FORMATION OF SUPPLY CHAIN CONTRACT: THEORY AND EXPERIMENT

By

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Abstract

FORMATION OF SUPPLY CHAIN CONTRACT: THEORY AND EXPERIMENT

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In recent years, the globalization in business has transformed the traditional linear supply chain into a complex network of interactions among supply chain participants across different tiers. In such a supply chain system, firms are facing the challenges of making better operational decisions on strategic sourcing and collaborative/competitive negotiations. My dissertation explores the formation of supply chain contract under competitive scenarios in complex supply chain networks from both theoretical and behavioral perspectives. Specifically, Essay 1 examines the implications of asymmetric bilateral relations for supply contract negotiations under retail competition and highlights the intuition that a firm should not only focus on the best terms of trade from potential partners but also consider competitive consequences of partner choice. Essay 2 theoretically and behaviorally investigates contract bargaining in two-sided supply chain networks with multiple retailers/suppliers on each side and develops a new behavioral theory to explain and predict the contract bargaining behaviors. Essay 3 theoretically and behaviorally studies the contract auction mechanism design from supplier's perspective in decentralized supply chain structures with one supplier and multiple potential retailers and finds that contract auction behaviors have substantial impact on subsequent market decisions.

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Essay 1: Bargaining in a Supply Chain Network: Coexist or Exclude?

Introduction

In a supply chain, considerable amount of the strategic interaction occurs among retailers and suppliers who have bilateral relations, which is a central determinant of economic activity. In this paper, we consider a bilateral relation as a premise of potential trade between supply chain members, which might be lacking due to various reasons such as high transportation costs, international trade restrictions, technological incompatibility, etc. (Jackson 2010). There are many examples from practice where firms compete in an asymmetric business environment and utilize existing bilateral relation asymmetries to gain significant returns. For instance, both Flex and Foxconn were suppliers for Apple and Huawei. However, due to trade restrictions imposed by US government, Flex terminated the business relationship with Huawei in 2019. As Huawei's top competitor in mobile vendor market, Apple then exploited this trade limitation by improving its cooperation with Foxconn and gained significant competitive advantage. Consequently, both Flex and Huawei suffered huge losses while Apple and Foxconn reached a "win-win" situation (Choudhury 2020).

Motivated by the externalities that emerge due to asymmetry of bilateral relations, we consider a simple supply chain setup where two retailers negotiate with two suppliers over exclusive supply contracts. We name the set of suppliers that have bilateral relationships with a retailer as that retailer's "supplier base," and consider a supply chain in which two retailers have different supplier bases. In particular, we consider that one retailer has access to only one supplier (i.e., "common supplier") and the other retailer has access to both suppliers (i.e., "common supplier" and "exclusive supplier"). Hereafter, we name this particular supply chain structure as *supply chain network*. In this supply chain network, we consider the following sequence of events. There are two stages. In the first stage, each retailer simultaneously negotiates with the accessible supplier(s) to secure an exclusive supply contract. The supply contract consists of a wholesale price and a fixed transfer fee (i.e., a two-part tariff), and we model contract negotiations as a multi-player infinite horizon discrete time bargaining game that internalizes the supply chain network restrictions (Corominas-Bosch 2004, Nakkas and Xu 2019). In the second stage, the retailer(s) who secure a contract from a supplier determine their order quantity before selling to the consumer market for profits.

In this setup, the supply chain network structure favors the retailer with larger supplier base (i.e., the retailer has "relationship advantage" due to his connection with both common and exclusive suppliers) and provides a relatively higher negotiation power. We refer to the retailer with larger supplier base as *focal retailer* and the retailer with smaller supplier base as *peripheral retailer*. The focal retailer can exercise his negotiation power via two potential strategies: (i) *exclusive strategy*: the focal retailer may strategically target the common supplier to gain exclusive selling rights, lock out the peripheral retailer, and hence soften its retail competition but have to pay a higher acquisition cost or (ii) *coexistence strategy*: the focal retailer may choose to pay the lowest possible acquisition cost through contracting with the exclusive supplier, but have to face more aggressive retail competition. In the former case, the focal retailer becomes a monopoly whereas in the latter case there is a duopoly competition in the market.

We show that if the suppliers' products are sufficiently substitutable, then there exists a unique subgame perfect Nash equilibrium where the focal retailer successfully drives out the peripheral retailer from the market by targeting the common supplier in the supply contract negotiations and becomes a monopoly (i.e., the focal retailer exercises the exclusive strategy). If, however, the suppliers' products are not sufficiently substitutable, then both retailers secure a contract in the equilibrium and engage in a duopoly competition in the market (i.e., the focal retailer exercises the coexistence strategy). Furthermore, we demonstrate that if the product substitutability level continues to rise, then the focal retailer can gain benefits in contract agreement due to higher leverage under the exclusive strategy. In addition, we show that the exclusive strategy can generate more total supply chain network profit than the coexistence strategy even though, in equilibrium, the exclusive supplier and peripheral retailer are excluded from participating in the market when focal retailer employs the exclusive strategy. This implies that total supply chain network profit can be higher when there are restrictions over trade as compared to the case where there is no trade restrictions (i.e., when all retailers' have same supplier bases).

Our results provide the following managerial insights. First, procurement decisions such as choosing best supply partner can be powerful strategical tools to gain competitive advantage. A retailer's procurement strategy should not only focus on getting the best terms of trade from his suppliers but also consider the competitive consequences of supplier choice. Retail competition has strong implications on supply contract bargaining and *vice versa*. Second, markets that supply similar (i.e., substitutable) goods in asymmetric supply chain networks are more vulnerable to be dominated by single retailers. In such a market, suppliers are more eager to focus on relations that eliminate retail competition. Further, a competitive retail market shrinks the "pie" size for each supply chain that offers a product to the market. In our setup, this implies that a supplier's negotiation power decreases as the supplier's outside option becomes "bargaining for a smaller pie". Thus, the common supplier is more eager to agree on contract terms that are better for the focal retailer when the product substitutability is higher. Third, asymmetry of bilateral relations can increase total supply chain network profit when products are highly substitutable. This result is especially crucial for supply chain networks where the bilateral relations are significantly affected by industry/government decisions.

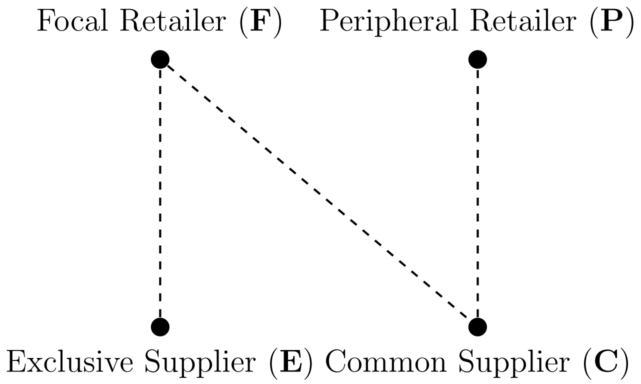
The literature on supply chain competition is vast. However, existing literature mainly focuses on *symmetric* supply chain network structure (i.e., in our paper terms, the set of supplier bases are same for all retailers). These structures can be one-retailer-one-supplier (e.g., Cachon and Lariviere 2005, Feng et al. 2015), one-supplier-multiple-retailers (e.g., Bernstein and Federgruen 2005, Netessine and Zhang 2005), one-retailer-multiple-suppliers (e.g., Aydin and Heese 2015), competing supply chains each with one-retailer-one-supplier (e.g., Ha and Tong 2008, Wu and Chen 2010), and multiple-retailers-multiple-suppliers (e.g., Adida and DeMiguel 2011, Korpeoglu et al. 2020). There are also other papers that consider supply contract bargaining in supply chains with symmetric structures. Lovejoy (2010) studies multi-tier negotiation in a supply chain where only one firm will be selected from each tier through horizontal competition. Feng and Lu (2012) investigates the impact of cost differential on bargaining under supply chain structures either with one-supplier-one-manufacturer or one-supplier-two-manufacturers. Guo and Iyer (2013) explores how retail price dispersion level between two retailers and proportion of unloyal consumers can affect the manufacturer's bargaining protocol preference. Our paper diverges from the supply chain competition literature by considering supply contract bargaining incentives in a supply chain network with asymmetric bilateral relations.

Also related is the economics literature on network competition. Majority of research in this area focus on centralized trading mechanisms to achieve competitive and/or efficient matching outcomes. Kranton and Minehart (2001) studies the efficient network structure in a non-strategic sellers environment with centralized auction mechanism. Corominas-Bosch (2004) analyzes the impact of competitive network structures on negotiated equilibrium prices in a setting with common buyer valuations, which is further generalized by Nakkas and Xu (2019) into a setting with heterogenous buyer valuations. Bimpikis et al. (2019) examines the impact of network structure on market competition among retailers. Our model differentiates from the literature by considering endogenous buyer valuations, which depends on the negotiation outcome of retailers and suppliers.

Model Setting

We consider a two-sided supply chain system with two retailers and two suppliers. We study the simplest *asymmetric* bilateral relations with *balanced* supply and demand (i.e., same number of suppliers and retailers) and show the network representation in Figure 1. This setup allows us to understand the implications of network asymmetry on the contract bargaining incentives of supply network players in the most clear way. In this asymmetric supply chain network, each node represents a firm and the retailers/suppliers are arbitrarily set on the top/bottom. Hereafter, we denote *Focal Retailer* and *Peripheral Retailer* by **F** and **P**, and denote *Exclusive Supplier* and *Common Supplier* by **E** and **C**. An edge (i.e., dashed link) between a retailer (denoted as "he") and a supplier (denoted as "she") represents that there exists a bilateral relationship between two firms and they can contract with each other through negotiation. Conversely, absence of a dashed link means that two firms cannot contract with each other. Each supplier/retailer can at most reach a contract agreement

Figure 1: An asymmetric supply chain network with two retailers and two suppliers.



Note: Dotted lines represent bilateral relationships among firms. Only connected firms can, but do not have to, form a contract.

with one retailer/supplier. The contract bargaining procedure follows an alternating multi-round process, described below, with potentially an infinite number of rounds (Rubinstein 1982). With a contract agreement, a retailer can order products from his supply partner and then sell to consumers, which is modeled as a quantity-setting game with linear pricing functions.

Figure 2 presents our two-stage sequential game formulation. In the first stage, retailers and suppliers bargain with each other to reach contract agreement. A supply contract takes the form of a wholesale price of w per unit and a fixed transfer fee of T (i.e., two-part tariff). We use two-part tariff as it is commonly used in both theory and practice (Weng 1995, Cachon 2003). The negotiation procedure among the linked firms in the supply chain network is as follows. In the first negotiation round, retailers simultaneously make the first contract offer to each linked supplier, and each supplier then decides whether to accept one contract offer from the linked retailer(s) or reject all.[1] If a contract agreement is reached between a retailer and a supplier, they move to the second stage while their nodes together with all their links

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[1] We also did full analysis for suppliers move first scenario. More details are shown in Appendix C.

are removed from the supply chain network. If both suppliers accept the contract proposal from one retailer, then the supply contract is randomly assigned to one supplier. Firms that could not trade in Round 1 remain in the contract negotiation stage as long as they have connection(s) with each other. Then, in Round 2, remaining suppliers make a contract offer, and remaining retailers respond to accept an offer or not. Our sequential bargaining process can repeat itself potentially with infinite rounds for remaining firms who are connected with each other. Without connections, each of the remaining firms gets 0 reservation amount. Each firm has a common discount factor $\delta \in [0, 1]$ for each additional negotiation round.

