the retailer prefers not to postpone if and only if: $\Pi_{NPOS}^{T*} = \Pi_{TS}^{T*} > \Pi_{POS}^{T*}$, in which case the optimal procurement quantity of Product $E$, $Q_{E}^{TS*}$, and optimal cash reserve, $M_{TS}^{T*}$, are given by Proposition 1. Otherwise, the retailer uses the postponement option, yielding unique optimal quantities:

$$Q_{E}^{NRL*} = \frac{1}{p_E - w_E^\tau} \left( \frac{b}{p_E} - w_E^\tau \right),$$

$$p_E (1 - F_E(Q_{E}^{TS*})) - w_E^\tau w_N (p_N (1 - F_N\left(\frac{b - w_N^\tau Q_{E}^{RL*}}{w_N} \right)) - w_N) = 0,$$

$$Q_{N}^{RL*} = \frac{b - w_N^\tau Q_{E}^{RL*}}{w_N}.$$ 

if Product $N$ is not released, if Product $N$ is released.
From Proposition 2, the following corollary states the manufacturer’s preference in the flexible system.

**Corollary 2.** In the flexible system, the manufacturer prefers that the retailer postpones her procurement decision.

This result is quite intuitive and flows from two factors: first, if the retailer postpones, she retains her entire endowment until learning whether Product $N$ is released, thus, she has more cash on hand in case it is released; second, postponement increases the input price of the rival product (Product $E$), making it less attractive, and consequently Product $N$ more attractive.

To investigate the incremental value of having a postponement option (for the retailer), we define the *postponement premium*, $V(\theta,b)$, as follows:

$$V(\theta,b) = \Pi_r^{POS^*} - \Pi_r^{NPOS^*} = \Pi_r^{POS^*} - \Pi_r^{TS^*},$$

where for a given $\theta$ and $b$, $V(\theta,b) > 0$ indicates that the retailer gains from having the postponement option, whereas $V(\theta,b) \leq 0$ implies that this option is of no value (and not used by the retailer). The following two lemmas provide further insight into the behaviour of the retailer in the flexible system.

**Lemma 1** (Postponement Interval). For any given endowment $b$, if there exists a $\tilde{\theta} \in [0,1]$ for which $V(\tilde{\theta},b) \geq 0$, then there exists a unique postponement interval $[\theta_{b_{\min}}, \theta_{b_{\max}}] \subset [0,1]$, such that:

1. For all $\theta \in [\theta_{b_{\min}}, \theta_{b_{\max}}]$ the retailer postpones her procurement decision of Product $E$,
2. For all $\theta \notin [\theta_{b_{\min}}, \theta_{b_{\max}}]$ she does not postpone.

If $V(\theta,b) < 0$, $\forall \theta$, the retailer never postpones (and we set $\theta_{b_{\min}} = \theta_{b_{\max}} = 0$).

As Lemma 1 demonstrates, the retailer prefers not to postpone for all $\theta > \theta_{b_{\max}}$ and $\theta < \theta_{b_{\min}}$. Intuitively, for higher ($\theta > \theta_{b_{\max}}$) and lower ($\theta < \theta_{b_{\min}}$) values of $\theta$, the expected gain from postponing - as a result of the resolved uncertainty about the release of Product $N$ and thus the ability to invest with complete information - is less than its expected cost - because of purchasing Product $E$ at a higher wholesale price. Specifically, when $\theta$ is close to 1, the retailer is almost certain that Product $N$ will be released and thus can set aside the required reserve $M^*$ at the early stage, benefiting from the lower procurement cost of Product $E$. Indeed, if $\theta \approx 1$, then $\Pi_r^{POS^*} \approx \Pi_r^{RL^*} = \Pi_r^{TS^*}|_{w_E = w_r} < \Pi_r^{TS^*}$. On the other hand, if $\theta$ is close to 0, the likelihood that
Product $N$ will be released is too low to justify paying higher procurement cost for Product $E$ under the postponement option. Thus, the postponement premium is, once again, negative.

The following result provides further precision on the relationship between the postponement premium and retailer’s endowment.

**Lemma 2.** For any given $\theta$, the postponement premium decreases as $b$ increases. Consequently, if the length of the postponement interval is greater than zero, it shrinks as $b$ increases.

Lemma 2 implies that for sufficiently large endowments, the loss from postponing dominates its gain for all possible $\theta$ values (i.e., the length of the postponement interval is equal to zero). Thus, for such endowments, the retailer’s incentive to postpone totally disappears. This is also quite intuitive: if the endowment is sufficiently large, the retailer can do both: procure Product $E$ at the advantageous early price and have sufficient on-hand cash reserve should Product $N$ be released. What is more interesting is that the dependence of the postponement interval $[\theta_{\text{min}}, \theta_{\text{max}}]$ on $b$ creates “uncertainty” with respect to the “best” $\theta$ value for the manufacturer. Recall that the manufacturer always wants the retailer to postpone, thus would like to have $\theta$ inside the postponement interval. However, a value inside this interval for one level of $b$ may be outside of the interval for another. As we will see in Section 4, this mechanism is crucial for the existence of the “truthful reporting” equilibrium.

**Example 1.** The key insights can be illustrated by a numerical example in which the demands for Products $E$ and $N$ are uniformly distributed on intervals $[0, 50]$ and $[0, 150]$, respectively. Assume, $w_E = 4, w^*_E = 5, w_N = 5, p_E = 20$, and $p_N = 35$. Figure 3 depicts the postponement premium, $V(\theta, b)$, for different endowments. Several observations are noteworthy. First, as stated in Lemma 1, given endowment $b$, there exists a unique postponement interval $[\theta_{\text{min}}^b, \theta_{\text{max}}^b]$ (the interval corresponding to the region under the curve and above $V = 0$) where the retailer postpones if and only if $\theta \in [\theta_{\text{min}}^b, \theta_{\text{max}}^b]$. Second, in line with Lemma 2, the postponement premium and thus the postponement interval shrinks as $b$ increases. Moreover, for large enough endowments ($b = 500$), $V(\theta, b) < 0 \ \forall \theta$, thus, the retailer never postpones (the postponement cost outweighs the benefit).

Some additional insight can be obtained from Lemmas 1 and 2. As can be seen in Figure 3, for $\theta$ values with high unpredictability (e.g., $\theta$ in the neighborhood of 0.5), a retailer with a low endowment ($b = 300$ or $b = 400$) postpones her procurement decision, whereas a retailer with a high endowment ($b = 500$) will not postpone. This implies that a manufacturer producing a highly unpredictable product may prefer a smaller retailer over a larger one. The reason for this
is that such a retailer is willing to wait for him, i.e., postpone her decisions until the uncertainty is resolved. This result is consistent with the observation that for the first generation iPhone, which was a product with high uncertainty,\footnote{“The Untold Story: How the iPhone Blew Up the Wireless Industry”, \textit{Wired News}, Jan., 2008.} Apple negotiated a (secretive) exclusive deal with the smallest of the major wireless communications service providers (at the time), Cingular Wireless, later acquired by AT&T, since it was going to take a chance and wait for Apple’s new product. Another example is Boeing’s highly ambitious 787 Dreamliner project. For this highly uncertain product (indeed, due to the plane’s complexity, its launch was postponed for more than two years),\footnote{“Boeing, in Embarrassing Setback, Says 787 Dreamliner Will Be Delayed”, \textit{The Wall Street Journal}, Oct., 2007.} the launch customer was All Nippon Airways, a mid-size Japanese airline.

