Asymmetric Cost Information and Enforcement in Supply Contract Design

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This paper studies a supply contracting problem where a buyer sources a product from a supplier to satisfy uncertain market demand. With the increasing length and complexity of today’s global supply chains, the buyer may face two issues when designing the supply contract: adverse selection (i.e., the supplier’s cost structure is private information) and lack of enforcement (i.e., the supplier’s capacity investment is not enforceable). We derive the buyer’s optimal contracting strategies and analyze their properties. We find that although the buyer’s optimal mechanism is generally complex, it may reduce to a two-part tariff under certain conditions (i.e., a single, linear contract could be optimal for the buyer). Even when the two-part tariff is suboptimal, it performs nearly as well as the optimal mechanism for a wide range of situations. These findings indicate that the value of achieving enforceability and the value of using complex menu are negligible in such a supply chain setting. Therefore, our research demonstrates that the two-part tariff is an attractive option for buyers whose goal is to ensure supply while facing both cost uncertainty and enforcement issues. It also provides a new explanation for the prevalence of such simple contracts in practice.

Keywords: Supply contract, information asymmetry, enforcement, two-part tariff, global supply chains

1 Introduction

Contracting to assure supply is one of the central issues in supply chain management. Consider a buyer who sources an input (e.g., a product or a component) from a supplier. The buyer faces uncertain demand and, due to procurement time lags, the supplier needs to make capacity-related decisions before the demand has been established. The buyer wants the supplier to be flexible enough to deal with any demand fluctuations, while the supplier needs to keep the risk of overages to a minimum in case the demand for his output ceases. Here, a classic incentive conflict exists within the supply chain: While a more flexible supply may benefit both supply chain members, the supplier may not be willing to undertake the entire risks.

How to achieve sufficient supply to satisfy uncertain demand has become an increasingly important question in the ever-changing market environment. Failing to do so may cause substantial
losses in profits and market shares for both the individual firms and the supply chain. To mention a few examples: In 1999, Apple’s fourth-quarter earnings were severely affected by problems in obtaining enough processors from Motorola to meet demand for its Power Mac G4 desktop computers (Miles, 1999). While seeking to fill a press of aircraft orders, Boeing experienced a shortage of state-of-the-art fasteners at its suppliers (Lunsford and Glader, 2007). Qualcomm executives reported that a capacity shortage at its foundry supplier may prevent it from meeting strong market demand (McGrath, 2012). In view of these lessons, practitioners surely understand the importance of supply flexibility, and many buyers have taken this into consideration when designing sourcing strategies. Sun Microsystems claims that availability and flexible supply will be critical when making their sourcing decisions in case a steep ramp-up is required after introducing a new product (Carbone, 2005). Apple tends to push the suppliers to expand their manufacturing facility to meet the rush demand for its new products, while the suppliers are cautious of overexpanding on Apple hopes (Dou and Luk, 2014). More evidence can be found in both the business media and academic literature (e.g., Tsay, 1999 and Lakenan, Boyd, and Frey, 2001).

By requesting sufficient flexibility, the buyer essentially pushes the supplier to undertake more risks, i.e., the supplier has to carry additional capacity or inventory that will be used only if the realized demand is high. Various contracts that help improve supply chain efficiency have been widely studied in the literature. Most of these studies consider a supply chain consisting of a newsvendor buyer and share two common features. First, it has been assumed that the buyer has complete information about the supplier’s cost structure (i.e., the buyer knows the exact cost for producing and delivering the product). Second, both firms will meet their financial responsibility of capacity or inventory investment (i.e., the firms’ responsibilities are enforceable). For instance, the supplier must faithfully make capacity investment as specified by the contract. This is the so-called forced compliance in the literature (see Cachon, 2003 for a comprehensive survey).

Clearly, the complete information assumption is not perfectly realistic. Firms in a decentralized supply chain are independent organizations and thus often have disparate information. In particular, the supplier’s cost structure should be highly confidential because it conveys significant bargaining power when negotiating a contract. As a result, normally the buyer does not know the supplier’s exact cost in reality, which gives rise to the so-called adverse selection issue. While the forced compliance assumption is reasonable in certain situations (e.g., when firms care about long-term relationships or a penalty mechanism is feasible), there are many cases where enforceability is difficult to achieve. As discussed in Cachon and Lariviere (2001), the contracted capacity may not be enforceable for a couple of reasons: First, capacity is a complex decision that involves
many factors including the supplier’s managerial effort; thus, when a supplier fails to deliver the promised quantity, it might be hard to verify whether this is due to underinvestment in effort or due to reasons beyond the supplier’s control. Second, if the cost of enforcement (e.g., the cost of capacity verification and the cost of lawsuit) is prohibitively high, contract terms that penalize a dishonest supplier might not be credible. Thus we may use voluntary compliance to describe the case where firms’ risk responsibilities are not enforceable in a supply chain.

The above observations indicate that the information and enforcement issues are not uncommon in supply contract design. These issues have become more prominent nowadays because many firms expand their manufacturing and distribution networks overseas, which leads to situations where trading partners are new and distant from each other. For example, in global supply chains of products such as apparel, reneging on contract could be a significant concern (Narayanan and Raman, 2000). These supply chains are prone to the above problems because firms are located in different countries and contract agreements are written long before final delivery. On one hand, buyers might find it difficult to monitor the manufacturer’s activities; on the other hand, manufacturers often worry about that buyers may refuse to accept the products when the realized demand is unexpectedly low. Moreover, global supply chains may lead to higher contract enforcement costs. The World Bank (2008) provides a comparison of the judicial system’s efficiency in resolving commercial disputes in different countries or regions. It shows that developing countries are often associated with less efficient judicial systems (e.g., longer wait time, higher litigation fees, and more complex procedures), which present a major obstacle for these countries to attract foreign businesses and investments (see also Ahlquist and Prakash, 2010). Thus, allowing for asymmetric information and voluntary compliance would be a more appropriate assumption when managing global supply chains.

Although there is a large body of literature on how to improve supply chain efficiency via contractual arrangements, inadequate attention has been paid to supply contracting under asymmetric cost information and voluntary compliance. In particular, these realistic issues have not been fully explored for the classic supply chain setting where a newsvendor buyer procures from an upstream supplier. The main purpose of this paper is to fill such a gap by introducing both incentive issues. A few natural questions arise in this study: What are the buyer’s optimal (profit-maximizing) contracts? How do these incentive issues interact with each other in contract design? How much is the value of using a complex menu as stipulated by the optimal mechanism? Are there any attractive strategies we should recommend to buyers facing such contracting problems? We investigate these questions and obtain the following findings.
First, we study the joint impact of information asymmetry and voluntary compliance on the buyer’s contract design problem. To this end, we derive the buyer’s optimal mechanism under forced compliance as a benchmark, and then compare the buyer’s optimal mechanism under voluntary compliance to the benchmark. We find that the impact of voluntary compliance depends critically on the cost uncertainty faced by the buyer. For ease of exposition, we introduce the modified reverse hazard rate (MRHR) defined by the supplier’s cost distribution. When there is a decreasing MRHR, the buyer can achieve the benchmark solution by offering a menu of linear contracts. Each contract in the menu is essentially a two-part tariff, where the buyer pays the supplier a wholesale price for each product delivered, and charges the supplier a lump-sum payment. However, if the MRHR is strictly increasing for any cost range, then the benchmark solution can no longer be implemented using linear contracts; instead, the buyer can use a menu of quadratic contracts to achieve the benchmark solution. That is, lack of enforcement does not lead to a lower profit for the buyer, but it may require a more complex contract format in implementation.