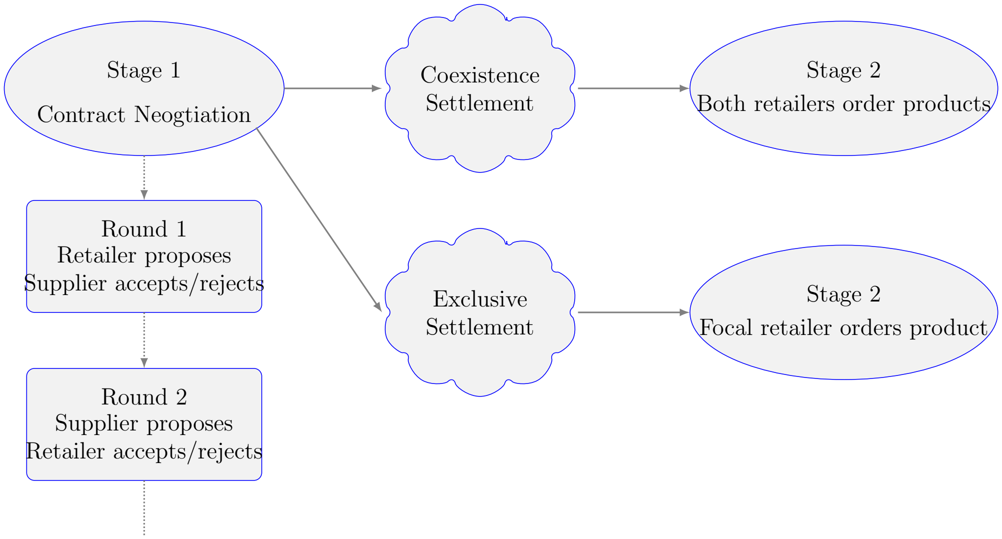

Figure 2: Sequence of Events

In the second stage, with his contract agreement, retailer $i \in \{F, P\}$ can order q_i from the supply partner $j \in \{C, E\}$ with the payment: $w_i \cdot q_i + T_i$ where w_i and T_i are the contract terms that retailer i commits to paying to supplier j. There are two possible contract agreement configurations in our supply chain network illustrated by Table 1. In one configuration, the focal retailer contracts with the exclusive supplier while the peripheral retailer contracts with the common supplier. We call it *coexistence settlement* since both retailers can order products from their supply partner before selling to the consumer market. In another configuration, the focal retailer contracts with the common supplier while the other two firms end the game without contract agreement. We call it *exclusive settlement* since only the focal retailer can order products from the supply partner before selling to the consumer market.

The consumer market is modeled as a quantity-setting game with linear price functions. Specifically, the retail price is assumed to be common knowledge, and takes the linear form of $p_i = \alpha - \beta \cdot q_i - \gamma \cdot q_{\neg i}$, for $i \in \{F, P\}$, where q_i (or $q_{\neg i}$) is the quantity of product ordered by retailer i (or retailer other than retailer i) from the respective supply partner, p_i is the per-unit retail price of the product ordered by retailer i, and γ refers to the level of product substitutability. If a retailer does not have a contract agreement in the previous stage, then its quantity is assumed to be zero. In the case where both retailers have contracts, they compete and the parameter γ, the level of product substitutability, represents the intensity of retail competition.[2] We assume that $\alpha > c \geq 0$ to exclude the trivial case of not reaching optimality by producing and selling the product (Feng and Lu 2013). We also assume $0 \leq \gamma \leq \beta$ to ensure that the retail price for a product should be more (or at least equally) sensitive to changes in its quantities than to changes in the quantities of the other substitutable product (Lus and Muriel 2009). This demand model is consistent with a consumer choice model introduced by Singh and Vives (1984) and has been widely applied (Goyal and Netessine 2007, 2011).

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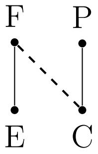
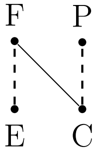
[2] Our theoretical analysis can also apply to product complementarity scenario. More discussions are shown in Section and Appendix C.

Table 1: Possible Contract Agreement Configurations after Negotiation

Coexistence Settlement		**F**ocal Retailer contracts with **E**xclusive Supplier; **P**eripheral Retailer contracts with **C**ommon Supplier.
Exclusive Settlement		**F**ocal Retailer contracts with **C**ommon Supplier; Other players end game with no contract agreement.

Note: Dotted lines mean that the firms have bilateral relationship, but do not form a contract. Solid lines mean that the contracts have been formed.

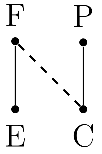
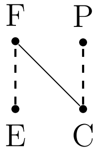
We assume that each supplier produces a product with a constant production cost c and has unlimited capacity. Thus, the profit of supplier $j \in \{C, E\}$ who contracts with retailer $i \in \{F, P\}$ in round t is $\pi_j^t = \delta^t((w_i - c) \cdot q_i + T_i)$. The product has no salvage value and thus retailer sells all of the amount ordered from the supply partner. Then, the profit of retailer $i \in \{F, P\}$ who contracts with supplier $j \in \{C, E\}$ in round t is $\pi_i^t = \delta^t((p_i - w_i) \cdot q_i - T_i)$. Therefore, the partnership profit between retailer $i \in \{F, P\}$ and supplier $j \in \{C, E\}$ in round t is $\pi_{ij}^t = \pi_i^t + \pi_j^t$. All players who cannot reach a contract agreement during the game will get 0 reservation amount, and the total supply chain network profit (denoted by Π) is the sum of all players' profits in the game. All the notations are summarized in Appendix A.

In what follows, we analyze the impact of network asymmetry on contract bargaining outcomes between retailers and suppliers within the supply chain network. We derive the subgame perfect Nash equilibrium strategy, and investigate how it will be affected by product substitution and contract negotiation power.

Analysis

In our setting, the subgame perfect Nash equilibrium (SPNE) is unique. Depending on the parameters of the setting, the SPNE can be one of the two configurations, referred to as the *coexistence settlement* and *exclusive settlement*. Table 2 shows the equilibrium order quantity under each settlement. Furthermore, the associating equilibrium contract wholesale price is the production cost (i.e., $w_i^* = c$). All proofs are presented in Appendix B.

Table 2: Equilibrium Order Quantity under Contract Agreement Configurations

Coexistence Settlement		**F**ocal retailer orders $q_F^* = \frac{\alpha-c}{2\beta+\gamma}$ **P**eripheral retailer orders $q_P^* = \frac{\alpha-c}{2\beta+\gamma}$
Exclusive Settlement		**F**ocal retailer orders $\hat{q}_F^* = \frac{\alpha-c}{2\beta}$

Note: Dotted lines mean that the firms have bilateral relationship, but do not form a contract. Solid lines mean that the contracts have been formed.

Result 1: When products become more substitutable, the equilibrium switches from coexistence to exclusive settlement.

Proposition 1

(i) If $\gamma \in \left[0, 2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}} - 1\right)\right)$, *then the equilibrium contract agreement configuration is the coexistence settlement.*

(ii) If $\gamma \in \left[2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}} - 1\right), \beta\right]$, *then the equilibrium contract agreement configuration is the exclusive settlement.*

Proposition 1 demonstrates that both retailers coexist in the market when the product substitutability is low, whereas the focal retailer is the sole provider to the market when the product substitutability is high. Note that this result, on the surface, contradicts traditional supply chain management conclusion. Specifically, in previous supply chain competition literature, a higher product substitutability usually leads to a higher level of competition, which in turns, results in lower retailer and supply chain profits. What drives our new result, seemingly contradictory to past literature, is the asymmetry in the network of supplier-retailer relationships and endogeneity of supplier selection. Due to the supplier base advantage, the focal retailer has the opportunity to exclude the peripheral retailer through contracting with the common supplier, and move to the exclusive settlement. Specifically, when product substitutability increases, competition does increase in the coexistence settlement which leads to a lower profit for the focal retailer. Thus, he may exploit the advantage and exclude the peripheral retailer with more payment to the common supplier in the negotiation process. Note that the peripheral retailer has no such option as the focal retailer can always contract with the exclusive supplier. As a result, the focal retailer will deploy this "exclude-peripheral-retailer" strategy, and achieve a monopoly, when the product substitutability is high enough.

We illustrate this intuition in Figure 3, showing the focal retailer's payoff in coexistence settlement and exclusive settlement as a function of product substitutability. The red (blue) line represents the payoffs for the exclusive (coexistence) settlement, and the intersection of two lines corresponds to the equilibrium switching point between the two settlements. When product substitutability is low, the coexistence settlement is on equilibrium and the corresponding payoff (blue) dominates. When it is high, the exclusive settlement is on equilibrium and the corresponding payoff (red) dominates.

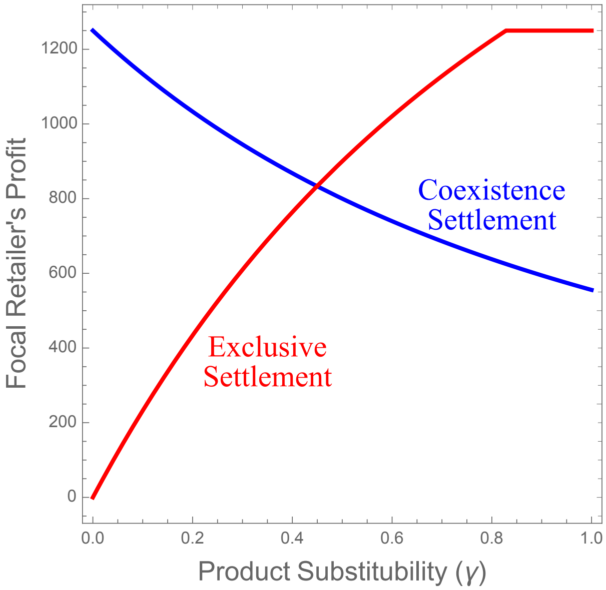


Figure 3: The impact of γ on the focal retailer's profit under coexistence settlement vs. exclusive settlement given $\alpha = 100$, $\beta = 1$ and $\delta = 1$.

In summary, Result 1 shows that network asymmetry can have significant impact on supply contract negotiations with retail competition. Our finding suggests that firms should not only focus on getting the best terms of trade from the potential partners but also consider the competitive consequences of their partner choices. Without considering the above factors, this feature may not be well captured although it is widely shown in business applications (Otto 2020).

Result 2: When the equilibrium is exclusive, focal retailer's profit increases with the level of product substitutability.

Proposition 2

If $2\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right)\beta \leq \gamma \leq \min\left\{2\left(\sqrt{\frac{1+\delta}{\delta}}-1\right)\beta, \beta\right\}$, *the focal retailer's profit increases with* γ.

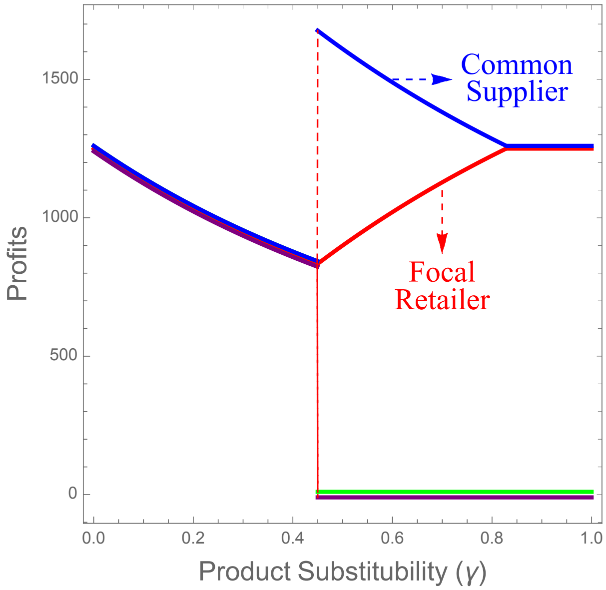


Figure 4: The impact of γ on each player's equilibrium bargaining payoff given $\alpha = 100$, $\beta = 1$ and $\delta = 1$

In the exclusive settlement, product substitutability has no impact on the total supply chain network profit extracted from consumers, as the peripheral retailer is no longer competing in the market. However, the focal retailer's payoff (i.e., the portion of the total profit he receives) increases when product substitutability increases. The reason is that the amount focal retailer has to pay to the common supplier to exclude the peripheral retailer is the counter-factual partnership profit between peripheral retailer and common supplier (i.e., π_{PC}), which is lower when product substitutability increases due to a higher level of retail competition in the counter-factual coexistence settlement. When the product substitutability, γ, increases beyond $\min\left\{2\left(\sqrt{\frac{1+\delta}{\delta}}-1\right)\beta, \beta\right\}$, the common supplier will strategically ignore the peripheral retailer. In this situation, the focal retailer's bargaining payoff no longer changes with product substitutability since he earns a fixed share of the partnership profit according to their time patience level in contract negotiation.