4 The Cheap Talk Game

In this section, we explore the forecast communication game played between the manufacturer and the retailer in both the traditional and the flexible systems. In both settings, to analyze the effect of uncertainty on the manufacturer’s ability to share his forecast with the retailer, we consider two information structures: one in which the manufacturer has perfect information about...
the retailer’s endowment (which we label as one-sided asymmetric information structure as the only private information, the true value of $\theta$, is held by the manufacturer), and the other in which the manufacturer is uncertain about the retailer’s endowment (labeled as the two-sided asymmetric information structure). To avoid repetition, we set-up the communication game in the more general two-sided asymmetric information structure, and treat the one-sided structure as a special case.

In the two-sided asymmetric information structure, the manufacturer has a private forecast of the likelihood of the release of his product, $\theta$ (which we denote as his “type”), whereas the retailer has perfect and private information about her endowment (her type) $b$. To highlight our main insights, we make a standard simplifying assumption (see, for example, Cachon and Lariviere (2001), Ha and Tong (2008), Anand and Goyal (2009), and Kong et al. (2013)) that allows the manufacturer and the retailer to be of one of two types: $L$ or $H$. That is, we assume $\theta \in \Theta = \{\theta^L, \theta^H\}$, with $0 \leq \theta^L < \theta^H < 1$, and $b \in B = \{b^L, b^H\}$, where $0 < b^L < b^H$. Let $\alpha \in \Delta(\Theta \times B)$ be a strictly positive joint prior probability distribution over the profile of the types, which is regularly assumed to be common knowledge. We make the information structure general by allowing the manufacturer’s type and the retailer’s type to be correlated. This could, for instance, reflect our observation that a manufacturer with a highly unpredictable product is more likely to interact with a smaller retailer (a retailer with low endowment) - see the discussion at the end of Section 3.2, or be due to the fact that the manufacturer would exert more effort to release his product when he believes that the retailer has a high endowment (see, for example, Cremer and McLean (1985), McAfee and Reny (1992), Watson (1996), and Koessler and Renault (2012) for articles in the economics literature that consider a correlated information structure).

The above structure reduces to a one-sided asymmetric information structure by assuming that $\alpha(b^i|\theta) \in \{0, 1\}, i \in \{L, H\}$ (i.e., conditional on $\theta$, $\alpha(.)$ is a point mass on $b^L$ or $b^H$, implying that the retailer’s type is known to the manufacturer).

To formally define the communication game, we must first define the set of feasible reports that the manufacturer can use. As is common in the cheap talk literature, and without loss of generality (Ottaviani and Sørensen (2006)), we assume that the set of feasible reports is equal to $\Theta$. We define the manufacturer’s reporting strategy $S : \Theta \rightarrow \Theta$, where $S(\theta) = \hat{\theta}$ if the manufacturer reports $\hat{\theta}$ when his private forecast is $\theta$. (Note that we use symbol $\hat{\theta}$ when we refer to a report, and $\theta$ when we refer to the manufacturer’s private forecast.) Finally, let $K : \Theta \times B \rightarrow \mathbb{R}^+$ denote the cash holding strategy of the retailer, where $K(\hat{\theta}, b) = M$ if the retailer retains the cash reserve $M$ when her endowment is $b$ and the manufacturer’s report is $\hat{\theta}$. Note that we only consider the retailer’s cash holding strategy since the procurement quantities can be automatically derived from the cash.
reserve (see Propositions 1 and 2).

The timing of the communication game is as follows: (i) at the beginning of the time horizon both the manufacturer and the retailer observe their type; (ii) having observed their types $\theta$ and $b$, the manufacturer has a (subjective) probability distribution $\alpha_m(\cdot|\theta)$ over the retailer’s types, whereas the retailer has a (subjective) prior probability distribution $\alpha_r(\cdot|b)$ over the manufacturer’s types. As in most incomplete information models, we assume that the manufacturer and the retailer share common prior beliefs expressed by conditional probabilities:

$$
\alpha_m(b^i|\theta) = \frac{\alpha(\theta,b^i)}{\sum_{y \in B} \alpha(\theta,y)}
$$
and

$$
\alpha_r(\theta^i|b) = \frac{\alpha(\theta^i,b)}{\sum_{y \in \Theta} \alpha(y,b)}, \ i \in \{L, H\};
$$

(iii) the manufacturer sends the report $\hat{\theta} = S(\theta)$ to the retailer; (iv) the retailer observes the report $\hat{\theta}$ and makes her cash holding decision $M = K(\hat{\theta}, b)$; the rest of the events follows as described in Sections 3.1 and 3.2.

In this communication game, it is easy to see that truthful reporting by the manufacturer benefits the retailer. However, it may not be beneficial for the manufacturer to truthfully reveal his forecast. Specifically, the manufacturer may want to distort his report of $\theta$ to ensure that the retailer holds abundant cash for the possible release of his product. Given such an incentive, the retailer may not find the report credible, and instead rely on her prior belief. The issues of incentives and credibility in such communication are due to two main factors: first, given the nature of the manufacturer’s private information, the retailer cannot verify (ex post) whether the manufacturer truthfully reported his private forecast; second, by distorting his report, the manufacturer does not incur a direct cost. This type of communication with costless, nonbinding, and unverifiable messages belongs to a class of games with incomplete information, referred to as “cheap talk” games (Crawford and Sobel (1982)).

As is common in cheap talk games, the equilibrium concept we employ to obtain a solution to our manufacturer-retailer communication game is Perfect Bayesian Nash Equilibrium (PBNE) (Fudenberg and Tirole (1991)). In our context, the PBNE requires that: (1) given the retailer’s cash holding strategy ($K(\hat{\theta}, b)$) and posterior belief ($\alpha_r(\theta|\hat{\theta}, b)$), the manufacturer will not deviate from his reporting strategy ($S(\theta)$), if it maximizes his total expected profit; and (2) given the manufacturer’s reporting strategy ($S(\theta)$) and her own endowment ($b$), the retailer chooses a cash reserve ($K(\hat{\theta}, b)$) that maximizes her total expected profit, updating her belief about the manufacturer’s private information using Bayes’ rule. To formalize this discussion, recall that the manufacturer’s profit is denoted by $\Pi_m(\cdot)$, while the retailer’s expected profit in the traditional and flexible systems is represented by $\Pi^{TS}_r(\cdot)$ and $\Pi^{FS}_r(\cdot)$, respectively. The following definition formalizes the PBNE in our context.