Second, we show that regardless of the enforcement scheme, the optimal menu of contracts reduces to a single two-part tariff when there is a constant MRHR. In other words, a single, linear contract could be optimal for the buyer. This is true, for example, when the supplier’s cost follows a uniform distribution, which corresponds to situations where the buyer has very limited cost information. When it is optimal for the buyer to exclude some high cost types, the two-part tariff will further simplify to a single wholesale price. This is essentially the pull contract that has been widely observed in practice, where the supplier undertakes the inventory risk and charges the buyer a wholesale price for each unit delivered.

Third, even when a single two-part tariff is not optimal, we find that it yields nearly optimal profit for the buyer for a wide range of practical situations. This means the value of using a complex menu in our problem setting is negligible. Interestingly, we also find that the supply chain profit under the two-part tariff is close to that under the optimal mechanism. This indicates that the simple two-part tariff is also attractive from the supply chain’s perspective. Further investigation shows that both the simple and optimal contracts result in similar capacity levels for the supply chain, which helps explain the above results.

In summary, we show that the value of achieving enforceability and the value of using complex menu are negligible in our contracting problem. This suggests that a more effective way to improve buyer profit is to reduce the information asymmetry rather than design complex screening contracts. However, if reducing uncertainty in supplier cost is not a viable strategy, then we recommend the two-part tariff to managers whose goal is to ensure supply under both adverse selection and
enforcement issues. Such a contract has a simple format, yields nearly optimal profit, and is enforcement-free. This key result corroborates the prevalence of such simple contracts in practice.

The rest of the paper is organized as follows. The next section reviews the literature and Section 3 describes the model. Section 4 presents the optimal contracts for the buyer under different enforcement schemes and analyzes their properties. Section 5 compares these contracts and discusses the managerial implications. This paper concludes with Section 6. All proofs are given in the Appendix.

2 Literature Review

This paper studies a contracting problem in a supply chain consisting of a supplier and a newsvendor buyer. Several key elements have been considered in this research: (1) asymmetric cost information; (2) enforcement of risk responsibilities; and (3) performance of simple contracts. Based on these elements, the related literature can be divided into the following categories.

First, this paper is related to the growing literature that study supply chain management under asymmetric cost information. A detailed review of earlier studies can be found in Chen (2007). Among these studies the closest work is Ha (2001). Ha (2001) considers a similar supply chain setting except that the retailer is a price-setting newsvendor with private cost information. It has been shown that a menu of contracts with a cut-off level is optimal for the supplier, and the optimal order quantity is lower under asymmetric information than under complete information. Other representative studies that involve retailer private cost information include Corbett (2001), Corbett et al. (2004), and Lutze and Özer (2008). In our model, a newsvendor procures from a supplier whose capacity cost is private information, which is different from these existing studies. In addition, although these studies consider asymmetric cost information, they do not focus on the issues of enforcement and the performance of simple contracts.

Second, there are papers that consider the enforcement of capacity risk allocation in a supply chain, which is related to the problem we study here. Cachon and Lariviere (2001) study demand information sharing between supply chain members. They coin the terms “forced compliance” and “voluntary compliance” to distinguish between different enforcement scenarios. Durango-Cohen and Yano (2006) study a quantity flexibility contract with a non-enforceable supplier. However, the supplier can make capacity commitment to his customer and may face shortage penalties if he deviates from the committed quantity. In our paper we adopt the voluntary compliance defined in Cachon and Lariviere (2001), where the supplier can freely choose his capacity decision because non-verifiability prevents any potential shortage penalty imposed on the supplier.
There is a literature in economics that investigates asymmetric information and moral hazard in the principal-agent framework. Under moral hazard, the observable outcome is contaminated by a random noise; as a result, the principal may not be able to verify the agent’s effort based on the outcome. Clearly, moral hazard could give rise to non-verifiability. Laffont and Tirole (1986), McAfee and McMillan (1986), and Caillaud et al. (1992), among others, show that a menu of linear contracts is optimal for the principal in various problem settings. Melumad and Reichelstein (1989) characterize the condition under which the value of communication has no value, i.e., the principal only needs to offer a single contract (rather than a menu of contracts). Such principal-agent framework has later been applied to study quality improvement and cost reduction efforts in outsourcing settings; see, for example, Lewis and Sappington (1991) and Kim and Netessine (2013). Our paper differs from this line of research in important aspects. First, moral hazard is not necessarily equivalent to voluntary compliance. If the observed outcome is informative enough to determine the agent’s actual effort, then the agent action becomes essentially enforceable via severe penalty even under moral hazard. One example is when the random noise has a bounded support so that there is a positive probability that the principal can infer the agent’s action (see Bolton and Dewatripont, 2005). Second, we study a supply chain setting in which the supplier makes capacity investment decision (to improve product availability under demand uncertainty), rather than effort decision (to improve cost or quality). Third, our paper demonstrates that a single, linear contract could be optimal for the principal under certain conditions; even when it is suboptimal, the contract can yield close-to-optimal performance. These results, to our knowledge, have not been reported in the literature.

Lastly, the importance of simplicity in procurement contract design has long been recognized in the literature. Hart and Holmstrom (1987) point out there is a contrast between the complexity of theoretically optimal contracts and the simplicity of many real-world arrangements. A number of economics studies have been devoted to explaining such a discrepancy between theory and practice; see, for example, Chu and Sappington (2007) and the references therein. Recently, there have been a growing number of studies in operations management that investigate the performance of simple procurement mechanisms, including Cachon and Zhang (2006), Kayş et al. (2013), Zhang (2010), Kalkanci et al. (2011), Duenyas et al. (2013), and Lobel and Xiao (2013). Our paper is in a similar spirit by providing an explanation of the prevalence of simple contracts (either two-part tariff or wholesale price contracts) in supply chain settings. However, both the model setting and analysis are quite different from these existing studies.
3 Model Description

We consider a two-stage supply chain consisting of a buyer and a supplier. Hereafter we use “she” to refer to the buyer and “he” the supplier. The buyer can be viewed as a newsvendor firm. She sources a perishable product from the supplier and then sells it to customers in a single selling season. There is an exogenously given market price $p$ and market demand is uncertain. Let $D$ denote the random demand with distribution function $\Phi$ and density function $\phi$. For ease of exposition, we assume that the salvage value for any excess capacity is zero. Also there is no penalty cost for unsatisfied demand during the selling season. Including a positive salvage value or penalty cost will not change the qualitative results from our model.

Due to long acquisition lead times, the supplier needs to make capacity investments before the selling season starts. The capacity may refer to all the resources (e.g., raw materials, production facility, and labor) that are needed to produce the product for the buyer. We assume the capacity can be instantly converted into the product at zero cost. Alternatively, we may assume the supplier builds up inventory to satisfy the buyer’s order, which is quite common in the supply contracting literature. Thus the concepts of capacity and inventory are exchangeable in this paper. There is a unit capacity cost $c$, which is the supplier’s private information. Due to various uncertain factors (e.g., technology, production yield, and raw material price), the buyer does not know the exact cost $c$, but she has an unbiased belief about its distribution. Without losing generality, let $[0, \bar{c}]$ $(\bar{c} > 0)$ be the support of $c$, and let $F$ and $f$ denote its distribution and density functions, respectively. We assume $F$ has a decreasing reversed hazard rate (RHR), i.e., $f(x)/F(x)$ is decreasing in $x$. This is equivalent to the log-concavity assumption widely adopted in mechanism design problems. We use the decreasing RHR assumption rather than the log-concavity assumption because we will introduce a modified reversed hazard rate (MRHR) later in this paper. Most commonly used distributions have a decreasing RHR, including uniform, normal, exponential, and logistic distributions (see Bagnoli and Bergstrom, 2005 for details).