Figure 4 illustrates these intuitions, by showing each player's equilibrium bargaining payoff as a function of the product substitutability γ level. The red/purple line represents for the focal/peripheral retailer's payoff while the blue/green line represents for the common/exclusive supplier's payoff. As Result 1 states, with low product substitutability, the equilibrium strategy corresponds to the coexistence settlement. All four players earn less bargaining payoff when product substitutability increases as shown on the left side of Figure 4. When γ level continues to increase, the equilibrium switches to exclusive settlement. As shown in the middle of Figure 4, the focal retailer's payoff increases with γ level until the common supplier strategically ignores the peripheral retailer. Then, the focal retailer and the common supplier will split the partnership profit with a fixed share, while the peripheral retailer and exclusive supplier earn 0 profit due to no contract agreement.

Intuitively, Result 2 predicts that higher product substitutability may not always hurt each retailer's bargaining payoff in a supply chain with network asymmetry. In contrast, the focal retailer can even generate more payoff under the exclusive settlement when products substitutability increases. It indicates that firms should consider exploiting their competitive advantage on supply chain connections for more profits through excluding their competitors in the market.

Result 3: When firms are more time patient in contract negotiation, the equilibrium switches to exclusive settlement at a lower level of product substitutability.

Proposition 3

The threshold of γ level (i.e., $\gamma = 2\left(\sqrt{\frac{2+\delta}{1+\delta}} - 1\right)\beta$) that switching from coexistence settlement to exclusive settlement decreases with δ.

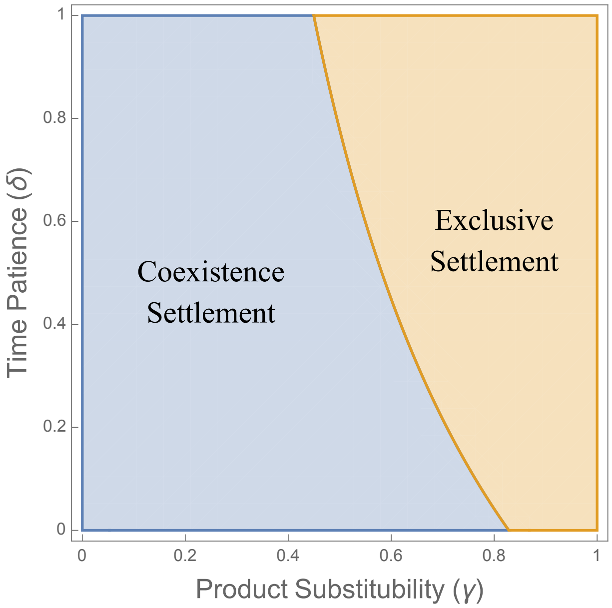


Figure 5: Settlement Regions in SPNE given $\beta = 1$

When firms are more time patient in contract negotiation, the equilibrium switches to exclusive settlement at a lower level of product substitutability under the retailers move first scenario. In coexistence settlement, the focal retailer's bargaining payoff decreases with δ level because a higher level of time patience in contract negotiation among firms leads to a lower level of his first mover advantage. However, in exclusive settlement, the focal retailer's bargaining payoff is not affected by δ since he always offers the common supplier the counterfactual partnership profit between peripheral retailer and common supplier. Therefore, when δ increases, the focal retailer would prefer exclusive settlement more, and thus the equilibrium switches from a coexistence to exclusive settlement at a lower level of product substitutability.

As an illustration, Figure 5 shows the settlement regions in SPNE under retailers move first scenario given combinations of product substitutability level (i.e., γ level) and time patience level in contract negotiation (i.e., δ level) when $\beta = 1$, which limits $0 \leq \gamma \leq 1$. In Figure 5, the blue/yellow region represents the coexistence/exclusive settlement region on

SPNE respectively. First of all, when δ increases, the γ level at the boundary of two settlement regions decreases. It indicates that the equilibrium switches to exclusive settlement at a lower level of product substitutability when firms become more time patient in contract negotiation. Besides that, we also find that the equilibrium always corresponds to the coexistence settlement when $\gamma = 0$ because the products sold by two retailers are independent and the focal retailer does not have an incentive to exclude the peripheral retailer by providing a higher offer to the common supplier without any benefit. In contrast, when $\gamma = 1$, the equilibrium always corresponds to the exclusive settlement because the benefit for the focal retailer overwhelms the higher payment to the common supplier when the selling products from both retailers are perfect substitutable.

Result 4: When the level of product substitutability is high enough, total supply chain network profit in equilibrium is higher under asymmetric rather than symmetric network.

Proposition 4

(i) If $\gamma \in \left[0, 2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}} - 1\right)\right)$, total supply chain network profit under the asymmetric network (Π) is the same as under the symmetric network (Π_0).

(ii) If $\gamma \in \left[2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}} - 1\right), 2\beta\left(\sqrt{2} - 1\right)\right)$, total supply chain network profit under symmetric network (Π_0) is higher.

(iii) If $\gamma \in \left[2\beta\left(\sqrt{2} - 1\right), \beta\right]$, total supply chain network profit under asymmetric network (Π) is higher.

In this section, we formalize the impact of network asymmetry on total supply chain network profit by comparing current, asymmetric, setting with a symmetric network where both retailers can form contractual relationships with both suppliers. In the symmetry network, the SPNE result always corresponds to the coexistence settlement. Recall that coexistence settlement also applies in the asymmetric setting when the level of product substitutability is low. However, under the asymmetric network, the equilibrium switches from coexistence settlement to exclusive settlement when products become more substitutable (i.e., Result 1). Under the exclusive settlement, only the focal retailer and the common supplier can reach contract agreement while the other two players exit from the game without any profit. The exclusive settlement clearly hurts total supply chain network profit due to no contract agreement in SPNE. However, in coexistence settlement, although all players in the supply chain network can reach the contract agreement in SPNE, total supply chain network profit will continuously drop because of more intensive competition when products become more substitutable. It may reach the level that products become highly substitutable and total supply chain network profit in the exclusive settlement under asymmetric network overtakes that in the coexistence settlement under symmetric network.

In Figure 6, the red/blue line represents the total supply chain network profit under asymmetric/symmetric network respectively. First of all, as shown on the left side of Figure 6, under low level of product substitutability, the total supply chain network profit under both networks is equivalent and the coexistence settlement applies to both networks in SPNE. When the γ level continues to move up, under the asymmetric network, the SPNE switches to exclusive settlement and the total supply chain network profit does not change due to no retail competition as red line shows. However, under the symmetric network, the total supply chain network profit is always decreasing with γ level due to more intensive retail competition

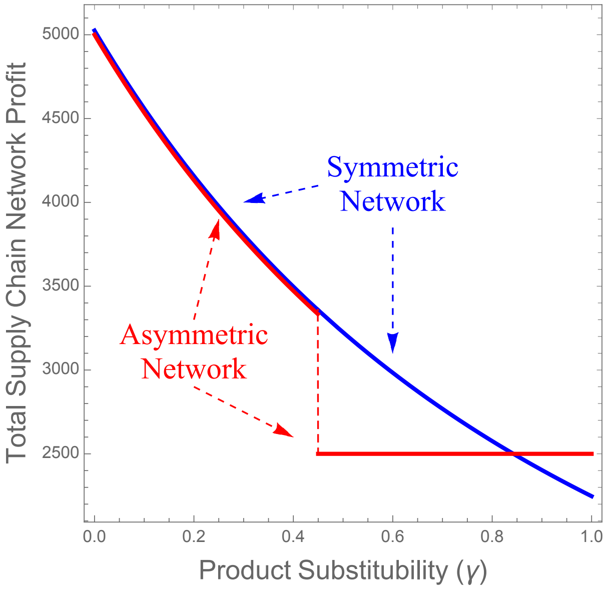


Figure 6: The impact of γ on total supply chain network profit under asymmetric vs. symmetric network in SPNE given $\alpha = 100$ and $\beta = 1$

in coexistence settlement. Thus, asymmetric network may not always be harmful and can even help protect total supply chain network profit in contrast with symmetric network under high level of product substitutability. It also provides implication for industry/government to be cautious when they decide on either expanding or restricting the structures of supply chain networks.

Extensions

The current model makes specific assumptions with respect to both product differentiation and competition. In this section, we explore whether our conclusion holds if we relax these assumptions, and focus on illustrating the managerial insights. The model setting details and the mathematical analysis of the extended models are provided in Appendix C.

In the first extension, we study the scenario where both suppliers' products are *complements* (i.e., $\gamma < 0$) instead of substitutes (i.e., $\gamma > 0$). In this case, the focal retailer would no longer have an incentive to exclude the peripheral retailer and the unique SPNE outcome is the coexistence settlement. This is mainly because the focal retailer has the incentive to coexist with the peripheral retailer to gain benefits from product complementarity. In the second extension, we relax the assumption that the price response to a retailer's quantity change (i.e, β) is identical across retailers. We show that our main conclusions hold even in the asymmetric case where the price responses are not too "different". That is, if $\frac{\beta_2}{\beta_1}$, where β_1 and β_2 are price response coefficients for the focal and the peripheral retailer respectively, are within a lower threshold $\underline{\beta}$ and an upper threshold $\overline{\beta}$. (Please refer to Appendix C for mathematical details.) However, if $\frac{\beta_2}{\beta_1} < \underline{\beta}$, then the focal retailer can no longer generate enough profit in the exclusive settlement, where he pays more to the common supplier to exclude the peripheral retailer. On the flip side, if $\frac{\beta_2}{\beta_1} > \overline{\beta}$, the focal retailer will have an upper hand in the coexistence settlement. He no longer has the incentive to exclude the peripheral retailer from the competition as the peripheral retailer can protect the focal retailer from splitting with the supply partner on the difference of the partnership profit between two pairs. In either case, the outcome will be the coexistence settlement.

Conclusion

We investigate the role of asymmetry of bilateral relations in a multi-retailers-multi-suppliers supply chain system in which retailers negotiate supply contracts with their suppliers and compete in the consumer market. We build upon a classical retail competition model where a higher substitutability between products of retailers generally leads to higher competition and lower profits. We find that the introduction of asymmetry in bilateral relations drastically alters the conclusion. In particular, a sufficiently high product substitutability leads to the *exclusive settlement*, and further increase of product substitutability leads to higher, not lower, retailer profits. Also, the asymmetric network can protect the total supply chain network profit from the competition when products are highly substitutable. The main insight is that asymmetry in bilateral relations allows the "more connected" retailer (i.e., the focal retailer who has the "relationship advantage") to exclude the "less connected" one (i.e., the peripheral retailer). Furthermore, the higher the product substitutability, the lower the focal retailer has to offer the common supplier in this strategy because higher competition in the alternative *coexistence settlement* outcome provides a lower profit for the peripheral retailer to negotiate with. Essentially, when the competition is high, it is more profitable, for both the focal retailer and the supply chain, to exclude the peripheral retailer and achieve an exclusive settlement. From the total supply chain network profit perspective, this asymmetry in bilateral relations can be beneficial because it can help keep out competition. Of course, from a retailer perspective, only the focal retailer can benefit and the retailer who is excluded loses.

From a managerial perspective, our findings point to three implications. First, while a retailer is choosing his potential sourcing partners, he should be mindful of the implications of his, and also his competitors', bilateral relationships with potential suppliers. Specifically, retailers should not only focus on negotiating the best terms of trade from his suppliers but also consider the competitive consequences of his supplier choice. He may be able to develop a competitive advantage in the operational perspective by having more connections with potential suppliers compared to his competitors. The retailing giant Walmart is a good example, with its emphasis on building relationships with a large network of manufacturers globally. This is one of their major competitive advantages over smaller retail firms that allows Walmart to dominate (Kenton 2019). Second, when the retail market is more competitive, it may be easier to leverage the relationship advantage and negotiate exclusive arrangements with suppliers and exclude competing retailers because the competition would have less to offer. Third, the industries/governments need to be cautious when they decide on either expanding or restricting the structures of supply chain networks, which can substantially impact the total supply chain network profit.