**Definition 1.** (Perfect Bayesian Nash Equilibrium) The manufacturer’s reporting strategy $S(\cdot)$, the
retailer’s cash holding strategy \( K(\cdot) \), and the retailer’s posterior (updated) belief \( \alpha_r(\theta|\hat{\theta}, b) \) constitute a perfect Bayesian Nash equilibrium if:

1. For each \( \theta \in \Theta \), \( S(\theta) = \arg\max_{\hat{\theta} \in \Theta} \sum_{b \in B} \alpha_m(b|\theta)\Pi_m(K(\hat{\theta}, b)) \),

2. For each \( \hat{\theta} \in \Theta \),

\[
K(\hat{\theta}, b) = \begin{cases} 
\arg\max_{M} \sum_{\theta \in \Theta} \alpha_r(\theta|\hat{\theta}, b)\Pi_r^T(M, \theta, b), & \text{in the traditional system,} \\
\arg\max_{M} \sum_{\theta \in \Theta} \alpha_r(\theta|\hat{\theta}, b)\Pi_r^F(M, \theta, b), & \text{in the flexible system,}
\end{cases}
\]

3. The retailer’s belief is consistent, such that whenever possible, she updates her belief about the manufacturer’s private information using Bayes’ Rule, i.e., \( \alpha_r(\theta|\hat{\theta}, b) = \frac{I\{S(\theta) = \hat{\theta}\}\alpha_r(\theta|b)}{\sum_{y \in \Theta} I\{S(y) = \hat{\theta}\}\alpha_r(y|b)} \), where \( I\{\cdot\} \) is the indicator function.

In the above definition, the first condition implies that the manufacturer sends a report that maximizes his expected profit, taking the retailer’s cash holding strategy as given. The second and third conditions indicate that the retailer responds optimally (determines the optimal cash reserve that maximizes her total expected profit) to each possible report, using Bayes’ rule to update her prior belief (whenever possible).

Our focus is on identifying equilibrium conditions in which the manufacturer truthfully reports his forecast and the retailer believes him (it is without loss of generality that we restrict our analysis to such equilibrium (see Battaglini (2002))). We refer to such a PBNE as a “truthful revealing” equilibrium, which is formally defined as follows.

**Definition 2. (Truthful Revealing Equilibrium)** A truthful revealing equilibrium is a PBNE in which:

1. \( S(\theta) = \theta, \ \forall \theta \in \Theta \),

2. \( \alpha_r(\theta|\theta, b) = 1, \ \forall (\theta, b) \in (\Theta, B) \).

Definition 2 states that in a truthful revealing equilibrium, the manufacturer sends a truthful report (condition (1)) and the retailer believes him (condition (2)).

### 4.1 Communication in the Traditional System

We begin by examining the information exchange in the traditional system assuming the manufacturer has perfect information about the retailer’s endowment. Recall from Proposition 1 that in
the traditional system, the retailer’s cash reserve is increasing in \( \theta \). Moreover, Corollary 1 indicates that in this system, the manufacturer’s profit is increasing in the retailer’s cash reserve \( M \). Consequently, to ensure that the retailer holds abundant cash for the possible release of his product, the manufacturer has an incentive to inflate his report of \( \theta \). Anticipating such an incentive, the retailer would not consider the manufacturer’s report credible, regardless of whether he is telling the truth or not. This discussion is formalized in the following lemma.

**Lemma 3.** In the traditional system with one-sided asymmetric information structure, the manufacturer always wants the retailer to believe that \( \theta = \theta^H \). Anticipating such an incentive, the retailer ignores the report in equilibrium, relying only on her prior belief. Thus, no truthful revealing equilibrium exists.

Driving the above result is the manufacturer’s incentive to inflate, and the retailer’s inability to verify ex post the truth of the report. Therefore, no matter what reporting strategy the manufacturer uses (note that the manufacturer’s equilibrium reporting strategy is not unique) the retailer would simply ignore it and make her cash holding decision regardless of the report, relying only on her prior belief. Such an equilibrium, in which the manufacturer’s report is independent of his type and the retailer’s strategy is independent of the report, is referred to as a “babbling” equilibrium (Farrell and Rabin (1996)).

The result of Lemma 3 can be generalized to the case where the manufacturer is uncertain about the retailer’s endowment. Specifically, since for each possible endowment \( b \in B \), the manufacturer’s profit is increasing in the retailer’s cash reserve (Corollary 1), his expected profit (expectation taken over retailer types) is also increasing in it. Therefore, in order to induce the retailer to hold more cash, he has an incentive to inflate his report of \( \theta \), regardless of his knowledge of \( b \). Knowing this incentive, the retailer does not consider the report credible. The following theorem formalizes this argument.

**Theorem 1.** In the traditional system, the manufacturer always wants the retailer to believe that \( \theta = \theta^H \), regardless of his knowledge about \( b \). Knowing this incentive, the retailer ignores the report in equilibrium, determining her optimal strategy based on her prior belief. Therefore, in the traditional system, no truthful revealing equilibrium exists. In fact, the only PBNE is the babbling equilibrium.

The above discussion illustrates that in the traditional system, information cannot be shared credibly because of incentive misalignment between the manufacturer and the retailer. More precisely, since \( \theta \) only influences the retailer’s cash reserves, and since the reserve is increasing in
θ, the manufacturer’s incentive is to always inflate θ. The question we next answer is whether procurement flexibility can align the incentives of the parties to allow credible forecast sharing.

Recall that the crucial difference between the traditional and the flexible system is that, in the latter, the value of θ influences two decisions of the retailer: whether to postpone and how much cash reserve to hold for Product N in case the postponement option is not chosen. As we will show, in this case the manufacturer is no longer certain whether inflating or deflating θ is beneficial.

4.2 Communication in the Flexible System

Before presenting our main result, to gain intuition, we first discuss the equilibrium outcome in the flexible system when the manufacturer has perfect knowledge about the retailer’s endowment. Recall from Lemma 1 that for each possible endowment b ∈ B there exists a unique postponement interval [θ_{min}^b, θ_{max}^b] (which can be empty), such that for all θ ∈ [θ_{min}^b, θ_{max}^b] the retailer postpones her procurement decision. Moreover, Corollary 2 indicates that the manufacturer always prefers that the retailer postpones her procurement decision. Given these results, and assuming that the manufacturer has perfect knowledge of b, we obtain the following cases:

Completely Aligned Incentives: if Θ = {θ_L, θ_H} ⊆ [θ_{min}^b, θ_{max}^b], the retailer postpones her procurement decision for both θ_L and θ_H. In this case, the manufacturer has no incentive to misreport, thus, a truthful revealing equilibrium exists. While this shows that procurement flexibility can align the incentives of the two firms such that they achieve their mutually beneficial outcome even in the absence of communication (the mutually beneficial outcome can never be achieved in the traditional system), it also indicates that truthful reporting is supported in equilibrium because the shared information does not alter the retailer’s postponement decision (i.e., it is as if no communication has taken place). Such a truthful revealing equilibrium is referred to as a noninfluential equilibrium (Austen-Smith (1994) and Chakraborty and Harbaugh (2010)).