As discussed in the introduction, we consider two enforcement schemes in this paper. Under forced compliance, the firms will faithfully meet their risk responsibilities. In this case, the contract may include terms that govern the capacity risk allocation between the firms. For instance, the contract may explicitly require a capacity investment for the supplier. Under voluntary compliance, in contrast, the firms’ actions are not verifiable or contract enforcement is prohibitively costly. As a result, there could be non-enforceability issues in the supply chain (e.g., the global supply chain for apparel products described in Narayanan and Raman, 2000). In this case, it is no longer viable for
firms to devise contract terms to enforce capacity investment from the supplier. For example, the buyer cannot specify a target capacity investment for the supplier and then penalize the supplier if he fails to meet the target. This is because the supplier can always claim that the shortage is not due to underinvestment in capacity but for reasons beyond his control. An alternative interpretation of the voluntary compliance is that the firms want to arrange an enforcement-free (or incentive compatible) contract, i.e., they do not contract on capacity risk responsibilities to avoid any enforcement related costs (e.g., monitoring, litigation, etc.). These two enforcement schemes, though extreme, may serve as useful benchmarks to study supply contracting problems. For example, Cachon and Lariviere (2001) are among the first to analyze and compare these two schemes when studying demand forecast sharing. Thus in this paper we will follow the literature to focus on these two enforcement schemes.

We assume the buyer takes the initiative to offer a take-it-or-leave-it contract to the supplier. Both supply chain firms are risk neutral and the objective is to maximize their own expected profit. In general, the supplier may have a reservation profit, which is defined as the value of the best outside option. A higher reservation profit corresponds to a more advantageous bargaining position for the supplier. We normalize the supplier’s reservation profit to zero because adding a positive reservation profit does not generate much new insight. All parameters are common knowledge except the supplier’s capacity cost, $c$. The sequence of events is as follows: (1) the buyer offers a menu of contracts to the supplier; (2) the supplier chooses a contract from the menu and then invests in capacity accordingly; (3) market demand is confirmed and the buyer orders from the supplier to satisfy demand. For simplicity, we assume there will be no re-negotiation after the supplier reveals its cost information.

Define $\Phi = 1 - \Phi$. Let $E$ denote the expectation operation and $K$ be the supplier’s capacity level. Then the supply chain’s expected profit can be written as $\pi_{sc}(K) = pE_D[\min(K, D)] - cK$ (we use subscript $sc$ for supply chain), and the optimal capacity that maximizes $\pi_{sc}(K)$ is given by the critical fractile solution $K^*(c) = \Phi^{-1} \left( \frac{p-c}{p} \right)$. It is clear that if the buyer knows the supplier’s cost, then she will choose the supply chain optimal capacity and extract all the surplus. This is the so-called first-best solution in the literature. Next we study the buyer’s contract design problem when she is not perfectly informed about the supplier’s cost; in this case, the buyer’s optimal contract is commonly referred to as the second-best solution. Given the existence of information asymmetry, we will use the second-best solution as the benchmark to evaluate other suboptimal contracts. Thus in the rest of the paper, by “optimal” we refer to the “second-best” outcome. For example, the buyer’s optimal profit is defined as her profit in the second-best solution.
4 Analysis of Optimal Contracts

This section presents the optimal contracts that maximize the buyer’s profit under two enforcement schemes: forced compliance and voluntary compliance. We characterize the optimal contracts for each scheme and then compare their properties. Solving the buyer’s optimal contract is essentially an optimal mechanism design problem. A mechanism is a mapping from the supplier’s information space to the firms’ action and payment schedules. Although the range of possible mechanisms is quite large, according to the Revelation Principle (see Bolton and Dewatripont 2005, Laffont and Mattrimort 2002), there exists a direct (i.e., the supplier’s information space is his private cost) and truth-inducing (i.e., the supplier finds it optimal to reveal his true cost value) mechanism that is optimal for the buyer. Thus we will focus on the direct and truth-inducing mechanisms in this section.

4.1 Adverse Selection under Forced Compliance

First we study the buyer’s contract design problem under forced compliance, i.e., the supplier will faithfully undertake the risk responsibility stipulated by the contract. Due to the presence of information asymmetry, the buyer needs to offer a menu of contracts to the supplier. By choosing a contract from the menu, the supplier essentially announces his capacity cost. Consider the following menu of contracts \( \{K(x), T(x)\} \): If the supplier announces his capacity cost to be \( x \) (by choosing the corresponding contract), then the supplier will build a total capacity \( K(x) \) and receive a lump-sum payment \( T(x) \) from the buyer. In our model setting, the buyer’s payoff only depends on the supply chain total profit and the split of the profit between the two parties. Since the supply chain profit is solely determined by \( K(x) \) and the profit split can be implemented using \( T(x) \), the terms \( K(x) \) and \( T(x) \) will be sufficient when solving the buyer’s optimal mechanism. In other words, it is without losing optimality to focus on the contract format \( \{K(x), T(x)\} \). Although such a format is not natural from a practical perspective (e.g., the payment \( T(x) \) between the two parties is independent of the actual transaction volume), it will serve as a theoretical benchmark to evaluate other contracts studied in this paper. It is worth noting that there are alternative contract formats that can implement the same outcome as \( \{K^o(x), T^o(x)\} \). For example, we may replace the lump-sum payment term \( T^o(x) \) by a unit price \( w^o(x) \). Since the buyer is risk-neutral, the contract \( \{K^o(x), w^o(x)\} \) would be equivalent to \( \{K^o(x), T^o(x)\} \) as long as \( w^o(x)ED[\min(K^o(x), D)] = T^o(x) \).

Next we derive the optimal functions \( \{K^o(x), T^o(x)\} \) that maximize the buyer’s expected profit.

Suppose the supplier’s true cost is \( c \) but he announces \( x \); then the supplier’s profit function is
\( \pi_s(x; c) = T(x) - cK(x). \)  
\hspace{1cm} (1)

In the profit function, \( x \) is a decision variable while \( c \) is a parameter. The buyer’s profit can be written as (we use subscript \( b \) for buyer):

\[ \pi_b(x) = pE_D[\min(K(x), D)] - T(x). \]  
\hspace{1cm} (2)

There are two constraints imposed on the mechanism design problem. The first constraint is the incentive-compatibility constraint (IC), which guarantees supplier’s truth-telling:

\[ c = \arg \max_x \pi_s(x; c) \text{ for all } c \in [0, \bar{c}]. \]  
\hspace{1cm} (3)

The second is the individual rationality constraint (IR), which guarantees the participation from the supplier:

\[ \pi_s(c; c) \geq 0 \text{ for all } c \in [0, \bar{c}]. \]  
\hspace{1cm} (4)

The right-hand side of the inequality is zero because we have assumed that the supplier has a zero reservation profit. Now the buyer’s optimal mechanism can be solved from the following optimal control problem:

\[
\max_{\{K(\cdot), T(\cdot)\}} \int_0^{\bar{c}} \pi_b(x)f(x)dx \\
s.t. \ (3), \ (4),
\]
\hspace{1cm} (5)

where \( \pi_b(x) \) is given in (2). Let \( \hat{c}^o \) be the solution to

\[ p - (x + F(x)/f(x)) = 0 \]
\hspace{1cm} (6)

if a solution exists within \([0, \bar{c}]\); otherwise set \( \hat{c}^o = \bar{c} \). Then we have the following proposition.