To the best of our knowledge, we are the first to integrate asymmetric bilateral relationships into the negotiation of supply contracts with retail competition. This potentially opens up a new research area with many natural extensions. First, the contract takes the form of two-part tariff in our setting. It would be interesting to investigate other contract forms in a similar context. Second, we consider the network of bilateral relationships as exogenous. A natural question is whether the network itself is stable, and whether the behaviors and incentives studied in this paper would encourage certain kinds of network and discourage others. Finally, our results are driven by game theoretical analysis, and there is a need to verify our conclusions empirically with either laboratory experiments or field data.

References

Adida E, DeMiguel V (2011) Supply chain competition with multiple manufacturers and retailers. *Operations Research* 59(1):156–172.

Aydin G, Heese HS (2015) Bargaining for an assortment. *Management Science* 61(3):542–559.

Bernstein F, Federgruen A (2005) Decentralized supply chains with competing retailers under demand uncertainty. *Management Science* 51(1):18–29.

Bimpikis K, Ehsani S, Ilkılıç R (2019) Cournot competition in networked markets. *Management Science* 65(6):2467–2481.

Cachon GP (2003) Supply chain coordination with contracts. *Handbooks in operations research and management science* 11:227–339.

Cachon GP, Lariviere MA (2005) Supply chain coordination with revenue-sharing contracts: strengths and limitations. *Management science* 51(1):30–44.

Choudhury SR (2020) Apple supplier foxconn is ahead of its peers in diversifying out of china, analyst says. *CNBC. https://www.cnbc.com/2020/08/14/apple-supplier-foxconn-ahead-of-competitors-in-diversifying-out-of-china.html* .

Corominas-Bosch M (2004) Bargaining in a network of buyers and sellers. *Journal of Economic Theory* 115(1):35–77.

Feng Q, Lai G, Lu LX (2015) Dynamic bargaining in a supply chain with asymmetric demand information. *Management Science* 61(2):301–315.

Feng Q, Lu LX (2012) The strategic perils of low cost outsourcing. *Management Science* 58(6):1196–1210.

Feng Q, Lu LX (2013) Supply chain contracting under competition: Bilateral bargaining vs. stackelberg. *Production and Operations Management* 22(3):661–675.

Goyal M, Netessine S (2007) Strategic technology choice and capacity investment under demand uncertainty. *Management Science* 53(2):192–207.

Goyal M, Netessine S (2011) Volume flexibility, product flexibility, or both: The role of demand correlation and product substitution. *Manufacturing & service operations management* 13(2):180–193.

Guo L, Iyer G (2013) Multilateral bargaining and downstream competition. *Marketing Science* 32(3):411–430.

Ha AY, Tong S (2008) Contracting and information sharing under supply chain competition. *Management science* 54(4):701–715.

Jackson MO (2010) *Social and economic networks* (Princeton university press).

Kenton W (2019) Walmart effect. *Investopedia. https://www.investopedia.com/terms/w/walmart-effect* .

Korpeoglu CG, Körpeoğlu E, Cho SH (2020) Supply chain competition: A market game approach. *Management Science* .

Kranton RE, Minehart DF (2001) A theory of buyer-seller networks. *American economic review* 91(3):485–508.

Lovejoy WS (2010) Bargaining chains. *Management Science* 56(12):2282–2301.

Lus B, Muriel A (2009) Measuring the impact of increased product substitution on pricing and capacity decisions under linear demand models. *Production and Operations Management* 18(1):95–113.

Nakkas A, Xu Y (2019) The impact of valuation heterogeneity on equilibrium prices in supply chain networks. *Production and Operations Management* 28(2):241–257.

Netessine S, Zhang F (2005) Positive vs. negative externalities in inventory management: Implications for supply chain design. *Manufacturing & Service Operations Management* 7(1):58–73.

Otto O (2020) Become a "partner of choice" to unleash the full power of procurement. *Inbound Logistics. https://www.inboundlogistics.com/cms/article/Become-a-Partner-of-Choice-to-Unleash-Full-Power-of-Procurement/* .

Rubinstein A (1982) Perfect equilibrium in a bargaining model. *Econometrica: Journal of the Econometric Society* 97–109.

Singh N, Vives X (1984) Price and quantity competition in a differentiated duopoly. *The Rand journal of economics* 546–554.

Weng ZK (1995) Channel coordination and quantity discounts. *Management science* 41(9):1509–1522.

Wu OQ, Chen H (2010) Optimal control and equilibrium behavior of production-inventory systems. *Management Science* 56(8):1362–1379.

Appendix

Appendix A: Notations

Model parameters

c	per-unit production cost
t	contract negotiation round
δ	per-round discount factor
α	inverse demand curve intercept
β	inverse demand curve coefficient
γ	product substitutability level
p_i	retail price of each product sold by retailer $i \in \{F, P\}$

Decision variables

w_i	wholesale price of each product ordered by retailer $i \in \{F, P\}$
T_i	fixed transfer fee paid by retailer $i \in \{F, P\}$
q_i	order quantity by retailer $i \in \{F, P\}$

Profits

π_F	**F**ocal retailer's profit
π_P	**P**eripheral retailer's profit
π_C	**C**ommon supplier's profit
π_E	**E**xclusive supplier's profit
π_{ij}	partnership profit between retailer $i \in \{F, P\}$ and supplier $j \in \{C, E\}$
Π	total supply chain network profit

Appendix B: Proofs

We first show proofs of Lemma 1, 2 and 3, which are necessary to prove for all Propositions. Throughout the Appendix, we use **F** and **P** to represent *Focal Retailer* and *Peripheral retailer*, and use **E** and **C** to represent *Exclusive Supplier* and *Common Supplier.* Specifically, w_i and T_i are the wholesale price and fixed transfer fee that retailer $i \in \{F, P\}$ commits to paying to his supply partner, and q_i is his quantity choice. We use $*$ to notate equilibrium decisions/payoffs and $\widehat{}$ to represent for exclusive settlement.

Lemma 1 *For a given wholesale prices w_F and w_P,*

(i) in a coexistence settlement, $q_F^* = \frac{2\alpha\beta-\alpha\gamma-2\beta w_F+\gamma w_P}{4\beta^2-\gamma^2}$ and $q_P^* = \frac{2\alpha\beta-\alpha\gamma-2\beta w_P+\gamma w_F}{4\beta^2-\gamma^2}$

(ii) in an exclusive settlement, $\hat{q}_F^* = \frac{\alpha-\hat{w}_F}{2\beta}$

Proof of Lemma 1. In our supply chain network, there are two possible contract agreement configurations:

(i) Coexistence settlement: In this case, focal retailer and peripheral retailer engage in a quantity competition as both of them secure a supply contract. Retailer $i \in \{F, P\}$ maximizes his profit $\pi_i = (\alpha - \beta q_i - \gamma q_{\neg i} - w_i)\, q_i - T_i$ by ordering q_i^* from his supply partner. Notice that retailer i's profit (π_i) is concave in q_i since $\partial^2\pi_i/\partial q_i^2 < 0$. So, the following first-order conditions determine the unique optimal quantity choices of each retailer:

$$\alpha - 2\beta q_F - \gamma q_P - w_F = 0$$

$$\alpha - 2\beta q_P - \gamma q_F - w_P = 0$$

Solving (q_F, q_P) jointly gives $q_F^* = \frac{2\alpha\beta-\alpha\gamma-2\beta w_F+\gamma w_P}{4\beta^2-\gamma^2}$ and $q_P^* = \frac{2\alpha\beta-\alpha\gamma-2\beta w_P+\gamma w_F}{4\beta^2-\gamma^2}$.

(ii) Exclusive settlement: In this case, the focal retailer maximizes his profit $\hat{\pi}_F = (\alpha - \beta \cdot \hat{q}_F - \hat{w}_F) \cdot \hat{q}_F - \hat{T}_F$ by ordering $\hat{q}_F^*$ from common supplier while both peripheral retailer and exclusive supplier end the game with no trade. By solving the first order condition for $\hat{q}_F$, we have $\hat{q}_F^* = \frac{\alpha - \hat{w}_F}{2\beta}$. □

Lemma 2 *In any equilibrium,* $w_i^* = c$.

Proof of Lemma 2. On the contrary, suppose that in an equilibrium we have $w_i > c$ for retailer $i \in \{F, P\}$. We will show that retailer i has a profitable deviation. It is enough to consider focal retailer's strategy since in the coexistence settlement both retailers has symmetric strategies and in the exclusive settlement peripheral retailer receives zero.

First, suppose that we are in the coexistence settlement in which focal retailer trades with exclusive supplier. By using q_i^* from Lemma 1, we determine

$$\begin{aligned}\pi_F &= \beta\left(\frac{2\beta(\alpha - w_F) - \gamma(\alpha - w_P)}{4\beta^2 - \gamma^2}\right)^2 - T_F \\ \pi_E &= (w_F - c)\frac{2\beta(\alpha - w_F) - \gamma(\alpha - w_P)}{4\beta^2 - \gamma^2} + T_F\end{aligned}$$

for a given strategy profile of all other players (i.e., (w_P, T_P) for peripheral retailer, Accept for exclusive and common suppliers). Notice that π_F is decreasing in w_F for a fixed strategy profile of all other players. Thus, by decreasing w_F, focal retailer can increase his profit. Suppose that focal retailer changes his strategy from (w_F, T_F) to $(c, \tilde{T}_F)$. In the new strategy, we have

$$\begin{aligned}\tilde{\pi}_F &= \beta\left(\frac{2\beta(\alpha - c) - \gamma(\alpha - w_P)}{4\beta^2 - \gamma^2}\right)^2 - \tilde{T}_F \\ \tilde{\pi}_E &= \tilde{T}_F\end{aligned}$$

Let $\tilde{T}_F$ be such that exclusive supplier is indifferent between contract offers (w_F, T_F) and $(c, \tilde{T}_F)$. That is,

$$\tilde{T}_F = (w_F - c)\frac{2\beta(\alpha - w_F) - \gamma(\alpha - w_P)}{4\beta^2 - \gamma^2} + T_F$$

Then, focal retailer has a profitable deviation if $\tilde{\pi}_F > \pi_F$, which simplifies to

$$w_F > c - \frac{\gamma^2}{2\beta^2 - \gamma^2}\left((\alpha - c) - \frac{\gamma}{4\beta}(\alpha - w_P)\right)$$

Since the right hand side is smaller than c, the inequality holds and focal retailer has a profitable deviation for all $w_F > c$. This implies that in all coexistence equilibria, $w_i^* = c$ must hold for retailer $i \in \{F, P\}$.

Next, consider the exclusive settlement in which focal retailer trades with common supplier. By using $\hat{q}_i^*$ from Lemma 1, we determine

$$\begin{aligned}
\hat{\pi}_F &= \frac{(\alpha - \hat{w}_F)^2}{4\beta} - \hat{T}_F \\
\hat{\pi}_C &= (\hat{w}_F - c)\frac{\alpha - \hat{w}_F}{2\beta} + \hat{T}_F
\end{aligned}$$

for a given strategy profile of all other players. Notice that $\hat{\pi}_F$ is decreasing in $\hat{w}_F$. Suppose that focal retailer changes his strategy from $(\hat{w}_F, \hat{T}_F)$ to $(c, \tilde{T}_F)$. In the new strategy, we have

$$\begin{aligned}
\tilde{\pi}_F &= \frac{(\alpha - c)^2}{4\beta} - \tilde{T}_F \\
\tilde{\pi}_C &= \tilde{T}_F
\end{aligned}$$

Let $\tilde{T}_F$ be such that S_2 is indifferent between contract offers $(\hat{w}_F, \hat{T}_F)$ and $(c, \tilde{T}_F)$. That is,

$$\tilde{T}_F \;=\; (\hat{w}_F - c)\frac{\alpha - \hat{w}_F}{2\beta} + \hat{T}_F$$

Then, focal retailer has a profitable deviation if $\tilde{\pi}_F > \hat{\pi}_F$, which simplifies to $\hat{w}_F > c$. Thus, focal retailer has a profitable deviation and in all exclusive equilibria, $\hat{w}^*_F = c$ must hold. $\square$

Lemma 3

(i) In the coexistence settlement, the unique subgame perfect Nash equilibrium predicts that both retailers get a payoff of $\frac{\beta}{1+\delta}\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$ *and both suppliers get a payoff of* $\frac{\delta\beta}{1+\delta}\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$.