Misaligned Incentives: if Θ ∉ [θ_{min}^b, θ_{max}^b], there may be partial incentive misalignment, where only one manufacturer type falls within the postponement interval; or full incentive misalignment, where both types fall outside the postponement interval. In both cases, the manufacturer has an incentive to distort his report. Specifically, in case of partial misalignment, the manufacturer type (either θ_L or θ_H) that does not belong to the postponement interval [θ_{min}^b, θ_{max}^b] would alter his report - he inflates his report if θ < θ_{min}^b and deflates it when θ > θ_{max}^b - to induce the retailer to postpone her procurement decision. In the complete misalignment case, the retailer never postpones, thus, the manufacturer always wants to report θ_H (as in the traditional system). In both cases, anticipating the manufacturer’s incentive to deceive, the retailer will not believe the
Lemma 4 provides a formal statement of the above discussion.

**Lemma 4.** In the flexible system with one-sided asymmetric information structure:

(i) If $\Theta \subset [\theta^b_{\min}, \theta^b_{\max}]$, a truthful revealing (noninfluential) equilibrium exists.

(ii) If $\Theta \not\subset [\theta^b_{\min}, \theta^b_{\max}]$, no truthful revealing equilibrium exists. In this case, the only PBNE is the babbling equilibrium.

While the above result seems somewhat encouraging (due to the emergence of truthful reporting in equilibrium in one case), it also shows that in the flexible system with one-sided asymmetric information, truthful reporting is supported in the equilibrium only when knowledge of $\theta$ would not affect the retailer’s postponement decision. We next focus on our main result and show that procurement flexibility coupled with the manufacturer’s uncertainty about the retailer’s endowment can, under fairly plausible conditions, result in the manufacturer truthfully sharing his private forecast, i.e., a truthful revealing and influential equilibrium can emerge.\footnote{In an influential equilibrium (Austen-Smith (1994) and Chakraborty and Harbaugh (2010)), the manufacturer’s report influences the retailer’s postponement decision, i.e., the retailer’s postponement decision (in equilibrium) is not the same for all reports.}

**Main Result:** As stated above, in the flexible system, the manufacturer always prefers that the retailer postpones her procurement decision (Corollary 2). Moreover, for each of the retailer’s possible endowment $b \in B$ there exists a unique postponement interval $[\theta^b_{\min}, \theta^b_{\max}]$ such that the retailer postpones her procurement decision if and only if $\theta \in [\theta^b_{\min}, \theta^b_{\max}]$ (Lemma 1), where the length of this interval shrinks as $b$ increases (Lemma 2). These results indicate that (unlike in the traditional system where the manufacturer always prefers $\theta^H$) in the flexible system the manufacturer’s preferred reports (of his type) may differ for various endowments (i.e., he may wish to report a particular type for one realization of $b$, while a different type may be reported for another realization). Specifically, if the manufacturer has perfect knowledge of $b$, we know from Lemma 4 that under partial incentive misalignment he may want to inflate, deflate, or not change his report to induce the retailer to postpone, i.e., given the postponement interval $[\theta^b_{\min}, \theta^b_{\max}]$, he would inflate his report (report $\theta^H$) if $\theta < \theta^b_{\min}$, deflate (report $\theta^L$) if $\theta > \theta^b_{\max}$, and truthfully report if $\theta \in [\theta^b_{\min}, \theta^b_{\max}]$. Furthermore, the manufacturer would inflate his report if he knows that the retailer’s endowment is sufficiently large (the reason for this is that the retailer never postpones for such endowments - see Lemma 2 and the complete misalignment case of Lemma 4).
mixture of preferred reports coupled with the endowment uncertainty results in the manufacturer not being able to perfectly predict the retailer’s reaction to each of his reports (because of the changing postponement interval as \( b \) changes). This uncertainty may induce the manufacturer to truthfully reveal his private information.

The above discussion indicates that truthful reporting rests on the manufacturer’s mixture of preferred reports. Therefore, to formally characterize the equilibrium, we quantify this mixture of preferences.

**Definition 3. (Preferred Report Mixture Measure)** We define the preferred report mixture measure, \( \delta \), as follows:

\[
\delta = \frac{\Delta \Pi(\theta,b^H)}{\Delta \Pi(\theta,b^\ell)} = \frac{\Pi_m(K(\theta^H,b^H)) - \Pi_m(K(\theta^L,b^H))}{\Pi_m(K(\theta^H,b^\ell)) - \Pi_m(K(\theta^L,b^\ell))}
\]

A negative \( \delta \) implies that the manufacturer has a “preference reversal”, where he prefers to report a high \( \theta \) for one value of \( b \) and a low \( \theta \) for the other. A positive \( \delta \) means that the manufacturer prefers one value of \( \theta \) over the other for all possible \( b \) values, i.e., he prefers to report \( \theta^L \) if \( \Delta \Pi(\theta, b^i) < 0 \), \( i = L, H \), while preferring \( \theta^H \) when \( \Delta \Pi(\theta, b^i) > 0 \), \( i = L, H \). A special case is \( \Delta \Pi(\theta, b^L) = \Delta \Pi(\theta, b^H) = 0 \), where the manufacturer is indifferent between reporting \( \theta^L \) and \( \theta^H \) (because the retailer postpones her decision for all possible reports, i.e., \( V(\theta,b) \geq 0, \forall (\theta,b) \in \{\Theta \times B\} \)). This degenerate case generalizes the completely aligned incentives case of Lemma 4, thus, the implication of Lemma 4 is still applicable: a truthful revealing but noninfluential equilibrium exists.

The next theorem characterizes the necessary and sufficient conditions that guarantee the existence of a truthful revealing and influential equilibrium.

**Theorem 2.** In the flexible system with two-sided asymmetric information structure, a truthful revealing (and influential) equilibrium exists if and only if:

\[
(I) \quad \delta < 0,
\]

\[
(II) \quad \frac{\alpha(\theta^L,b^L)}{\alpha(\theta^H,b^H)} \geq |\delta|,
\]

\[
(III) \quad \frac{\alpha(\theta^H,b^L)}{\alpha(\theta^L,b^H)} \geq \frac{1}{|\delta|}.
\]

In such an equilibrium, the manufacturer truthfully reports his forecast of \( \theta \), and the retailer believes him.

As stated earlier, truthful reporting relies on the manufacturer being uncertain about the retailer’s reaction (or equivalently uncertain about the postponement interval). Using this fact,
Theorem 2 establishes conditions on the prior probability distribution over the profile of the types for which credible information sharing is supported in equilibrium. The theorem implies that for a truthful revealing and influential equilibrium to exist, it must be that: (0) a postponement option must exist for the retailer, (1) the manufacturer is uncertain about the retailer’s endowment, (2) the manufacturer has preference reversal, where he prefers to send different reports for different endowments (condition (I)), and (3) there is relatively a greater probability that the manufacturer-retailer types match (conditions (II) and (III)). The type matching conditions are plausible and are consistent with the observation that a manufacturer producing a highly unpredictable product (which can be denoted as a low type manufacturer) is more likely to interact with a smaller retailer (see the Apple and Boeing examples at the end of Section 3.2). Theoretically, conditions (II) and (III) indicate that the prior distribution \( \alpha(\theta, b) \) satisfies the monotone likelihood ratio property (Milgrom (1981)), a standard assumption in mechanism design and contract theory (see, for example, Milgrom and Weber (1982), Hart and Holmström (1986), Bikhchandani et al. (1992), and Bergemann and Välimäki (2002)). In our context, an interpretation of this property is that high types are more likely to match because the manufacturer exerts more effort to release his product (thus is more likely to be a high type) when the retailer’s endowment is high. Collectively, the three conditions imply that, for each manufacturer type, his expected profit (the expectation is over \( b \) ) is higher under truthful reporting.