**Proposition 1** Under forced compliance, the following menu of contracts \( \{K^o(x), T^o(x)\} \) is optimal for the buyer: For \( x > \hat{c}^o \), there is \( K^o(x) = 0 \) and \( T^o(x) = 0 \), i.e., the buyer procures nothing from the supplier; otherwise there is

\[ K^o(x) = \Phi^{-1} \left( \frac{p - (x + F(x)/f(x))}{p} \right), \]  
\hspace{1cm} (7)

\[ T^o(x) = xK^o(x) + \int_x^{\hat{c}} K^o(z)dz. \]  
\hspace{1cm} (8)
The buyer’s optimal mechanism in Proposition 1 represents a threshold policy. When \( \hat{c}_o < \bar{c} \), the buyer would refuse to do business with the supplier if his cost is greater than the threshold value, \( \hat{c}_o \). Note that \( \hat{c}_o \) only depends on the price \( p \) and the distribution function \( F \). Similar threshold policies appear elsewhere in the literature on contracting under asymmetric information; examples include Ha (2001), Corbett et al. (2004), and Lutze and Özer (2008). Due to the log-concavity property of \( F \), an immediate result is that \( K_o(x) \) is decreasing in \( x \), i.e., a higher supplier cost leads to a lower capacity in the optimal mechanism. It is clear that \( K_o(x) < K^*(x) \) for \( F(x)/f(x) > 0 \), i.e., the optimal mechanism does not coordinate the supply chain. This distortion is caused by the buyer’s intention to maximize her own profit under asymmetric information. The lump-sum payment in the optimal mechanism consists of two parts: The first part is to compensate the supplier’s capacity investment, while the second is the supplier’s information rent (or expected profit).

4.2 Adverse Selection under Voluntary Compliance

We proceed to study the buyer’s contracting problem under voluntary compliance, i.e., the supplier’s action is not contractible due to lack of enforceability. In particular, the contract cannot force the supplier to build sufficient capacity, nor can it penalize the supplier for deviating from a target capacity level. Instead, the buyer can only offer a contract based on the supplier’s delivered quantity, which may induce the capacity that the buyer desires. Consider a menu of payments \( \{T(x, z)\} \) the buyer may offer to the supplier, where \( x \) is the announced capacity cost (or, equivalently, the menu selected by the supplier), \( z = \min(K, D) \) is the actual quantity delivered by the supplier, and \( T \) is a general function of \( x \) and \( z \). Under this contract, the supplier chooses the cost-to-announce \( x \) and capacity decision \( K \) to maximize his profit function:

\[
\pi_s(x, K; c) = E_D [T(x, \min(K, D))] - cK.
\]

The first-order condition for the supplier’s optimal capacity choice given cost \( c \) is

\[
\frac{\partial \pi_s(x, K; c)}{\partial K} = (1 - \Phi(K)) \frac{\partial T(x, K)}{\partial K} - c = 0.
\]

Under truth-telling, the above first-order condition becomes

\[
(1 - \Phi(K)) \frac{\partial T(x, K)}{\partial K} - x = 0 \quad \text{for all } x. \tag{9}
\]

The buyer’s profit function given supplier cost \( x \) can be written as

\[
\pi_b(x) = p E_D(\min(K, D)) - E_D [T(x, \min(K, D))]. \tag{10}
\]
The IC and IR constraints are the same as in (3) and (4). Then the buyer’s optimal mechanism design problem is as follows:

\[
\max_{\{T(\cdot, \cdot)\}} \int_0^\infty \pi_b(x)f(x)\,dx
\quad\text{s.t. (3), (4), and (9).}
\]

where \(\pi_b(x)\) is given in (10).

The analysis of the optimal mechanism for voluntary compliance is more involved because the payment schedule \(T(x, z)\) is a function of both \(x\) and \(z\). Before presenting the optimal solution, we define the modified reversed hazard rate (MRHR) to be

\[
H(x) = \frac{xf(x)}{F(x)}.
\]

We call it MRHR because it is defined as the RHR multiplied by \(x\). It has been assumed there is a decreasing RHR (i.e., \(f(x)/F(x)\) is decreasing in \(x\)); however, this does not guarantee the MRHR is also decreasing. In fact, the MRHR may be either increasing or decreasing in \(x\). Later we will see that the monotonicity property of the MRHR plays an important role in the optimal mechanism.

An interesting comparison can be made with the increasing Failure Rate (FR) and the increasing Generalized Failure Rate (GFR) properties studied in Lariviere and Porteus (2001) and Lariviere (2006). There are three major differences here: First, in the setting studied by Lariviere and Porteus, the GFR and FR concepts are associated with the demand distribution, while the RHR and MRHR concepts are defined on the cost distribution; second, here we focus on the reversed hazard rate (rather than the hazard rate/failure rate); third, MRHR is not a generalized version of RHR because a decreasing RHR does not necessarily imply a decreasing MRHR. As preparation, the following lemma characterizes the properties of the buyer’s optimal mechanism.

**Lemma 1** Under voluntary compliance, the following conditions must hold in a truth-telling optimal mechanism:

(i) The payment schedule \(T(x, z)\) satisfies

\[
\frac{\partial^2 T(x, K)}{\partial x \partial K} \left(1 - \Phi(K)\right) - \left(\frac{\partial T(x, K)}{\partial K}\right)^2 \phi(K) \geq 0.
\]

(ii) It induces the capacity level given in (7), i.e., \(K^o(x) = \Phi^{-1}\left(\frac{p - (x + F(x)/f(x))}{p}\right)\).

The inequality in Lemma 1(i) is the second-order condition for truth-telling, or incentive compatibility (see the proof of Lemma 1). This condition will later help explain how \(H(x)\) affects the
format of the optimal mechanism. Lemma 1(ii) states that the (induced) optimal capacity under voluntary compliance should be identical to that under forced compliance. This is intuitive because $K_0(x)$ represents the most efficient capacity investment under adverse selection according to Proposition 1. Given this condition, we only need to focus on the payment schedule that can induce the capacity $K_0(x)$. Next we present the buyer’s optimal mechanism under decreasing MRHR and increasing MRHR, respectively.

4.2.1 Decreasing MRHR

We first consider the case where $F$ has a decreasing MRHR. The buyer’s optimal mechanism is given by the following proposition. Although $T(x, z)$ can take any general functional format, the proposition shows that a menu of linear contracts can achieve the second-best solution for the buyer.