(ii) In the exclusive settlement, the unique subgame perfect Nash equilibrium predicts that focal retailer gets a payoff of $\left(\min\left\{1-\left(\frac{2\beta}{2\beta+\gamma}\right)^2, \frac{1}{1+\delta}\right\}\right)\frac{(\alpha-c)^2}{4\beta}$, *common supplier gets a payoff of* $\left(\max\left\{\left(\frac{2\beta}{2\beta+\gamma}\right)^2, \frac{\delta}{1+\delta}\right\}\right)\frac{(\alpha-c)^2}{4\beta}$, *while both peripheral retailer and exclusive supplier get zero payoff.*

Proof of Lemma 3.

(i) Suppose that we are in the coexistence settlement where focal retailer trades with exclusive supplier and peripheral retailer trades with common supplier. Given that $w^*_i = c$ from Lemma 2, the partnership profit of each pair is $\pi^*_{FE} = \pi^*_{PC} = \beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$. Then, this setup is a special case of Corominas-Bosch (2004) model. By applying the equilibrium result of Corominas-Bosch (2004), we conclude that focal retailer receives $\pi^*_F = \frac{1}{1+\delta}\pi^*_{FE}$ and exclusive supplier receives $\pi^*_E = \frac{\delta}{1+\delta}\pi^*_{FE}$, while peripheral retailer receives $\pi^*_P = \frac{1}{1+\delta}\pi^*_{PC}$ and common supplier receives $\pi^*_C = \frac{\delta}{1+\delta}\pi^*_{PC}$ in the equilibrium. By substituting the values of π^*_{FE}

and π^*_{PC}, we get the expressions in the lemma.

(ii) Suppose that we are in the exclusive settlement where focal retailer trades with common supplier. Given that $\hat{w}^*_F = c$ from Lemma 2, the partnership profit between focal retailer and common supplier is $\hat{\pi}^*_{FC} = \frac{(\alpha-c)^2}{4\beta}$. Notice that the valuation for peripheral retailer's supply chain is still $\pi^*_{PC} = \beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$ as peripheral retailer can only trade in a coexistence settlement case. The exclusive settlement equilibrium has to ensure that common supplier has no incentive to deviate and form a supply chain with peripheral retailer. That is, the payment for common supplier has to be at least $\beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$. Thus, this setup is a special case of Rubinstein (1982) with outside options. If we apply the equilibrium result of Rubinstein (1982) for the case where common supplier's outside option is π_{PC}, we conclude that focal retailer receives $\hat{\pi}^*_F = \min\{\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{1}{1+\delta}\hat{\pi}^*_{FC}\}$ where in the first case the outside option of common supplier is high enough to impact the equilibrium and in the second case the outside option is too small to tempt common supplier. Thus, the equilibrium payment of common supplier is $\hat{\pi}^*_C = \max\{\pi^*_{PC}, \frac{\delta}{1+\delta}\hat{\pi}^*_{FC}\}$. By substituting the values of $\hat{\pi}^*_{FC}$ and π^*_{PC}, we get the expressions in the lemma. $\square$

Proof for Proposition 1

Part (i). First, notice that only focal retailer can dictate whether to be in the coexistence settlement or exclusive settlement due to his favorable bargaining position. Then, the unique equilibrium strategy correspond to the coexistence settlement when $\pi^*_F > \hat{\pi}^*_F$, or equivalently $\frac{1}{1+\delta}\pi^*_{FE} > \min\{\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{1}{1+\delta}\hat{\pi}^*_{FC}\}$. After substitutions and simplifications, the inequality reduces to

$$\frac{1}{1+\delta}\left(\frac{2\beta}{2\beta+\gamma}\right)^2 > \min\left\{1-\left(\frac{2\beta}{2\beta+\gamma}\right)^2, \frac{1}{1+\delta}\right\}$$

First, suppose that $1-\left(\frac{2\beta}{2\beta+\gamma}\right)^2 \geq \frac{1}{1+\delta}$. In this case, the inequality reduces to $\left(\frac{2\beta}{2\beta+\gamma}\right)^2 \geq 1$, which is a contradiction since $1-\left(\frac{2\beta}{2\beta+\gamma}\right)^2 \leq 0 < \frac{1}{1+\delta}$ given $\delta \in [0,1]$. Now, suppose that $1-\left(\frac{2\beta}{2\beta+\gamma}\right)^2 < \frac{1}{1+\delta}$. In this case, the inequality holds only if $2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right) > \gamma$. Thus, focal retailer prefers to be in the coexistence settlement when $\gamma \in \left[0, 2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right)\right)$.

Part (ii). The unique equilibrium strategy correspond to the exclusive settlement when $\pi_F^* \leq \hat{\pi}_F^*$, or equivalently $\frac{1}{1+\delta}\pi_{FE}^* \leq \min\{\hat{\pi}_{FC}^* - \pi_{PC}^*, \frac{1}{1+\delta}\hat{\pi}_{FC}^*\}$. After substitutions and simplifications, the inequality reduces to

$$\frac{1}{1+\delta}\left(\frac{2\beta}{2\beta+\gamma}\right)^2 \leq \min\left\{1-\left(\frac{2\beta}{2\beta+\gamma}\right)^2, \frac{1}{1+\delta}\right\}$$

First, suppose that $1-\left(\frac{2\beta}{2\beta+\gamma}\right)^2 \geq \frac{1}{1+\delta}$, or equivalently $\frac{\delta}{1+\delta} \geq \left(\frac{2\beta}{2\beta+\gamma}\right)^2$. In this case, the inequality reduces to $\left(\frac{2\beta}{2\beta+\gamma}\right)^2 \leq 1$, which is always true since $1 > \frac{\delta}{1+\delta} \geq \left(\frac{2\beta}{2\beta+\gamma}\right)^2$ given $\delta \in [0,1]$. Thus, focal retailer prefers to be in the exclusive settlement when $\frac{\delta}{1+\delta} \geq \left(\frac{2\beta}{2\beta+\gamma}\right)^2$, which is equivalent to $2\beta\left(\sqrt{\frac{1+\delta}{\delta}}-1\right) \leq \gamma$. Now, suppose that $1-\left(\frac{2\beta}{2\beta+\gamma}\right)^2 < \frac{1}{1+\delta}$, or equivalently $2\beta\left(\sqrt{\frac{1+\delta}{\delta}}-1\right) > \gamma$. In this case, the inequality holds only if $2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right) \leq \gamma$. Thus, focal retailer also prefers to be in the exclusive settlement when $2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right) \leq \gamma < 2\beta\left(\sqrt{\frac{1+\delta}{\delta}}-1\right)$. In general, we can conclude that focal retailer prefers to be in the exclusive settlement when $\gamma \in \left[2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right), \beta\right]$. □

Proof for Proposition 2

In Proposition 1, we prove that the unique equilibrium strategy corresponds to the exclusive settlement when $2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right) \leq \gamma \leq \beta$. Further, when $2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right) \leq \gamma \leq \min\left\{2\beta\left(\sqrt{\frac{1+\delta}{\delta}}-1\right), \beta\right\}$, focal retailer's profit in SPNE is $\hat{\pi}_F^* = \hat{\pi}_{FC}^* - \pi_{PC}^* = \frac{(4\beta\gamma+\gamma^2)(\alpha-c)^2}{4\beta(2\beta+\gamma)^2}$. In this case, the first derivative of $\hat{\pi}_F^*$ with respect to γ is $\frac{d\hat{\pi}_F^*}{d\gamma} = \frac{2\beta(\alpha-c)^2}{(2\beta+\gamma)^3} > 0$ since we assume $\alpha > c \geq 0$ and $0 \leq \gamma \leq \beta$. Thus, focal retailer's profit increases with γ level when the unique equilibrium strategy corresponds to exclusive settlement and the outside option of common supplier is high enough to impact the equilibrium. $\square$

Proof for Proposition 3

In Proposition 1, we prove that the threshold of γ level on the equilibrium switching from coexistence settlement to exclusive settlement is $\gamma_T = 2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}}-1\right)$. By deriving the first derivative of γ_T with respect to δ, we find that $\frac{d\gamma_T}{d\delta} = -\frac{\beta}{(1+\delta)^2\sqrt{\frac{2+\delta}{1+\delta}}} < 0$ since we assume $0 \leq \gamma \leq \beta$ and $0 \leq \delta \leq 1$. Thus, under retailers move first scenario, the unique equilibrium strategy switches from coexistence settlement to exclusive settlement at a lower γ level when δ level increases. $\square$

Proof for Proposition 4

Based on Lemma 3, we derive that total supply chain network profit under asymmetric network is $\Pi = 2\beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$ (or $\Pi = \frac{(\alpha-c)^2}{4\beta}$) when the unique equilibrium strategy corresponds to coexistence (or exclusive) settlement. In contrast, total supply chain network profit under symmetric network is $\Pi_0 = 2\beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$ since the unique equilibrium strategy always corresponds to coexistence settlement. Thus, $\Pi = \Pi_0$ if the equilibrium strategy under the asymmetric network corresponds to coexistence settlement (i.e., $\gamma \in \left[0, 2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}} - 1\right)\right)$). However, when the equilibrium strategy under asymmetric network switches to exclusive settlement (i.e., $\gamma \in \left[2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}} - 1\right), \beta\right]$), $\Pi \geq \Pi_0$ if $\gamma \geq 2\beta(\sqrt{2} - 1)$ and $\Pi < \Pi_0$ if $\gamma < 2\beta(\sqrt{2}-1)$. Thus, total supply chain network profit in equilibrium is lower (or higher) under the asymmetric rather than the symmetric network if $\gamma \in \left[2\beta\left(\sqrt{\frac{2+\delta}{1+\delta}} - 1\right), 2\beta(\sqrt{2} - 1)\right)$ (or $\gamma \in \left[2\beta(\sqrt{2} - 1), \beta\right]$). $\square$

Appendix C: Extensions

1. Product Complementarity

In this section, we consider the case where both suppliers' products are *complements* (i.e., $\gamma < 0$) instead of *substitutes* (i.e., $\gamma > 0$) (Singh and Vives 1984). In Lemma 3, we prove that $\pi^*_{FE} = \pi^*_{PC} = \beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$ when the equilibrium strategy corresponds to coexistence settlement; while $\hat{\pi}^*_{FC} = \frac{(\alpha-c)^2}{4\beta}$ when the equilibrium strategy corresponds to exclusive settlement. In Table 3, we provide each player's bargaining payoff under asymmetric network in both coexistence and exclusive settlements when $\gamma < 0$:

Table 3: Bargaining Payoff when $\gamma < 0$

Asymmetric Network	Coexistence Settlement	Exclusive Settlement
Focal Retailer	$\frac{1}{1+\delta}\pi^*_{FE}$	$\min(\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{1}{1+\delta}\hat{\pi}^*_{FC})$
Peripheral Retailer	$\frac{1}{1+\delta}\pi^*_{PC}$	0
Exclusive Supplier	$\frac{\delta}{1+\delta}\pi^*_{FE}$	0
Common Supplier	$\frac{\delta}{1+\delta}\pi^*_{PC}$	$\max(\pi^*_{PC}, \frac{\delta}{1+\delta}\hat{\pi}^*_{FC})$

Then, we derive the first derivative of π^*_{PC} with respect to γ and prove that $\frac{d\pi^*_{PC}}{d\gamma} = -\frac{2\beta(\alpha-c)^2}{(2\beta+\gamma)^3} < 0$ since we assume $\alpha > c \geq 0$ and $\beta \geq -\gamma > 0$ in complement scenario, which indicates that $\pi^*_{PC} > \hat{\pi}^*_{FC} > 0$ when $\gamma < 0$ since $\hat{\pi}^*_{FC} = \pi^*_{PC}|_{\gamma=0}$. Thus, $\frac{1}{1+\delta}\pi^*_{FE} > \min(\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{1}{1+\delta}\hat{\pi}^*_{FC}) = \hat{\pi}^*_{FC} - \pi^*_{PC}$ always holds when $\gamma > 0$, and the unique SPNE always correspond to coexistence settlement. Intuitively, retailers are viewed as "alliances" instead of "competitors" when products are complement in the consumer market. Thus, focal retailer no longer has the incentive to exclude peripheral retailer from the supply chain network.