It is noteworthy that when both conditions (II) and (III) are violated (i.e., \( \alpha(\theta^L, b^L) > |\delta| \) and \( \alpha(\theta^H, b^H) < \frac{1}{|\delta|} \)), a revealing and influential equilibrium still exists. However, in this equilibrium, the manufacturer is not truthful, i.e., his reporting strategy is \( S(\theta^L) = \theta^H \) and \( S(\theta^H) = \theta^L \), and the retailer reverses the report, i.e., \( \alpha_r(\theta|\theta, b) = 0, \forall(\theta, b) \). Moreover, if only one of the two conditions (II) or (III) is violated, truthful reporting is not supported in the equilibrium. Specifically, when \( \frac{\alpha(\theta^L, b^L)}{\alpha(\theta^H, b^H)} \geq |\delta| \) and \( \frac{\alpha(\theta^H, b^H)}{\alpha(\theta^L, b^L)} < \frac{1}{|\delta|} \), the manufacturer is better off by reporting \( \theta^L \), while if \( \frac{\alpha(\theta^L, b^L)}{\alpha(\theta^H, b^H)} < |\delta| \) and \( \frac{\alpha(\theta^H, b^H)}{\alpha(\theta^L, b^L)} \geq \frac{1}{|\delta|} \), he prefers \( \theta^H \).

We next construct a simple example to better demonstrate the intuition behind Theorem 2.

**Example 2.** Suppose \( \Theta = \{\theta^L = 0.5, \theta^H = 0.85\} \) and \( B = \{b^L = 350, b^H = 450\} \), and assume that the other parameters are identical to those in Example 1. The resulting postponement premiums for each endowment are shown in Figure 4. The top (bottom) plot shows the postponement premium when the retailer’s endowment is low (high). The figure illustrates the postponement interval for the two endowments. As can be seen, when the retailer’s endowment is low (\( b^L \)), she gains from having the postponement option (she postpones when \( \theta \) falls within the postponement
interval \([\theta_{min}^{b}, \theta_{max}^{b}]\)], whereas for a high endowment \((b^{H})\), the postponement option is useless (she never postpones). The retailer’s best response, assuming that she trusts the manufacturer and makes her cash holding decision according to the manufacturer’s report is:

\[
\begin{cases} 
\text{if } b = b^{L} : & \{ 
\text{if } S(\theta) = \theta^{L} \rightarrow \text{postpone and hold } K(\theta^{L}, b^{L}) = b^{L} \\
\text{if } S(\theta) = \theta^{H} \rightarrow \text{not postpone and hold } K(\theta^{H}, b^{L}) < b^{L} \}
\end{cases}
\]

\[
\begin{cases} 
\text{if } b = b^{H} : & \{ 
\text{if } S(\theta) = \theta^{L} \rightarrow \text{not postpone and hold } K(\theta^{L}, b^{H}) \\
\text{if } S(\theta) = \theta^{H} \rightarrow \text{not postpone and hold } K(\theta^{H}, b^{H}) \}
\end{cases}
\]

From Section 3 we can infer: \(b^{L} = K(\theta^{L}, b^{L}) > K(\theta^{H}, b^{L})\) and \(K(\theta^{L}, b^{H}) < K(\theta^{H}, b^{H})\). Thus, since the manufacturer’s profit is increasing in the retailer’s cash reserve (see Corollaries 1 and 2), \(\Pi_m(K(\theta^{L}, b^{L})) > \Pi_m(K(\theta^{H}, b^{L}))\) and \(\Pi_m(K(\theta^{L}, b^{H})) < \Pi_m(K(\theta^{H}, b^{H}))\). Therefore, if the manufacturer had perfect information about the retailer’s endowment, he would send the report \(S(\theta) = \theta^{L}\) if \(b = b^{L}\), while reporting \(S(\theta) = \theta^{H}\) if \(b = b^{H}\). This implies that the manufacturer has a preference reversal, hence a negative \(\delta\). In this example, the preferred report mixture measure is

\[
\delta = \frac{\Pi_m(K(\theta^{H}, b^{H})) - \Pi_m(K(\theta^{L}, b^{H}))}{\Pi_m(K(\theta^{H}, b^{L})) - \Pi_m(K(\theta^{L}, b^{L}))} = \frac{2850 - 2770}{2360 - 2430} = -1.
\]

Therefore, from Theorem 2, a truthful revealing equilibrium exists if and only if:
that is, there is a greater probability that the manufacturer-retailer types match, i.e., \( \alpha(\theta^L, b^L) \geq \alpha(\theta^L, b^H) \) and \( \alpha(\theta^H, b^H) \geq \alpha(\theta^H, b^L) \), or equivalently, the prior distribution \( \alpha(\theta, b) \) satisfies the monotone likelihood ratio property. Therefore, under these conditions (see the discussion above on the plausibility of the conditions) the manufacturer is on average better off by truthfully sharing his forecast.

5 Conclusion

Using a stylized supply chain model, consisting of a retailer who solicits forecast information from a manufacturer, our goal is to examine conditions where the manufacturer would have an incentive to truthfully share his forecast with the retailer. The motivation for this analysis is the observation that while theoretical supply chain models often predict the need for complicated contracts or reputation mechanism to achieve credible information sharing, simple contracts are common in practice, and firms often use nonbinding and unverifiable reports (cheap talk) to communicate.

In our model, we find that if the manufacturer can anticipate the retailer’s reaction to his report (as in the traditional system), he has an incentive to be strategic on how he shares his forecast. Predicting such a behaviour, the retailer cannot find the report credible. Thus, in such a setting, credible forecast sharing is not supported in equilibrium.

Our main result, however, suggests that when the retailer has alternative options (e.g., a procurement postponement option), the manufacturer is no longer able to perfectly predict the retailer’s reaction to his report. This uncertainty can, under fairly plausible conditions, induce the manufacturer to truthfully share his forecast with the retailer. Therefore, we show that, under perfect rationality, and in the absence of a complex contract or a reputation mechanism, if the supply chain entity providing the report is uncertain about the receiving firm’s reaction to its report, it may, in equilibrium, credibly share its private forecast. This suggests that nonbinding and unverifiable forecast sharing can improve the supply chain coordination, even when the incentives of the parties are not fully aligned.

Although our key findings relate to equilibrium forecast sharing, our model also provides an explanation for the observation that manufacturers producing highly unpredictable products often release them through smaller retailers. The model suggests that, manufacturers with such products
prefer smaller retailers, because, those retailers are more willing to wait for the new products (i.e., they are likely to postpone their investment decisions), whereas larger retailers tend not to wait (i.e., they prefer not to postpone).