**Proposition 2** Suppose $F$ has a decreasing MRHR ($H'(x) \leq 0$) for $x \in [0, \bar{c}]$. Under voluntary compliance, the following menu of contracts \{ $T_0(x, z) = w_0(x)z + \hat{T}_0(x)$ \} is optimal for the buyer: For $x > \hat{c}^o$, there is $T_0(x, z) = 0$, i.e., the buyer procures nothing from the supplier; for $x \leq \hat{c}^o$, there is

\[
\begin{align*}
    w_0^o(x) &= \frac{pH(x)}{1 + H(x)}, \\
    \hat{T}_0^o(x) &= xK_0^o(x) - w_0^o(x)ED[\min(K_0^o(x), D)] + \int_0^{\hat{c}} K_0^o(z)dz,
\end{align*}
\]

where $K_0^o(x) = \Phi^{-1}\left(\frac{p-(x+F(x)/f(x))}{p}\right)$ is the capacity induced by $T_0^o(x, z)$.

An important observation from Proposition 2 is that when $H'(x) \leq 0$, the buyer’s second-best solution can be implemented using a menu of linear contracts. That is, for each contract in the menu, the buyer offers a wholesale price $w_0^o(x)$ to induce the desired capacity $K_0^o(x)$, and then use a side payment $\hat{T}_0^o(x)$ to split the profit between the two parties. This format represents the commonly observed two-part tariff arrangement; see Vettas (2011) for practical examples of such a contract format in retail, wholesale, and technology licensing markets. This contract has a linear format, so we will use linear contract and two-part tariff exchangeably in the rest of the paper. The two-part tariff contractual format has been widely studied in the literature. It is well known that such a contract can coordinate a decentralized distribution channel (see, e.g., Moorthy, 1987). Although our optimal contract \{ $T_0^o(x, z) = w_0^o(x)z + \hat{T}_0^o(x)$ \} has the same format as the traditional two-part tariff contract, its underlying rationale is different. In a coordinating two-part tariff contract, the
unit price must be equal to the supplier’s marginal cost to avoid double marginalization. However, here \( w^o \) must be greater than the supplier’s marginal cost in our setting (otherwise the supplier would invest nothing in capacity). The reason for this difference is as follows: It is the buyer who designs the contract and the buyer does not have perfect information about the supplier’s cost structure.

We may compare the optimal mechanisms under voluntary compliance (Proposition 2) and forced compliance (Proposition 1). First, the capacity levels are exactly the same in these two mechanisms. Second, in the \( \{ T^o(x, z) \} \) mechanism, the buyer needs to pay a wholesale price \( w^o(x) \) for each product delivered, which does not exist in the \( \{ K^o(x), T^o(x) \} \) mechanism; however, Equation (15) shows that such a wholesale price payment is subtracted from the lump-sum payment in the \( \{ T^o(x, z) \} \) mechanism. Combining these two observations we know that the optimal mechanisms in Propositions 2 and 1 are essentially identical, which implies that the buyer will be equally well-off regardless of the enforcement scheme if there is a decreasing MRHR. In other words, achieving enforceability has no value for the buyer when the cost distribution has a decreasing MRHR.

### 4.2.2 Increasing MRHR

We continue to study the buyer’s optimal mechanism when the MRHR can be strictly increasing, i.e., \( H'(x) > 0 \), for some \( x \).

**Proposition 3** Suppose \( F \) has a strictly increasing MRHR \( (H'(x) > 0) \) for some \( x \) in \([0, \bar{c}]\). Then, under voluntary compliance, the second-best solution cannot be achieved using a menu of linear contracts. However, there is a menu of quadratic contracts \( \{ T^o(x, z) = w_1^0 z^2 + w_2^0(x) z + \hat{T}^o(x) \} \) that can achieve the second-best solution for the buyer.

The above proposition indicates that under strictly increasing MRHR, the buyer can still achieve the second-best profit under voluntary compliance; however, a more complicated contract format (e.g., a quadratic payment schedule) is required for implementation. The explanation of this result is as follows. Suppose there is a linear payment function \( T(x, z) = w(x) z + \hat{T}(x) \). Then the condition in Lemma 1(i) becomes

\[
\frac{w'(x)}{-w(x)\phi(K)} \geq 0,
\]

or simply \( w'(x) \leq 0 \). That is, the second-order condition for truth-telling reduces to \( w'(x) \leq 0 \). Under such a linear payment scheme, the supplier faces a newsvendor problem and his optimal capacity satisfies \( \Phi(K) = \frac{w(x) - x}{w(x)} \). Together with Lemma 1(ii), we get

\[
w(x) = \frac{px}{x + F(x)/f(x)} = \frac{pH(x)}{1 + H(x)}.
\]
Clearly, $w'(x) \leq 0$ if and only if $H'(x) \leq 0$. So there is a conflict between the two conditions in Lemma 1 when there is $H'(x) > 0$ for some $x$. This reveals an interesting interaction between the two incentive issues studied in this paper: Lack of enforcement imposes an additional requirement on the wholesale price (since the buyer must rely on the wholesale price to induce a certain capacity level), which may counteract the incentive compatibility condition. Because of such a conflict, a linear payment function cannot be optimal for the buyer under strictly increasing MRHR. As a result, a more complicated contract format is needed in order to achieve the second-best profit for the buyer.

Although the buyer can still achieve the second-best profit, the quadratic payment schedule is complex and less intuitive. The simplicity of the linear format has been lauded in the incentive literature (see, e.g., Laffont and Tirole 1986 and McAfee and McMillan 1986). What will happen if the buyer is restricted to a linear contract format? We also investigate this question and find that under the more practical linear format, there will be bunching in the optimal mechanism because the buyer may be unable to screen all the supplier types. The next proposition formalizes this result. It can be readily shown that $H'(x) > 0$ holds for at most one interval for many commonly used distributions; therefore, for illustration purpose we will focus on this case in the following proposition.

**Proposition 4** Suppose $F$ has a strictly increasing MRHR ($H'(x) > 0$) for a single interval in $[0, \bar{c}]$. Then, under voluntary compliance, the linear contract $\{T(x, z) = w(x)z + \hat{T}(x)\}$ will lead to a bunching interval $[c_1, c_2]$, within which the contract reduces to a constant payment $\{T^o(z) = w^o z + \hat{T}^o\}$. In particular, we can solve $\{c_1, c_2, w^o\}$ from the following simultaneous equations:

\[
\begin{align*}
    w^o &= \frac{pH(c_1)}{1 + H(c_1)}, \quad (16) \\
    w^o &= \frac{pH(c_2)}{1 + H(c_2)}, \quad (17) \\
    0 &= \int_{c_1}^{c_2} \left( \frac{x}{\phi(K(x))(w^o)^2} \right) [ (p\Phi(K(x)) - x)f(x) - F(x) ] \, dx, \quad (18)
\end{align*}
\]

where $K(x) = \Phi^{-1} \left( \frac{w^o - x}{w^o} \right)$. If bunching starts at the lower bound of the support, then we replace (16) by $c_1 = 0$; if bunching ends at the upper bound of the support, then we replace (17) by $c_2 = \bar{c}$. The transfer payment $\hat{T}^o$ on the bunching interval is given by

\[
\hat{T}^o = c_2 K(c_2) - w^o E_D[\min(K(c_2), D)] + \int_{c_2}^{\bar{c}} K(x) dx. \quad (19)
\]

The optimal menu $\{T^o(x, z) = w^o(x)z + \hat{T}^o(x)\}$ for $x \notin [c_1, c_2]$ is the same as in Proposition 2.
When $H'(x) > 0$, the linear payment schedule will violate the incentive compatiibility constraint. Thus the buyer needs to offer constant contract terms to certain supplier types. The inability to screen the supplier types (i.e., pooling) under voluntary compliance may lead to a lower profit for the buyer compared to the case of full separating. This leads to another question: What is the trade-off between simplicity and lost profit under voluntary compliance with strictly increasing MRHR? In Section 5 we will shed some light on this question by examining the magnitude of such a profit loss caused by lack of enforcement when the buyer is restricted to a linear contract format.