2. Price Response Heterogeneity

In this section, we relax the homogeneity assumption of each product's price response to changes in its quantity ordered from retailer $i \in \{F, P\}$ (i.e., $\beta_F = \beta_P = \beta$), and assume that $0 \leq \gamma \leq \beta_i$ and $\beta_i \beta_{\neg i} - \gamma^2 > 0$ (Lus and Muriel 2009). Following Lemmas in Appendix B, we derive that $\pi^*_{FE} = \frac{\beta_F(2\beta_P-\gamma)^2(\alpha-c)^2}{(4\beta_F\beta_P-\gamma^2)^2}$, $\pi^*_{PC} = \frac{\beta_P(2\beta_F-\gamma)^2(\alpha-c)^2}{(4\beta_F\beta_P-\gamma^2)^2}$ and $\hat{\pi}^*_{FC} = \frac{(\alpha-c)^2}{4\beta_F}$. In Table 4 (or 5), we provide each player's bargaining payoff under asymmetric network in both coexistence and exclusive settlements when $\beta_F < \beta_P$ (or $\beta_F \geq \beta_P$):

Table 4: Bargaining Payoff when $\beta_F < \beta_P$

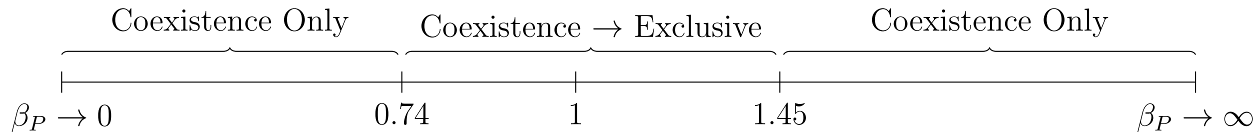
Asymmetric Network	Coexistence Settlement	Exclusive Settlement
Focal Retailer	$\pi^*_{FE} - \frac{\delta}{1+\delta}\pi^*_{PC}$	$\min(\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{1}{1+\delta}\hat{\pi}^*_{FC})$
Peripheral Retailer	$\frac{1}{1+\delta}\pi^*_{PC}$	0
Exclusive Supplier	$\frac{\delta}{1+\delta}\pi^*_{PC}$	0
Common Supplier	$\frac{\delta}{1+\delta}\pi^*_{PC}$	$\max(\pi^*_{PC}, \frac{\delta}{1+\delta}\hat{\pi}^*_{FC})$

Table 5: Bargaining Payoff when $\beta_F \geq \beta_P$

Asymmetric Network	Coexistence Settlement	Exclusive Settlement
Focal Retailer	$\frac{1}{1+\delta}\pi^*_{FE}$	$\min(\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{1}{1+\delta}\hat{\pi}^*_{FC})$
Peripheral Retailer	$\frac{1}{1+\delta}\pi^*_{PC}$	0
Exclusive Supplier	$\frac{\delta}{1+\delta}\pi^*_{FE}$	0
Common Supplier	$\frac{\delta}{1+\delta}\pi^*_{PC}$	$\max(\pi^*_{PC}, \frac{\delta}{1+\delta}\hat{\pi}^*_{FC})$

Figure 7 provides a node illustration on the impact of retailers' price response heterogeneity on bargaining settlement pattern in SPNE under all valid γ level. In general, our main findings still hold as long as the heterogeneity level is moderate. Otherwise, when $\frac{\beta_2}{\beta_1} > \overline{\beta}$ or $\frac{\beta_2}{\beta_1} < \underline{\beta}$, the unique SPNE always correspond to coexistence settlement under all valid γ level. To calculate for $\overline{\beta}$, we solve the inequality $\pi^*_{FE} - \frac{\delta}{1+\delta}\pi^*_{PC} > \min(\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{1}{1+\delta}\hat{\pi}^*_{FC}) = \frac{1}{1+\delta}\hat{\pi}^*_{FC}$ when $\gamma \to \beta_F$. Then to calculate for $\underline{\beta}$, we solve the inequality $\frac{1}{1+\delta}\pi^*_{FE} > \min(\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{1}{1+\delta}\hat{\pi}^*_{FC}) = \hat{\pi}^*_{FC} - \pi^*_{PC}$ when $\gamma \to \beta_P$. Due to the expression length of $\overline{\beta}$ and $\underline{\beta}$, we do not explicitly present them.

Figure 7: Impact of Price Response Heterogeneity on Bargaining Settlement Pattern in SPNE when $\beta_F = 1$ and $\delta = 1$



3. Suppliers Move First Scenario

In *suppliers move first scenario*, suppliers simultaneously make the first contract offer to each linked retailer, and each retailer then decides whether to accept one contract offer from the linked supplier(s) or reject all. The alternating bargaining process is the same as in *retailers move first scenario* and we still assume that $\alpha > c \geq 0$, $0 \leq \gamma \leq \beta$ and $0 \leq \delta \leq 1$.

First of all, Lemma 1 and Lemma 2 in Appendix B can still apply to this scenario. Thus, in coexistence settlement, the partnership profit of each pair is $\pi^*_{FE} = \pi^*_{PC} = \beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$. While, in exclusive settlement, the partnership profit between focal retailer and common supplier is $\hat{\pi}^*_{FC} = \frac{(\alpha-c)^2}{4\beta}$. By applying the equilibrium result of Corominas-Bosch (2004), we conclude that focal retailer's profit in equilibrium is $\pi^*_F = \frac{\delta}{1+\delta}\pi^*_{FE}$ (or $\hat{\pi}^*_F = \min\{\hat{\pi}^*_{FC} - \pi^*_{PC}, \frac{\delta}{1+\delta}\hat{\pi}^*_{FC}\}$) in coexistence (or exclusive) settlement.

In suppliers move first scenario, the unique equilibrium strategy correspond to the coexistence settlement when $\pi_F^* > \hat{\pi}_F^*$, or equivalently $\frac{\delta}{1+\delta}\pi_{FE}^* > \min\{\hat{\pi}_{FC}^* - \pi_{PC}^*, \frac{\delta}{1+\delta}\hat{\pi}_{FC}^*\}$. As Proposition 1 in Appendix B, we derive that the inequality holds only if $2\beta\left(\sqrt{\frac{1+2\delta}{1+\delta}} - 1\right) > \gamma$. Thus, focal retailer prefers to be in the coexistence settlement when $\gamma \in \left[0, 2\beta\left(\sqrt{\frac{1+2\delta}{1+\delta}} - 1\right)\right)$. In contrast, the unique equilibrium strategy correspond to the exclusive settlement when $\pi_F^* \leq \hat{\pi}_F^*$, or equivalently $\frac{\delta}{1+\delta}\pi_{FE}^* \leq \min\{\hat{\pi}_{FC}^* - \pi_{PC}^*, \frac{\delta}{1+\delta}\hat{\pi}_{FC}^*\}$. We derive that the inequality holds if $2\beta\left(\sqrt{\frac{1+2\delta}{1+\delta}} - 1\right) \leq \gamma \leq \beta$. Thus, focal retailer prefers to be in the exclusive settlement when $\gamma \in \left[2\beta\left(\sqrt{\frac{1+2\delta}{1+\delta}} - 1\right), \beta\right]$. Therefore, in *suppliers move first scenario*, when products become more substitutable, the equilibrium switches from coexistence to exclusive settlement.

Further, we derive that $\hat{\pi}_{FC}^* - \pi_{PC}^* \leq \frac{\delta}{1+\delta}\hat{\pi}_{FC}^*$ if $2(\sqrt{\frac{1+2\delta}{1+\delta}} - 1)\beta \leq \gamma < 2(\sqrt{1+\delta} - 1)\beta$. Correspondingly, focal retailer's profit in equilibrium is $\hat{\pi}_F^* = \hat{\pi}_{FC}^* - \pi_{PC}^* = \frac{(4\beta\gamma+\gamma^2)(\alpha-c)^2}{4\beta(2\beta+\gamma)^2}$. In this case, the first derivative of $\hat{\pi}_F^*$ with respect to γ is $\frac{d\hat{\pi}_F^*}{d\gamma} = \frac{2\beta(\alpha-c)^2}{(2\beta+\gamma)^3} > 0$ since we assume $\alpha > c \geq 0$ and $0 \leq \gamma \leq \beta$. Therefore, in *suppliers move first scenario*, focal retailer's profit increases with γ level of product when the unique equilibrium strategy corresponds to exclusive settlement and the outside option of common supplier is high enough to impact the equilibrium.

Also, we prove that the threshold of γ level on the equilibrium switching from coexistence settlement to exclusive settlement is $\gamma_T = 2(\sqrt{\frac{1+2\delta}{1+\delta}} - 1)\beta$ in suppliers move first scenario. By deriving the first derivative of γ_T with respect to δ, we find that $\frac{d\gamma_T}{d\delta} = \frac{\beta}{(1+\delta)^2\sqrt{\frac{1+2\delta}{1+\delta}}} > 0$ since we assume $0 \leq \gamma \leq \beta$ and $0 \leq \delta \leq 1$. Therefore, in *suppliers move first scenario*, when firms are more time patient in contract negotiation, the equilibrium switches to exclusive settlement at a higher level of product substitutability. Figure 8 shows the settlement regions in SPNE under *suppliers move first scenario* given combinations of product substitutability level (i.e., γ level) and time patience level in contract negotiation (i.e., δ level) when $\beta = 1$, which limits $0 < \gamma < 1$.

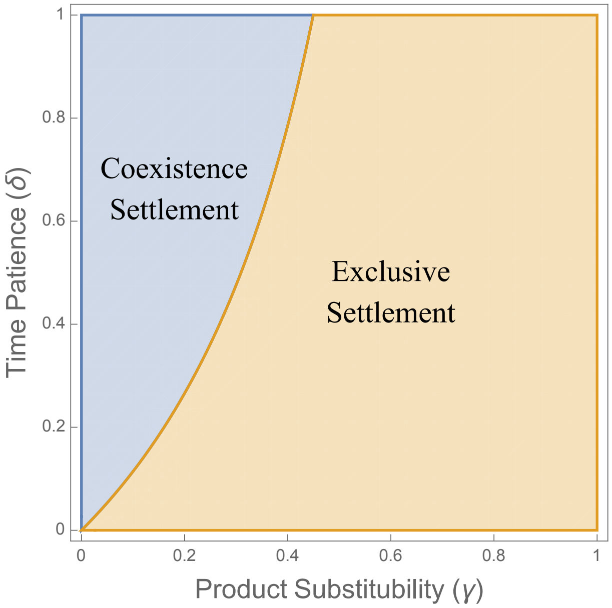


Figure 8: Settlement Regions in SPNE given $\beta = 1$ when suppliers move first

Finally, same as retailer moves first scenario, total supply chain network profit under asymmetric network is $\Pi = 2\beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$ (or $\Pi = \frac{(\alpha-c)^2}{4\beta}$) when the unique equilibrium strategy corresponds to coexistence (or exclusive) settlement. In contrast, total supply chain network profit under symmetric network is $\Pi_0 = 2\beta\left(\frac{\alpha-c}{2\beta+\gamma}\right)^2$ since the unique equilibrium strategy always corresponds to coexistence settlement. Thus, $\Pi = \Pi_0$ if the equilibrium strategy under the asymmetric network corresponds to coexistence settlement (i.e., $\gamma \in \left[0, 2\beta\left(\sqrt{\frac{1+2\delta}{1+\delta}} - 1\right)\right)$). However, when the equilibrium strategy under asymmetric network switches to exclusive settlement (i.e., $\gamma \in \left[2\beta\left(\sqrt{\frac{1+2\delta}{1+\delta}} - 1\right), \beta\right]$), $\Pi \geq \Pi_0$ if $\gamma \geq 2\beta(\sqrt{2} - 1)$ and $\Pi < \Pi_0$ if $\gamma < 2\beta(\sqrt{2} - 1)$. Thus, total supply chain network profit in equilibrium is lower (or higher) under the asymmetric rather than the symmetric network if $\gamma \in \left[2\beta\left(\sqrt{\frac{1+2\delta}{1+\delta}}-1\right), 2\beta(\sqrt{2}-1)\right)$ (or $\gamma \in \left[2\beta(\sqrt{2}-1), \beta\right]$). Therefore, in *suppliers move first scenario*, when the level of product substitutability is high enough, total supply chain network profit in equilibrium is higher under asymmetric rather than symmetric network.