There are several interesting avenues for future research. A natural extension of our paper is to extend the communication game to include more than two states for \( \theta \) and \( b \), i.e., \( \theta \in \{ \theta_E, \ldots, \theta_N \} \) and \( b \in \{ b_E, \ldots, b_N \} \). While most of our qualitative insights continue to hold (i.e., equilibrium information sharing is possible in the flexible system, while information sharing is blocked in equilibrium in the traditional system), such an extension would make the analyses more complex since it requires the introduction of partially revealing (also known as partial-pooling) equilibria, in which the manufacturer partially reveals his information. A second possible direction is to extend the model to allow the retailer to place multiple orders of the existing product. In particular, by considering a low enough fixed procurement/production/capacity cost of Product \( E \), we can endogenize the number times the retailer procures this product. In this case, a revealing equilibrium may still exist, but the analysis is more cumbersome. Finally, it would be interesting to extend the model to settings with multiple retailers and multiple manufacturers in order to specify exact conditions under which smaller retailers prefer to collaborate with risky manufacturers, whereas larger retailers interact with predictable ones.

References


Appendix - Proofs

**Proof of Proposition 1.** Due to no slackness, we can substitute $Q_N$ by $\frac{b-w_E Q_E}{w_N}$ in the objective function. To prove part (a), we show that the total expected profit, $\Pi_r^{TS}(Q, M, \theta, b)$, is concave in $Q_E$: it is sufficient to show that both $\Pi_E^{TS}(Q_E)$ and $\Pi_N^{TS}(Q_N) = \Pi_N^{TS}(\frac{b-w_E Q_E}{w_N})$ are concave in $Q_E$ (positive weighted sum of concave functions is concave). The first and second derivatives of these two functions are (using the Leibniz integral rule):

\[
\begin{align*}
\frac{\partial \Pi_E^{TS}(Q_E)}{\partial Q_E} &= p_E (1 - F_E(Q_E)) - w_E, \\
\frac{\partial^2 \Pi_E^{TS}(Q_E)}{\partial Q_E^2} &= -p_E f_E(Q_E) < 0.
\end{align*}
\]

\[
\begin{align*}
\frac{\partial \Pi_N^{TS}(Q_N)}{\partial Q_E} &= -\frac{w_E}{w_N} (p_N (1 - F_N(\frac{b-w_E Q_E}{w_N})) - w_N), \\
\frac{\partial^2 \Pi_N^{TS}(Q_N)}{\partial Q_E^2} &= -p_N (\frac{w_E}{w_N})^2 f_N(\frac{b-w_E Q_E}{w_N}) < 0.
\end{align*}
\]

The second derivative of both functions are negative, thus, both functions are concave. Since $\theta > 0$, we can conclude that $\Pi_r^{TS}(Q, M, \theta, b)$ is also concave in $Q_E$. This implies that the optimal order quantity of Product $E$, $Q_{TE}^*$, is the unique solution of the first-order condition (FOC):

\[p_E (1 - F_E(Q_E^*)) - w_E - \theta \frac{w_E}{w_N} (p_N (1 - F_N(\frac{b-w_E Q_E^*}{w_N})) - w_N) = 0.\]

The result of part (b) follows from no slackness and by the definitions of $M$. Finally, the comparative statics of part (c) is derived by employing the implicit function theorem. \hfill \square

**Proof of Corollary 1.** The proof follows from $\frac{\partial \Pi_m}{\partial \theta} = (w_N - c) \frac{\partial Q_N}{\partial \theta}$, and from Proposition 1(c) $\frac{\partial Q_{TS}^*}{\partial \theta} > 0$ and $\frac{\partial Q_{TS}^*}{\partial b} > 0$. \hfill \square

**Proof of Proposition 2.** Since $\Pi_r^{RL}(Q, b)$ and $\Pi_r^{NRL}(Q_E, b)$ are special cases of $\Pi_r^{TS}(Q, M, \theta, b)$, i.e., when $w_E = w_E^*$ and $\theta = 1$ or $\theta = 0$, they are both concave in $Q_E$ (see proof of Proposition 1), and thus have a unique maximum. Therefore, as proven in Proposition 1, the optimal order quantities can be derived by setting the FOC equal to zero. \hfill \square

**Proof of Corollary 2.** Since $\frac{\partial \Pi_m}{\partial Q_N} > 0$, it is sufficient to show that $Q_{RL_{TS}}^* \geq Q_{TS}^*$. From Proposition 1 we know $\frac{\partial Q_{TS}^*}{\partial \theta} > 0$, thus $Q_{TS}^*|_{\theta=1} \geq Q_{TS}^*$. Moreover, since $\frac{Q_{TS}^*}{\partial w_E} > 0$, thus $Q_{TS}^*|_{w_E=w_E^*} \geq Q_{TS}^*|_{w_E<w_E^*}$. Therefore:

\[Q_{RL}^* = Q_{TS}^*|_{\theta=1, w_E=w_E^*} > Q_{TS}^*.\]

\hfill \square
**Proof of Lemma 1.** The proof will follow by showing the for any given \( b \): (i) the postponement premium at the two extreme values of \( \theta \) is negative, and (ii) the postponement premium is concave in \( \theta \). We first show (i), that is \( V(\theta = 0, b) < 0 \) and \( V(\theta = 1, b) < 0 \).

- \( \theta = 0 \): Since \( \frac{\partial \Pi_{TS}^r}{\partial w_E} |_{\theta=0} = \frac{\partial \Pi_{FS}^r}{\partial w_E} |_{\theta=0} < 0 \), and given the assumption \( w_E < w_E^r \) we have
  \[
  \Pi_{POS}^r |_{\theta=0} = \Pi_{NRL}^r = \Pi_{FS}^r |_{\theta=0, w_E = w_E^r} < \Pi_{TS}^r |_{\theta=0}.
  \]
  Therefore, \( V(\theta = 0, b) = \Pi_{NRL}^r - \Pi_{TS}^r |_{\theta=0} < 0 \).

- \( \theta = 1 \): Since \( \frac{\partial \Pi_{FS}^r}{\partial w_E} |_{\theta=1} < 0 \), and given \( w_E < w_E^r \) we have
  \[
  \Pi_{POS}^r |_{\theta=1} = \Pi_{RL}^r = \Pi_{TS}^r |_{\theta=1, w_E = w_E^r} < \Pi_{FS}^r |_{\theta=1}.
  \]
  Therefore, \( V(\theta = 1, b) = \Pi_{RL}^r - \Pi_{FS}^r |_{\theta=1} < 0 \).