The above discussion spotlights the important role of the MRHR function, $H(x)$, in the format and performance of the buyer’s optimal contract. Since $H(x)$ is defined by the cost distribution $F$, we know the optimal contract depends critically on the shape of the cost uncertainty. The following proposition provides guidelines to verify the property of $H(x)$. Note that we restrict our attention to log-concave distributions in this paper.

**Proposition 5** Suppose $H(x)$ is the MRHR of the log-concave distribution function $F$ of a random variable $X$.

(i) The following statements are equivalent: (1) $H'(x) \leq 0$; (2) the distribution function of $\ln X$ is log-concave; (3) the RHR of the distribution function of $\lambda X$ ($\lambda \geq 1$) is increasing in $\lambda$; (4) $kX$ ($k > 0$) has a decreasing MRHR.

(ii) A necessary condition for $H'(x) \leq 0$ is that $F$ has an increasing generalized failure rate (IGFR).

(iii) $H'(x) \leq 0$ for uniform, exponential, gamma, beta, weibull, chi, chi-squared, and power function distributions.

(iv) For normal, logistic, and extreme value distributions, the condition $H'(x) \leq 0$ is violated for at most one interval.

We can see from Proposition 5 that under the log-concavity condition, many distributions have decreasing MRHR, including exponential, gamma, beta, chi, and chi-squared distributions. However, it is not uncommon for increasing MRHR to arise as well: For normal, logistic, and extreme value distributions, the condition $H'(x) \leq 0$ is violated for a single interval on the support. There are also some distribution functions that have constant MRHR (e.g., power function distribution and uniform distributions).
5 Simple Contracts

We have characterized the buyer’s optimal contracts for different enforcement scenarios in Section 4. These optimal contracts are complicated and therefore not straightforward to implement in practice: First, they involve complex menus that are difficult to derive and explain to managers; second, they require the supplier’s cost as an input, which imposes communication and evaluation burdens on the supplier. As mentioned in the literature review, simplicity is a virtue, and the importance of simple contracts has long been emphasized by both academics and practitioners.

For instance, how to implement the optimal menu of contracts by a single payment schedule has been discussed in the incentive literature (Melumad and Reichelstein, 1989 and Caillaud et al., 1992). It is noteworthy that a menu of contracts is not necessary to implement the second-best solution in our problem setting. To see this, let $\hat{x}^{-1}(K)$ denote the inverted function of $K^o(x)$, i.e., the supplier type that corresponds to the capacity $K^o$. It can be readily shown that the optimal mechanism can be implemented using a single payment schedule $T^o(K) = T^o(\hat{x}^{-1}(K))$ based on the supplier’s chosen capacity (rather than the announced cost $x$). However, such a single payment schedule is nonlinear and still quite complex. So what is the value of using a complex menu in supply contracting? To answer this question, we study a single two-part tariff $\{w^o, T^o\}$ in this section, i.e., the buyer pays a wholesale price $w^o$ and a lump-sum payment $T^o$ to the supplier. This contract is simpler than the optimal contracts in Section 4 because it only involves a single, linear payment function. Next we examine the performance of such a simple contract relative to the optimal contracts.

5.1 Optimality of Simple Contracts

Recall from Proposition 2 that the buyer’s second-best solution can be implemented by a menu of two-part tariffs $\{w^o(x), T^o(x)\}$, where $w^o(x) = \frac{pH(x)}{1+H(x)}$. If $H(x)$ is a constant ($H'(x) = 0$), then both $w^o(x)$ and $T^o(x)$ will be independent of $x$. This indicates that the optimal contracts may reduce to a single two-part tariff under certain conditions. The following proposition confirms this conjecture.

Proposition 6 If $H'(x) = 0$ for all $x \in [0, \bar{c}]$, then the optimal menu of contracts under both enforcement schemes reduces to a single two-part tariff $\{w^o, T^o\}$. This happens if and only if the supplier’s cost has a density $f(x) = \delta x^{\eta-1}$, $\delta > 0$, $\eta > 0$. Additionally, if $\bar{c}^o \leq \bar{c}$, then $w^o = \bar{c}^o$ and $T^o = 0$.
Proposition 6 states that a two-part tariff consisting of only two numbers \( \{w^o, T^o\} \) could be optimal for the buyer when \( H'(x) = 0 \) for all \( x \in [0, \bar{c}] \). Further, if \( \bar{c}^o \leq \bar{c} \), then there must be \( T^o = 0 \) and the \( \{w^o, T^o\} \) contract further reduces to a single wholesale price \( w^o = \bar{c}^o \) that can be easily determined. Note \( \bar{c}^o \leq \bar{c} \) means the buyer wishes to exclude some high cost types, which tends to happen if the supplier has too wide a cost support (or \( \bar{c} \) is relatively large compared to \( p \)). In this case, an exceedingly simple arrangement is optimal for the buyer: The two parties agree upon a unit price and the supplier decides on how much capacity to invest. This is essentially a *pull contract* widely observed in practice, under which the buyer pulls inventory from the supplier and meanwhile pays a wholesale price. Cachon (2004) discusses an example of pull contract from the high-end bicycle industry. In the semiconductor equipment industry, buyers often share a demand forecast with their suppliers. The demand forecast serves as an informal or soft order intended to guide the supplier’s production decisions. After observing the actual demand, a buyer is able to cancel or renegotiate the soft order (see Cohen et al., 2003 and Johnson, 2003). Similarly, Kurt Salmon Associates Reports (1993) indicate that 80% of the wholesale transactions in the grocery industry are “forward buy” in nature, where buyers place tentative orders in anticipation of demand growth. They are prone to cancelling their orders if the actual demand falls short of what they have expected. In all these examples, wholesale price arrangements are used and the buyer simply pulls inventory from the supplier when demand arrives.

Previous research suggests that a wholesale price contract may cause significant supply chain inefficiency due to double marginalization (see Lariviere and Porteus, 2001 and Cachon, 2004). However, interestingly, we find that it actually could be optimal for a buyer under adverse selection. While some existing research (e.g., Cachon and Zhang, 2006) shows that various simple procurement contracts could perform nearly as well as the complex optimal mechanisms, we identify situations where wholesale price contract is theoretically optimal from a buyer’s standpoint. The optimality of a wholesale price contract has not been previously reported in the literature, especially for the classic supply chain under study. It may provide a new explanation of the wide use of wholesale price contracts (e.g., pull contracts) in practice.