Essay 2: Desperateness in Contract Bargaining under Supply Chain Networks

Introduction

Since 2020, the COVID-19 epidemic has been widely spread in many countries and become one of the most severe global pandemic in recent decades. To prevent the uncertain threats from the cross infections, in the past year, many countries have set various trade policy restrictions. For instance, many major agricultural producing nations implemented international trade limitations over their main exporting products, which have caused disruptions to global food supply chain (Falkendal et al. 2021). According to the assessment of United Nations Conference on Trade and Development (i.e., UNCTAD), the COVID-19 outbreak could conservatively cause global foreign direct investments to shrink by 30-40% during 2020-2021.

Before the COVID-19 outbreak happens, the globalization process has provided a chance and triggered the movement of building up supply chains with complete bilateral relations. However, due to business restrictions across countries during the pandemic, bilateral relationship may lack among upstream and downstream firms in the global market, which prohibits the potential trade and leads to a huge impact on the contract negotiation procedure among firms (Shih 2020). However, this phenomenon is still underexplored in academic.

In this paper, we aim to fill this gap and study the contract negotiation in a two-tier supply chain setup with two retailers/suppliers arbitrarily on each side. In our supply chain setup, each retailer/supplier needs a bilateral relationship as a premise of negotiating and contracting with each other. We consider supply chain structures where a retailer/supplier may not link with every supplier/retailer on the other side, and the retailers may have heterogeneous price response to the ordered products from the supply partner in retail market. Hereafter, we name this particular set of supply chain structures as *supply chain network*. We explore the impact of network structure on firms' contract bargaining outcomes and total supply chain network profit from both theoretical and behavioral perspectives.

We first develop a game theoretic analytic model to investigate the impact of network structure and price response heterogeneity on firms' contract bargaining decision. As a theoretical benchmark, we predict that network structure can fundamentally impact contract bargaining outcomes while should not impact total supply chain network profit. Meanwhile in behavioral literature, previous studies have shown sufficient evidence of behavioral regularities that are important but not captured by the game-theoretical predictions (e.g., Ho and Zhang 2008, Katok and Wu 2009, Kremer et al. 2010), we further investigate the behavioral phenomena in our setting via lab experiment. Our experimental data suggests systematic deviations from the theoretical benchmark and reveal behavioral regularities on firms' contracting behaviors in supply chain network. In particular, we show that firms who link with more (or less) potential partners in supply chain tend to earn more (or less) than expectation in contract bargaining. Meanwhile, firms who have more (or less) perceived values can get benefits in contract bargaining procedure as well. Furthermore, we find that supply chain network structure has a significant impact on total supply chain network profit.

Motivated by these observations, we develop a new behavioral theory, referred to as *desperateness theory*. In general, our desperateness theory shows that firms who link with less potential supply chain partner or who has less perceived values in our supply chain networks are more desperate of making contract agreement, and thus need to "sacrifice" part of the contract bargaining split when bargaining with the corresponding "advantageous" firm(s) in each possible round. We also investigate the impact of total desperateness level on the total supply chain network profit, and show that the higher the total desperateness within the supply chain network, the lower the total supply chain network profit. We believe that our desperateness theory sheds lights on explaining and predicting contract bargaining behaviors in a supply chain with complex network of interactions.

In the following sections, we first review the relevant literature in §2 and provide game-theoretic analysis for the contract negotiation problem in two-sided supply chain networks in §3. Then, in §4 and §5 respectively, we illustrate experiment design and present main experimental observations. By stating our hypotheses based on experimental investigations, in §6, we develop the *desperateness theory* to explain and predict the contract bargaining behaviors. Finally, we summarize and conclude the paper in §7.

Literature Review

Supply chain contract negotiation has been explored in the operations management field for decades. Earliest stream of papers in this literature aims to design coordinated supply chain contracts that can strategically improve supply chain efficiency under a supply chain with one retailer and one supplier. (see Cachon 2003 for a review). Further exploration has been expanded into two different directions. The first direction provides theoretic analysis on supply chain contract negotiation with specific information environment (e.g., Feng et al. 2015) and/or under more complex supply chain networks such as one-retailer-multiple-suppliers (e.g., Aydin and Heese 2015), one-supplier-multiple-retailers (e.g., Bernstein and Federgruen 2005, Netessine and Zhang 2005), competing supply chains each with one-retailer-one-supplier (e.g., Ha and Tong 2008, Wu and Chen 2010) and multiple-retailers-multiple-suppliers (e.g., Adida and DeMiguel 2011, Korpeoglu et al. 2020). The second direction performs behavioral analysis on supply chain contract negotiation through free-format (e.g., Leider and Lovejoy 2016) and/or under one-retailer-one-supplier network. (e.g., Davis and Hyndman 2019, Haruvy et al. 2020). With both theoretical and behavioral analysis, our study aims to explore dynamic supply chain contract negotiation in two-sided supply chain networks with two retailers/suppliers on each side.

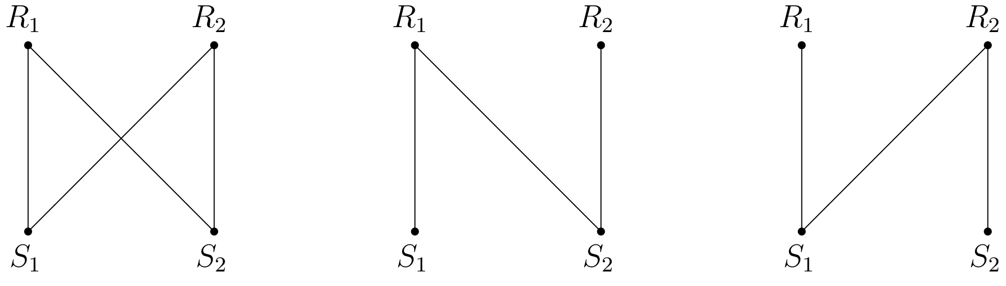
One closely related paper is Nakkas and Xu (2019) who theoretically studies the scenario that retailers with heterogeneous valuations on the product purchase it from one of the linked suppliers in different two-sided supply chain networks. Different from their paper, we consider bargaining over a supply chain contract instead of a single item in two-sided networks. Furthermore, besides the theoretic analysis, we also provide behavioral analysis which have shown remarkable importance by recent behavioral studies under different supply chain settings (e.g., Katok and Wu 2009, Özer et al. 2011, Long and Nasiry 2015). Some other theoretical papers also study supply chain negotiations in different contexts. For instance, Bimpikis et al. (2018) and Bimpikis et al. (2019) investigate the supply chain network structure design or formation either between markets and firms or between upstream and downstream firms. Different from their papers, we study the impact of different two-sided network structures on contract bargaining between retailers and suppliers.

Also related is the recent research stream on behavioral contract negotiation mostly under one-retailer-one-supplier network scenario. Leider and Lovejoy (2016) experimental studies multi-tier negotiation in a supply chain involving three tiers with only one firm emerging from each tier. Davis and Hyndman (2019) investigates wholesale price contract bargaining with uncertain demand and finds that supply chain efficiency improves when order quantity is included in the negotiation. Haruvy et al. (2020) finds the positive impact of allowing participants' concessions within contract bargaining process on the supply chain efficiency. Our study different from the above papers is that we examine the implications of supply chain network structures for contract bargaining with two retailers and suppliers on each side.

In addition, in economics literature on sequential bargaining, several papers subsequent to Rubinstein (1982) have conducted experiments on exploring how human behave in sequential bargaining with the manipulation of bargaining rounds or discounting factor (e.g., Güth et al. 1982, Neelin et al. 1988, Ochs and Roth 1989, Weg et al. 1990). One related paper is Charness et al. (2007) who extend the infinite-horizon Corominas-Bosch (2004) graph-theoretic model of buyers and sellers to a finite-horizon experimental game, and run economic experiments to explore the setting of bargaining values in two-sided networks. One key difference in this paper is that we investigate the application of sequential bargaining over a supply chain contract instead of a direct input. Previous behavioral research has shown that supply chain context matters in human decision. (e.g., Ho and Zhang 2008, Kremer et al. 2010). Furthermore, we restrict our attention to two-sided supply chain networks with two retailers/suppliers on each side while relaxing their homogeneity assumption on input values by allowing price response heterogeneity on order quantities between two retailers. In general, experimental results in Charness et al. (2007) broadly conforms to the theoretical prediction. While in this paper, we reveal strong behavioral regularities on firms' contracting behaviors in two-sided supply chain networks, and further develop a new behavioral theory to explain and predict the behavioral phenomena.

The Standard Model

We study a supply chain system with two retailers/suppliers on each side and examine the implications of different bilateral relations for contract bargaining. Figure 9 shows all possible network representations, in which two suppliers (denoted as "she") are arbitrarily resided at the bottom nodes (S_1 and S_2), and two retailers (denoted as "he") with different price response to ordered products in retail market are arbitrarily resided at the top nodes (R_1 and R_2). A link between a retailer and a supplier represents that there exists a bilateral relationship between two firms and they can contract with each other through negotiation. Conversely, absence of a link means that two firms cannot contract with each other. The contract bargaining procedure follows an alternating multi-round process (described below), and extends the infinite-horizon graph-theoretic model to a finite-horizon experimental game (Charness et al. 2007). Each supplier/retailer can at most reach a contract agreement with one retailer/supplier. With a contract agreement, a retailer can order products from his supply partner and then sell to the retail market, which is modeled as a quantity-setting game with linear pricing functions.



(X network) (N network) (Z network)

Figure 9: Two-retailers-two-suppliers network structures

In each supply chain network, firms play a two-stage sequential game. In the first stage, retailers and suppliers bargain with each other to reach contract agreement. A supply contract takes the form of a wholesale price of w per unit and a fixed payment of F (i.e., two-part tariff). We use two-part tariff as it is commonly used in both theory and practice (Weng 1995, Cachon 2003). In the first negotiation round, retailers simultaneously make the first contract offer to each linked supplier. Then, each supplier simultaneously decides whether to accept one contract proposal from the linked retailer(s) or reject all. If both suppliers accept one retailer's contract proposal, one supplier will be randomly matched with the retailer while the remaining supplier will match with the other retailer if he offers the same proposal. If a retailer and a supplier reach the contract agreement, they move to the second stage of the game while their nodes together with all of their link(s) are removed from the supply chain network. Firms that could not trade in Round 1 remain in the contract negotiation stage as long as they have connection(s) with each other.

In the second round, the remaining supplier(s) first make the contract offer(s) to each linked retailer(s), and then each remaining retailer decides whether to accept one contract proposal from the linked supplier(s) or reject all. To better fit for the experiment, we follow Charness et al. (2007) and extend the infinite versions of the graph-theoretic model to a finite experimental game. Our sequential bargaining process can repeat itself potentially with a maximum allowable rounds for remaining firms who are connected with each other. Specifically, there are at most $2n-1$ rounds of bargaining, where n represents retailer's potential number of proposal rounds and $n \geq 2$. [1] If the game proceeds to Round $2n-2$, there is a 50% chance that the game ends after that round or the next round $2n-1$, which

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[1] We prove that as long as the maximum allowable bargaining round is odd or even, the corresponding theoretical prediction does not depend on the specific value of n. In this paper, we use odd maximum allowable bargaining round as an illustration.

is a common knowledge for each firm remaining in the network.