To conclude the proof, we now prove (ii), that is \( V(\theta, b) \) is concave in \( \theta \). Since \( \frac{\partial^2 \Pi_{POS}^r}{\partial \theta^2} = 0 \), we have \( \frac{\partial^2 V(\theta, b)}{\partial \theta^2} = -\frac{\partial^2 \Pi_{FS}^r}{\partial \theta^2} \). Therefore, we must show that \( \Pi_{FS}^r \) is convex in \( \theta \). The derivative of \( \Pi_{FS}^r \) with respect to \( \theta \) yields:

\[
\frac{\partial \Pi_{FS}^r}{\partial \theta} = \Pi_{FS}^r N \left( p_E (1 - F_E(Q_{FS}^r)) - w_E - \frac{w_E}{w_N} (p_N (1 - F_N \left( \frac{b - w_E Q_{FS}^r}{w_N} \right)) - w_N) \right) - \Pi_{FS}^r N
\]

where the second equality holds because (from Proposition 1) \( p_E (1 - F_E(Q_{FS}^r)) - w_E - \frac{w_E}{w_N} (p_N (1 - F_N \left( \frac{b - w_E Q_{FS}^r}{w_N} \right)) = 0 \). Thus, \( \frac{\partial^2 \Pi_{FS}^r}{\partial \theta^2} = -\frac{\partial^2 \Pi_{FS}^r}{\partial \theta^2} < 0 \), which implies \( \frac{\partial^2 V}{\partial \theta^2} < 0 \).

**Proof of Lemma 2.** We must show that \( V(\theta, b) \) is monotonically decreasing in the endowment. Since we assume that the retailer’s endowment is not sufficient to procure the optimal unconstrained order quantity of both products, but is sufficient to procure the optimal unconstrained order quantity of any single product, the derivative of \( V(\theta, b) \) with respect to \( b \) yields

\[
\frac{\partial V(\theta, b)}{\partial b} = \theta \frac{\partial \Pi_{RL}^r}{\partial b} - \frac{\partial \Pi_{FS}^r}{\partial b},
\]

which after simplifying is

\[
\frac{\partial V(\theta, b)}{\partial b} = \frac{\theta P_N}{w_E} (F_N(Q_{FS}^r) - F_N(Q_{RL}^r)).
\]

From the proof of Corollary 2 we know \( Q_{RL}^r > Q_{FS}^r \), which implies \( F_N(Q_{RL}^r) > F_N(Q_{FS}^r) \). Thus, \( \frac{\partial V(\theta, b)}{\partial b} < 0 \).
**Proof of Lemma 3.** Assume that the retailer trusts the manufacturer and makes her cash holding decision according to the manufacturer’s report. For any given \( b \), let \( K^*(\hat{\theta} = \theta^i, b) = \arg \max M \Pi_r^{TS}(M, \theta^i, b) \), \( i \in \{L, H\} \) denote her optimal cash reserve given the received report \( \hat{\theta} \). We use contradiction to prove that truthful reporting is not supported in the equilibrium; thus assume a truthful revealing equilibrium exit. From Definition 2, in such an equilibrium, \( S(\theta^L) = \theta^L \) and \( S(\theta^H) = \theta^H \). This implies that for any given \( b \) the following conditions must hold:

\[
\Pi_m(K^*(\theta^i, b)) \geq \Pi_m(K^*(\theta^j, b)), \quad \forall i, \forall j \in \{L, H\}, \ j \neq i \quad (A1)
\]

Moreover, from Proposition 1, \( Q^{TS_\hat{\theta}}_E|_{\theta^L} \) and \( Q^{TS_\hat{\theta}}_E|_{\theta^H} \) are the unique solution to the following two FOCs:

\[
p_E(1 - F_E(Q^{TS_\hat{\theta}}_E|_{\theta^L})) - w_E - \theta^L w_E w_N (p_N(1 - F_N(b - w_E Q^{TS_\hat{\theta}}_E|_{\theta^L})) - w_N) = 0,
\]

\[
p_E(1 - F_E(Q^{TS_\hat{\theta}}_E|_{\theta^H})) - w_E - \theta^H w_E w_N (p_N(1 - F_N(b - w_E Q^{TS_\hat{\theta}}_E|_{\theta^H})) - w_N) = 0.
\]

From Proposition 1 we also know that \( \frac{\partial Q^{TS_\hat{\theta}}_E}{\partial \theta^L} < 0 \). Therefore, \( Q^{TS_\hat{\theta}}_E|_{\theta^L} > Q^{TS_\hat{\theta}}_E|_{\theta^H} \). Since \( K^*(\theta^L, b) = b - w_E Q^{TS_\hat{\theta}}_E|_{\theta^L} \) and \( K^*(\theta^H, b) = b - w_E Q^{TS_\hat{\theta}}_E|_{\theta^H} \), then \( K^*(\theta^L, b) < K^*(\theta^H, b) \). Finally, since \( \frac{\partial \Pi_m}{\partial M} > 0 \) (Corollary 1), we can conclude that \( \Pi_m(K^*(\theta^H, b)) > \Pi_m(K^*(\theta^j, b)) \quad \forall j \in \{L, H\} \), which contradicts \((A1)\). Therefore, truthful reporting is not supported in equilibrium.

**Proof of Theorem 1.** Assume that the retailer trusts the manufacturer and makes her cash holding decision according to the manufacturer’s report. Let \( K^*(\hat{\theta} = \theta^i, b) = \arg \max M \Pi_r^{TS}(M, \theta^i, b) \), \( i \in \{L, H\} \) denote her optimal cash holding decision given the report. As in Lemma 3, we use contradiction and thus assume that truthful revealing equilibrium exists. From Definitions 1 and 2, in such an equilibrium, the following conditions hold:

\[
\sum_{b \in B} \alpha_m(b|\theta^i) \Pi_m(K^*(\theta^i, b)) \geq \sum_{b \in B} \alpha_m(b|\theta^j) \Pi_m(K^*(\theta^j, b)), \quad \forall i, j \in \{L, H\}, \ j \neq i \quad (A2)
\]

Using the same steps as in Lemma 3 we observe that \( K^*(\theta^L, b) < K^*(\theta^H, b) \), \( \forall b \in B \), and thus \( \Pi_m(K^*(\theta^H, b)) > \Pi_m(K^*(\theta^L, b)), \ \forall b \in B \). This implies:

\[
\sum_{b \in B} \alpha_m(b|\theta^i) \Pi_m(K^*(\theta^H, b)) \geq \sum_{b \in B} \alpha_m(b|\theta^i) \Pi_m(K^*(\theta^j, b)), \quad \forall i, j \in \{L, H\}
\]

which contradicts \((A2)\). Therefore, truthful reporting is not supported in equilibrium. Since every cheap-talk game has a babbling equilibrium (Chen et al. (2008)), we can conclude that the only PBNE in the traditional system is the babbling equilibrium.
Proof of Lemma 4. We must look at the following two possible outcomes:

Completely Aligned Incentives \((\Theta \subseteq [\theta_{\text{min}}^b, \theta_{\text{max}}^b])\) Under this condition, the retailer will postpone her procurement decision for all possible reports. Moreover, from Lemma 2 we know that the manufacturer always prefers that the retailer postpones her procurement decision. From these two facts we observe that the manufacturer has no incentive to distort his report, since the retailer’s optimal strategy will always maximize his profit. Knowing that the manufacturer has no incentive to misreport, the retailer does not have any incentive not to trust the manufacturer.