To help the buyer choose the optimal contract format, we examine the distributions satisfying the condition in Proposition 6, i.e., \( f(x) = \delta x^{\eta-1} \) with \( \delta > 0 \) and \( \eta > 0 \). Such a condition is satisfied by many plausible density functions that could be either decreasing (\( \eta < 1 \)), increasing (\( \eta > 1 \)), or constant (\( \eta = 1 \)). Figure 1 shows several example distributions in which \( \delta = \eta / \bar{c}^o \) and \( \eta \in \{0.5, 1, 2\} \). Two special cases are worth mentioning. First, \( f \) is a uniform distribution when \( \eta = 1 \). A uniform distribution means that the buyer has no reason to believe that certain cost realizations
are more likely to happen than the others. Hence Proposition 6 indicates that a two-part tariff or even a pull contract could achieve the optimal profit if the buyer has extremely limited information about the supplier’s capacity cost. Interestingly, the adoption of a uniform cost distribution is in line with the Laplace Principle on decision making under uncertainty. The principle states that in the absence of reason to do otherwise, a decision maker may assume each of the possible outcomes of the random event has an equal likelihood of occurrence. This suggests that if the buyer does not know the supplier well (which could be quite common especially when the supplier is new or located far away), then the buyer may follow such a principle to assume a uniform cost uncertainty distribution. Then our result indicates that the simple pull contract may be optimal for the buyer.

Second, $f$ is an increasing function for $\eta \geq 2$. This means that the uncertainty is biased towards high capacity costs. Again this may lead to an optimal two-part tariff contract. From Figure 1 and the accompanying discussion, we can see that the optimality of simple two-part tariff contact or even pull contract may hold under quite reasonable cost uncertainties.

### 5.2 Performance of Simple Contracts

We know from Section 5.1 that the simple contract $\{w^o, T^o\}$ coincide with the optimal mechanism for cost distributions with $H'(x) = 0$. A natural question to ask next is: How does the simple contract perform under more general cost uncertainties? An analytical comparison between the simple contract and the optimal mechanism is challenging in general, so we first derive some insights.
using a special case with linear cost density and uniform demand distribution. Let \( \pi_b^{OM} \) and \( \pi_b^S \) denote the buyer’s profits under optimal mechanism and simple contract, respectively. Then the ratio \( (\pi_b^{OM} - \pi_b^S) / \pi_b^S \) (i.e., the percentage profit gain by using the optimal mechanism) can be used to measure the value of using a menu of contracts, which, equivalently, also measures the performance of the simple contract.

**Proposition 7** Suppose \( f(x) = \alpha + \delta x \) on a support \([0, 1]\) and \( \Phi \) is uniform on \([0, 1]\). Assume \( \hat{\alpha} \geq 1 \) and \( \hat{w} \geq 1 \), i.e., no supplier type is excluded under both contracts. Then the ratio \( (\pi_b^{OM} - \pi_b^S) / \pi_b^S \) has an upper bound \( \frac{1}{8\pi} \) (\( \approx 2.08\% \)) for \( 0 \leq \delta \leq 2 \), and an upper bound \( \frac{5}{80\pi} \) (\( \approx 2.40\% \)) for \(-1 \leq \delta < 0 \). In addition, the ratio decreases in \( p \) in both cases.

Proposition 7 indicates that the simple contract yields close-to-optimal performance in this special case, since the value of using a menu of contracts is bounded by a small number (2.40%). In addition, the profit difference tends to decrease in market price (or profit margin). To confirm that these findings apply more generally, we also conduct extensive numerical studies.

In the first numerical study, we generalize the linear density in Proposition 7 to a family of densities \( f(x) = \alpha + \delta x^{\eta-1} \) (\( \alpha > 0 \), \( \delta > 0 \), and \( \eta > 1 \)). This polynomial format represents a reasonable approximation of many monotonically increasing density functions. Under these distributions, there is \( H'(x) > 0 \) on the entire cost support, and the value of using a menu of contracts will be positive. We construct 1200 scenarios in total using the following parameter values. The market demand \( D \) follows a gamma distribution with mean \( \mu = 50 \) and coefficient of variation \( CV \in \{0.2, 0.4, 0.6, 0.8, 1.0\} \). We vary the \( CV \) while fixing \( \mu \) to investigate the impact of demand variability. The rest of the parameters are allowed to range from very low values to very high values so that the numerical study covers a wide range of practical situations: The supplier’s cost \( c \) has a support \([0, \bar{c}]\), where \( \bar{c} = \{1, 5, 10\} \), \( \eta \in \{1.5, 2.0, 2.5, 3.0\} \), and \( \delta = \eta(1 - \alpha \bar{c})/\bar{c}\). To ensure \( \delta > 0 \) (or \( 1 - \alpha \bar{c} > 0 \)), we set \( \alpha = \delta_\alpha / \bar{c} \), where \( \delta_\alpha \in \{0.01, 0.1, 0.5, 0.9\} \). Since the lower bound of the cost support is fixed at zero, the supplier’s mean cost increases in \( \bar{c} \). Thus we set market price \( p = \delta_p \bar{c} \) with \( \delta_p \in \{0.5, 1, 1.5, 2, 2.5\} \), where \( \delta_p \) measures the magnitude of market price relative to the cost (or the profit margin of the product).

For each of the above scenarios, we calculate the ratio \( (\pi_b^{OM} - \pi_b^S) / \pi_b^S \). Table 1 reports the performance of the simple contract, measured by \( (\pi_b^{OM} - \pi_b^S) / \pi_b^S \), across all scenarios. We group the data by different levels of demand uncertainties (i.e., \( CV \) values). For instance, under \( CV = 0.2 \), the buyer enjoys a 0.20\% or less profit increase for 90\% of the scenarios with an average of 0.09\% among all scenarios. We highlight several observations from this numerical study. First, the value
of using a menu of contracts is quite small: the average profit increase is 0.17% with a maximum of 2.34% among the 1200 tested scenarios. Second, we find that the simple contract tends to perform better for large $p$ values and low $CV$ values. Third, consistent with Proposition 6, we observe that $T^o = 0$ as long as $\bar{c} \leq \bar{c}$ in this numerical study, i.e., the two-part tariff reduces to a pull contract when the optimal mechanism excludes some high cost types. This happens among 55% of the tested scenarios.

Tables 2 to 4 present similar findings from three additional numerical studies. These numerical studies are identical to the first except that the supplier’s cost follows different distributions. In Table 2, the cost densities are given by $f(x) = \alpha + \delta x^{\eta-1}$ with $\delta < 0$, i.e., the density is decreasing in $x$. Due to the negative sign of $\delta$, we have used $\delta_\alpha = \left\{1.01, 0.5, 0.9\right\}$ in this numerical study.

Overall, the above analysis and numerical studies show that the two-part tariff $\{w^0, T^o\}$ (or just a pull contract $w^0$) is nearly optimal for the buyer (i.e., it yields almost the same profit as the optimal menu of contracts). As further robustness check, we have tested all the above numerical studies again using uniform demand distributions. The qualitative observations remain the same; more details are given in the Electronic Companion. Recall in Section 4.2.2, when there is $H^t(x) > 0$ under voluntary compliance, a restriction to linear contract format may entail a profit loss due to bunching. The above tables demonstrate that even when a full bunching contract is used, the profit loss is insignificant. Thus achieving enforceability provides little value even in the situation studied in Section 4.2.2 as well (i.e., the buyer faces $H^t(x) > 0$ and is confined by linear contract format). Therefore, our results suggest that the value of achieving enforceability and the value of using a complex menu are both negligible for a wide range of scenarios.

We take a step further to compare the supply chain performances under different contracts. Let $\pi_{sc}^{OM}$ and $\pi_{sc}^{S}$ denote the supply chain profits under the optimal and simple contracts, respectively; then the ratio $(\pi_{sc}^{OM} - \pi_{sc}^{S}) / \pi_{sc}^{S}$ may be used to measure the improvement in supply chain performance by adopting the optimal mechanism. We find that among all four numerical studies, the
ratio is $-0.41\%$ on average and $0.10\%$ at the maximum. Thus we can see that the simple contract and optimal mechanism perform closely for the supply chain as well. It is noteworthy that the ratio is negative in some scenarios, meaning that the supply chain profit could be higher under the simple contract than that under the optimal mechanism.