Misaligned Incentives \((\Theta \not\subseteq [\theta_{\text{min}}^b, \theta_{\text{max}}^b])\) Under this condition we must look at two cases: (i) full incentive misalignment \(\Theta \cap [\theta_{\text{min}}^b, \theta_{\text{max}}^b] = \emptyset\) and (ii) partial incentive misalignment \(\Theta \cap [\theta_{\text{min}}^b, \theta_{\text{max}}^b] \neq \emptyset\). We will show that in both cases no revealing PBNE exists:

Case (i): When \(\Theta \cap [\theta_{\text{min}}^b, \theta_{\text{max}}^b] = \emptyset\), regardless of the manufacturer’s type, the retailer will not postpone her procurement decision. Furthermore, from Section 3.2 we know that in the flexible system, when the retailer does not postpone, her optimization problem is the same as that of the traditional system. Thus, under this condition, the manufacturer’s incentive to inflate his report still remains. Therefore, the proof of Lemma 3 holds in this case; thus, we can conclude that in the flexible system when \(\Theta \cap [\theta_{\text{min}}^b, \theta_{\text{max}}^b] = \emptyset\), no revealing PBNE exists.

Case (ii): We next show that no revealing PBNE exists in the partial incentive misalignment case. As in case (i), for \(\theta \notin [\theta_{\text{min}}^b, \theta_{\text{max}}^b]\), the manufacturer’s profit in the flexible system is equal to his profit in the traditional system. Moreover, for \(\theta \in [\theta_{\text{min}}^b, \theta_{\text{max}}^b]\), the manufacturer’s profit in the flexible system is equivalent to that of the traditional system with \(\theta = 1\) and \(w_E = w_E^\tau\), i.e., \(\Pi_m(M_{\text{FS}}^*) = \Pi_m(M_{\text{TS}}^*|\theta = 1 \& w = w_E^\tau\)). It follows that we can construct a payoff equivalent type space for the manufacturer: (1) let \(\theta^{H'}\) denote an artificial manufacturer type with prior probability equal to the prior probability of the manufacturer type that falls within the postponement interval, and with the payoff \(\Pi_m(M_{\text{TS}}^*|\theta = 1 \& w = w_L\)); (2) define the sorted set \(\Theta' = \{\theta \in \Theta|\theta \in [\theta_{\text{min}}^b, \theta_{\text{max}}^b]\} + \theta^{H'}\), which is comprised of the non-postponement element of \(\Theta\) plus \(\theta^{H'}\). We can see that for the manufacturer, the sets \(\Theta\) and \(\Theta'\) are payoff equivalent, i.e., the manufacturer profit for the non-postponement type is the same in both sets, while his profit for the postponement type is equal to his profit for \(\theta^{H'}\). Therefore, for truthful reporting to be supported in equilibrium for the types in \(\Theta\), it must also be supported for the types in \(\Theta'\). However, following the proof of Lemma 3 we know that no such equilibrium exists for \(\Theta'\); thus, no revealing PBNE exists in the partial incentive misalignment case.

\(\Box\)
**Proof of Theorem 2.** From Definitions 1 and 2, necessary conditions for truthful reporting to be supported in equilibrium are:

\[
\sum_b \alpha_m(b|\theta^L)\Pi_m(K(\theta^L, b)) \geq \sum_b \alpha_m(b|\theta^L)\Pi_m(K(\theta^H, b))
\]

\[
\sum_b \alpha_m(b|\theta^H)\Pi_m(K(\theta^H, b)) \geq \sum_b \alpha_m(b|\theta^H)\Pi_m(K(\theta^L, b))
\]

i.e., the left hand side is the manufacturer’s expected profit from truthfully revealing his private information \((S(\theta) = \theta)\) while the right side is his expected profit from misreporting \((S(\theta) \neq \theta)\).

The above two conditions can be re-written as:

\[
\alpha_m(b^L|\theta^L)[\Pi_m(K(\theta^L, b^L)) - \Pi_m(K(\theta^H, b^L))] \geq \alpha_m(b^H|\theta^L)[\Pi_m(K(\theta^H, b^L)) - \Pi_m(K(\theta^L, b^L))], \quad (A3)
\]

\[
\alpha_m(b^H|\theta^H)[\Pi_m(K(\theta^H, b^H)) - \Pi_m(K(\theta^L, b^H))] \geq \alpha_m(b^L|\theta^H)[\Pi_m(K(\theta^L, b^L)) - \Pi_m(K(\theta^H, b^L))]. \quad (A4)
\]

To proceed, we need the following lemma.

**Lemma 5.** In the Flexible System and under non-degenerate postponement strategies,

\[
\Pi_m(K(\theta^L, b^L)) < \Pi_m(K(\theta^H, b^L)) \Rightarrow \Pi_m(K(\theta^H, b^L)) > \Pi_m(K(\theta^L, b^H)).
\]

**Proof.** Under non-degenerate postponement strategies (by non-degenerate strategies we mean that one retailer type’s optimal postponement strategy is to postpone whereas the other type’s strategy is not to postpone), \(\Pi_m(K(\theta^L, b^L)) < \Pi_m(K(\theta^H, b^L))\) implies that when \(b = b^L\), only \(\theta^H\) belongs to the postponement interval. Moreover, from Lemma 2 we know that the postponement interval shrinks as \(b\) increases. Therefore, when \(b = b^H\), the retailer will never postpone if \(\theta = \theta^L\), while it may or may not postpone if \(\theta = \theta^H\). If it does postpone, then, from Corollary 2, \(\Pi_m(K(\theta^H, b^H)) > \Pi_m(K(\theta^L, b^H))\). If she does not postpone, then from Corollary 1, \(\Pi_m(K(\theta^H, b^H)) > \Pi_m(K(\theta^L, b^H))\). \(\square\)

From the above lemma and from conditions (A3) and (A4), truthful reporting can be supported in equilibrium if:

\[
\Pi_m(K(\theta^L, b^L)) - \Pi_m(K(\theta^H, b^L)) > 0,
\]

\[
\Pi_m(K(\theta^H, b^H)) - \Pi_m(K(\theta^L, b^H)) > 0.
\]

Or, equivalently, the preferred report mixture measure must be negative:

\[
\delta = \frac{\Pi_m(K(\theta^H, b^H)) - \Pi_m(K(\theta^L, b^H))}{\Pi_m(K(\theta^H, b^L)) - \Pi_m(K(\theta^L, b^L))} < 0.
\]

By the definition of \(\delta\), and since \(\alpha_m(b|\theta) = \frac{\alpha(\theta, b)}{\sum_{y \in B} \alpha(\theta, y)}\), conditions (A3) and (A4) reduce to:
\[
\frac{\alpha(\theta^L, b^L)}{\alpha(\theta^H, b^H)} \geq |\delta|, \\
\frac{\alpha(\theta^H, b^H)}{\alpha(\theta^H, b^L)} \geq |\frac{1}{2}|.
\]

Finally, the conditions of the theorem are sufficient since they incorporate the retailer’s best-response into the manufacturer’s expected payoff so that truth-telling for the manufacturer is evaluated conditional on the retailer taking her best-reply in the fully revealing (separating) equilibrium in which \( \alpha_r(\theta|\hat{\theta} = \theta, b) = 1 \). \qed