Why does the simple contract perform so well? Cachon and Zhang (2006) study a contract design problem in which the supplier is modeled as a make-to-order manufacturer with private capacity cost. They demonstrate that the buyer’s profit is very flat in capacity cost under the optimal mechanism; therefore, some simple contracts with fixed parameters yield nearly optimal performance. However, in our problem setting, the buyer’s profit in the optimal contract is found to be highly variable in capacity cost. So the insight from Cachon and Zhang (2006) does not apply here. We then investigate and compare the supply chain capacities under the optimal and simple contracts. The capacity plays a key role in our model setting because it determines both the supply chain’s profit as well as the buyer’s revenue. Let $K^S(x) = \Phi^{-1}(\frac{w_0-x}{w_0})$ denote the capacity level induced by the simple contract. For each scenario tested above, we calculate the expected ratio $E\left(\frac{K^S(x)-K^S(x)}{K^S(x)}\right)$, i.e., the expected absolute percentage capacity difference. The mean and maximum values of the ratio are $2.70\%$ and $17.53\%$ among all the numerical studies. This finding suggests that in such a supply chain setting, the simple contract can induce quite close capacities as those stipulated by the optimal menu. Since the supply chain profit only depends on the capacity, this explains why the two contracts yield similar supply chain performances.

The small difference in capacity implies that the buyer’s expected revenues are close under the optimal and simple contracts. To see why the buyer’s profits are so close, we also calculate the buyer’s expected costs (i.e., the expected payments to the supplier) under these two contracts. It has been found that similar to capacity, the expected absolute percentage payment difference is also small: The mean and maximum values are $2.16\%$ and $17.78\%$ in the numerical studies. Thus the simple contract delivers nearly optimal profit because for the supply chain setting with a newsvendor buyer, both the expected revenue and cost are close to those under the optimal contract.

In summary, the two-part tariff contract is optimal when there is a constant MRHR. Even when it is suboptimal, the two-part tariff performs nearly as well as the optimal mechanism in our supply chain setting. It may further reduce to a pull contract consisting of just a wholesale price, when it is optimal for the buyer to exclude some high-cost supplier types. In addition to simplicity, the contract is also incentive compatible and therefore does not require any enforcement effort. These findings contribute to the literature in which simple contracts are shown to perform well in various
problem settings. They may also help explain the prevalence of simple contracts (e.g., wholesale price contracts) in practice.

6 Conclusion

This paper studies a contracting problem in a supply chain consisting of a newsvendor buyer and a supplier. Two commonly observed incentive issues have been taken into account when studying the buyer’s contracting strategies: First, there is asymmetric cost information in the supply chain (i.e., adverse selection issue); second, the supplier may shirk from his responsibility for capacity risks (i.e., enforcement issue). These issues have become more prominent in today’s global business environment where trading partners are often new and distant from each other. We find that although the buyer’s optimal mechanism is generally complex, it may reduce to a two-part tariff under certain conditions (i.e., a single, linear contract could be optimal for the buyer). When it is optimal for the buyer to exclude some high-cost supplier types, the two-part tariff will further simplify to a wholesale price (i.e., the widely observed wholesale price contract could be optimal for the buyer). Even when the two-part tariff is suboptimal, it performs nearly as well as the optimal mechanism for a wide range of situations. That is, a single two-part tariff contract can deliver either optimal or near-optimal profit for the buyer under both cost uncertainty and enforcement issues. These findings indicate that in the presence of both adverse selection and enforcement issues, using a complex menu and achieving enforceability provide little value to the buyer.

Our results bode well for practitioners facing supply contract design problems: For both ease of implementation and excellent performance, a buyer can simply use a two-part tariff contract (or sometimes just a wholesale price contract) when facing cost information asymmetry and enforcement issues. In addition, our findings imply that in such problem situations, the buyer should try all means to reduce the uncertainty about the supplier’s cost structure. This is because such uncertainty provides a robust protection of the information rent the buyer has to pay the supplier.

More research is needed to study supply chain contracting that involves informational and incentive issues. There are several potential directions for future research in this area. First, in this paper we focus on adverse selection and enforcement issues in the supply chain; it would be interesting to study a signaling game (rather than screening game) under voluntary compliance. Second, one may consider the impact of enforcement under the presence of both asymmetric demand information and asymmetric cost information. That is, the current model setting can be extended to include private demand information for the buyer. Finally, the supply chain studied in this research represents the simplest setting with one buyer and one supplier. It would be interesting to
extend our model to more general supply chain structures (e.g., there are either multiple suppliers or multiple buyers).

Table 1. Performance of simple contracts \((\frac{\pi^{OM}_{b} - \pi^{S}_{b}}{\pi^{S}_{b}})\) for cost density function \(f(x) = \alpha + \delta x^{\eta-1} (\delta > 0)\).

<table>
<thead>
<tr>
<th>Demand CV</th>
<th>Average (%)</th>
<th>90th percentile (%)</th>
<th>Maximum (%)</th>
</tr>
</thead>
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<tr>
<td>0.2</td>
<td>0.09</td>
<td>0.20</td>
<td>0.39</td>
</tr>
<tr>
<td>0.4</td>
<td>0.10</td>
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<td>0.28</td>
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<td>2.34</td>
</tr>
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</table>

Table 2. Performance of simple contracts \((\frac{\pi^{OM}_{b} - \pi^{S}_{b}}{\pi^{S}_{b}})\) for cost density function \(f(x) = \alpha + \delta x^{\eta-1} (\delta < 0)\).

<table>
<thead>
<tr>
<th>Demand CV</th>
<th>Average (%)</th>
<th>90th percentile (%)</th>
<th>Maximum (%)</th>
</tr>
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<td>0.19</td>
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Table 3. Performance of simple contracts \((\frac{\pi^{OM}_{b} - \pi^{S}_{b}}{\pi^{S}_{b}})\) for normal cost distribution.

<table>
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<td>0.83</td>
<td>1.68</td>
<td>2.23</td>
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<tr>
<td>1.0</td>
<td>1.08</td>
<td>2.31</td>
<td>3.13</td>
</tr>
</tbody>
</table>

Table 4. Performance of simple contracts \((\frac{\pi^{OM}_{b} - \pi^{S}_{b}}{\pi^{S}_{b}})\) for gamma cost distribution.

<table>
<thead>
<tr>
<th>Demand CV</th>
<th>Average (%)</th>
<th>90th percentile (%)</th>
<th>Maximum (%)</th>
</tr>
</thead>
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<tr>
<td>0.2</td>
<td>0.29</td>
<td>0.48</td>
<td>0.73</td>
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<tr>
<td>0.4</td>
<td>0.55</td>
<td>0.96</td>
<td>0.98</td>
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<tr>
<td>0.6</td>
<td>0.84</td>
<td>1.53</td>
<td>1.60</td>
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<tr>
<td>0.8</td>
<td>1.18</td>
<td>2.20</td>
<td>2.39</td>
</tr>
<tr>
<td>1.0</td>
<td>1.54</td>
<td>2.97</td>
<td>3.37</td>
</tr>
</tbody>
</table>

References