Then we move to the second stage. With the contract agreement, a retailer can order products from the supply partner with the payment: $(w \cdot q + F)$. For each unit ordered from the retailer, we assume that supplier incurs a production cost (c) with unlimited capacity. Then, for each additional round of bargaining, we assume that each firm incurs a negotiation cost (d). Thus, supplier's profit in Round t: $\pi_S = (w - c) \cdot q + F - d \cdot (t - 1)$. The retail market is modeled as a quantity-setting game with linear price functions. Specifically, the retailer price is assumed to be a common knowledge, and takes the linear form of $p_i = a - b_i \cdot q_i$, for $i = 1, 2$ and $i \neq j$, $a > 0$, $b_2 > b_1 > 0$, where q_i is quantity of product i ordered from retailer i and p_i is the per-unit retailer price of product i. We define k as the price response heterogeneity multiplier where $k = \frac{b_2}{b_1} > 1$. Product has no salvage value and thus retailer sells all of the amount ordered from the supply partner. Thus, retailer's profit in Round t is $\pi_R = (p - w) \cdot q - F - d \cdot (t - 1)$. All firms who can not reach a contract agreement during the game will get 0 reservation amount. All the notations are summarized in Appendix A.

In our setting, the subgame perfect Nash equilibrium (SPNE) is unique. Theorem 1 summarizes subgame perfect Nash equilibrium outcomes in all three supply chain networks. The corresponding theoretical derivation is included in Appendix B. In general, firms should reach contract agreement in the first negotiation round by setting wholesale price at production cost (i.e., $w = c$) and allocate trade surplus through fixed fee F. With contract agreement, each retailer i should order $q_i^* = \frac{a-c}{2b_i}$ from corresponding supply partner in each network.

THEOREM 1:

(i) In X and N networks, the unique subgame perfect Nash equilibrium predicts that both retailers propose a contract of $w^* = c$ *and* $F^* = \frac{(a-c)^2}{8b_2}$*, and both suppliers should accept the offer. With contract agreement, both retailers should order* $q_i^* = \frac{a-c}{2b_i}$ *from the supply partner before selling to the retail market.*

(ii) In Z network, the unique subgame perfect Nash equilibrium predicts that R_1 *should propose a contract of* $w^* = c$ *and* $F^* = \frac{k(a-c)^2}{8b_2}$*,* R_2 *should propose a contract of* $w^* = c$ *and* $F^* = \frac{(a-c)^2}{8b_2}$*, and* S_1 *and* S_2 *should accept the offer respectively. With contract agreement, both retailers should order* $q_i^* = \frac{a-c}{2b_i}$ *from the supply partner before selling to the retail market.*

Figure 10: General game-theoretic prediction of bargaining payoff under two-retailers-two-suppliers networks.

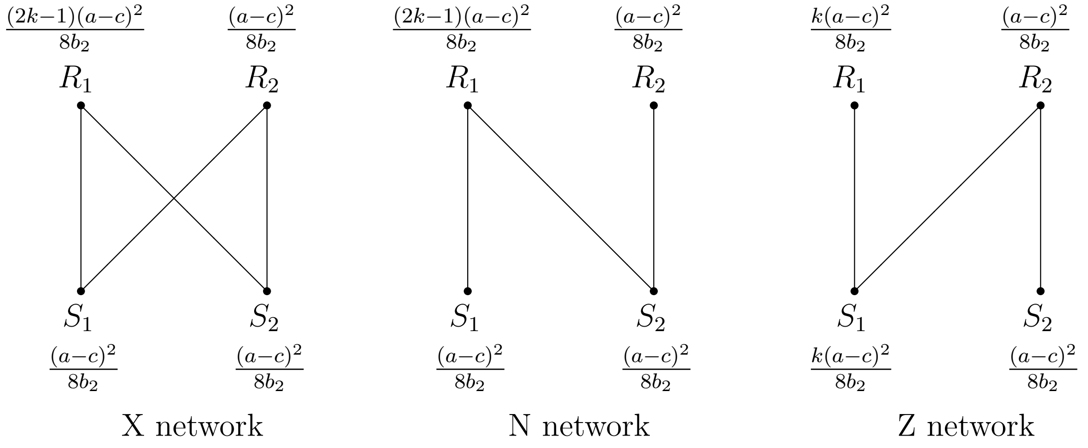

Figure 10 shows equilibrium bargaining payoff under all three supply chain networks. In X and N network where R_1 is well-connected, our prediction shows that R_1 can exploit the network advantage by not splitting the surplus profit of R_1 partnership over R_2 partnership with supply partner, which leads to a higher equilibrium payoff for himself compared to other firms within the same supply chain network. While, under Z network, since R_1 only connects with S_1, he is not able to preserve the surplus profit and needs to split the R_1 partnership profit with supply partner according to bargaining power, which leads to a different equilibrium bargaining payoff. Further, although the equilibrium bargaining payoff under supply chain networks can be different, our prediction shows that total supply chain network profit is always the same in all three networks which is $\Pi_T = \frac{(k+1)(a-c)^2}{4b_2}$.

Experimental Design and Procedures

In this section, we conducted human-subject experiments to examine the behavioral impact of network structure and price response heterogeneity on contract bargaining in a two-sided supply chain system by keeping other supply chain parameters at the same level in different treatments. In each treatment, subjects play the role of a firm in the supply chain network and first bargain with linked potential partner(s). With a contract agreement, retailer can order products from the supply partner before selling them to the retail market. Otherwise, the sequential bargaining process can repeat itself potentially with a maximum allowable rounds for remaining firms who are connected with each other. To focus on contract negotiation procedure and reduce the complexity of our experiment (Kalkanci et al. 2011), we automated the order quantity decision for each retailer, which maximizes his own payoff given the contract agreement.

All experiments were built and conducted on SoPHIE Labs, which is a flexible online experiment platform and can efficiently connect with Amazon MTurk. Thus, the participants of our experiment were directly recruited from Amazon MTurk. We conducted five treatments in experiment as summarized in Table 6. In each treatment, we conducted around 60 independent online games with 4 players within each game and each player could only participate in one game. Thus, our experiment completely rule out the possibility of reputation effects in the repeated game with a small number of participants. To participate, each player needs to first read the instructions of the experiment and pass the following quiz. During the online experiment, players (i.e., Amazon MTurk workers) interact with each other through the SoPHIE Lab online platform without knowing any personal identification information of other players. In each game, every player was randomly matched with another three players and the position within the network is also randomly assigned.

Table 6: Experimental Design and Sample Size

	With Price Response Heterogeneity (k = 2)	Without Price Response Heterogeneity (k = 1)
X network	60 games	59 games
N network	60 games	55 games [2]
Z network	63 games	

We determine our experiment parameters based on the following rule. Firstly, we investigate the impact of price response heterogeneity through manipulating the coefficient (i.e., b_i) in linear price function and keep the intercept the same for simplicity. Secondly, we set up a low level of negotiation cost and allow multiple potential bargaining rounds for both retailers and suppliers, which provide flexibility for subjects to bargain under two-sided supply chain networks. Moreover, with $p_i^* = 60$ and $c = 20$ for each ordered product i, we focus on high-profit-margin scenario, which leads to a higher potential profit gain from coordination

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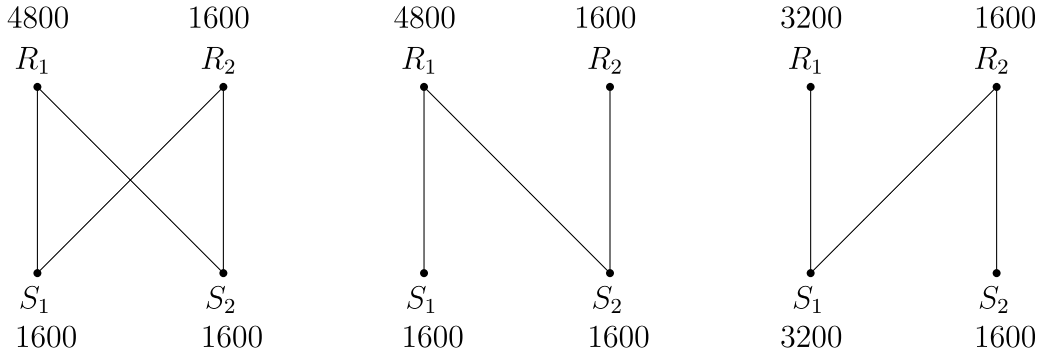
[2] Note that: N and Z networks are equivalent when there is no price response heterogeneity between two retailers (i.e., k = 1).

and has a higher possibility to be observed in reality (Katok and Wu 2009, Wu and Chen 2014).

The experimental parameters in all treatments are shown as follows and are the common knowledge for all players in the game. First of all, in the linear price function, the intercept a is set to 100 in all treatments, and the coefficient b_i is set to 0.25 and 0.5 for R_1 and R_2 respectively (or set to 0.5 for both retailers) in the treatments with (or without) price response heterogeneity. Secondly, the negotiation cost is set at 80 per round starting from Round 2, and the retailer's maximum number of proposal rounds in all treatments is set at 4 rounds (i.e., $n = 4$), which indicates that if the game proceeds to Round 6, there is 50% chance that the game ends after that round or the next Round 7. In addition, each supplier's production cost (c) is set at 20 for each ordered product.

Figure 11 (or Figure 12) shows the game-theoretic prediction of each player's bargaining payoff under each supply chain network with (or without) price response heterogeneity, where the price response multiplier k equals to 2 (or 1) under the treatments with (or without) price response heterogeneity respectively. Specifically, in treatments of X and N networks, both retailers should propose a contract of $w^* = 20$ and $F^* = 1600$ in Round 1 and both suppliers should accept the offer. While, in Z network, R_1 (or R_2) should offer a contract of $w^* = 20$ and $F^* = 3200$ (or $F^* = 1600$) under the treatment with price response heterogeneity and both suppliers should accept the corresponding offer in Round 1. With the contract agreement, R_1 (or R_2) should order $q^* = 160$ (or $q^* = 80$) respectively under the treatments with price response heterogeneity, while both should order $q^* = 80$ under other treatments.

Figure 11: Game-theoretic prediction of bargaining payoff under treatments with price response heterogeneity.



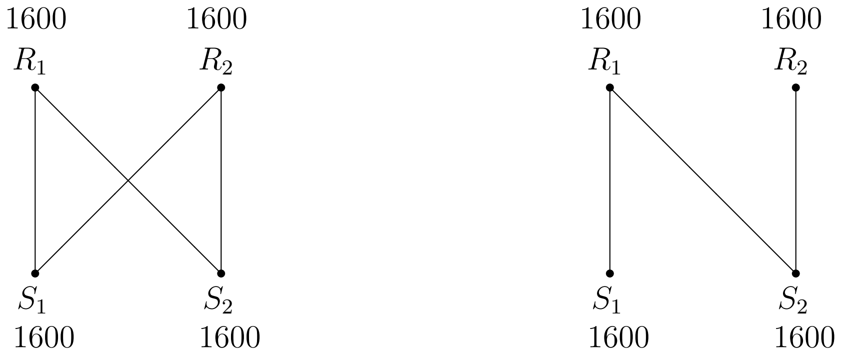
X network: 60 games N network: 60 games Z network: 63 games

Supply Chain Profit: 9600 Supply Chain Profit: 9600 Supply Chain Profit: 9600

Note: in treatments with price response heterogeneity, $a = 100$, $b_1 = 0.25$, $b_2 = 0.5$, $c = 20$, $d = 80$, $n = 4$.

Thus, $k = 2$, $w^* = 20$, $q_1^* = 160$, $q_2^* = 80$, $V_1^* = 6400$, $V_2^* = 3200$, $\Pi_T^* = 9600$.

Figure 12: Game-theoretic prediction of bargaining payoff under treatments without price response heterogeneity.



X network: 59 games N network: 55 games

Supply Chain Profit: 6400 Supply Chain Profit: 6400

Note: in treatments without price response heterogeneity, $a = 100$, $b_1 = b_2 = 0.5$, $c = 20$, $d = 80$, $n = 4$.

Thus, $k = 1$, $w^* = 20$, $q_1^* = q_2^* = 80$, $V_1^* = V_2^* = 3200$, $\Pi_T^* = 6400$.

To help understand our experimental game, we provide training process to each participant before actual game, which explains the experiment interface and decision tasks. We also provide a decision support tool during the experiment. Specifically, in each negotiation round, both proposers and responders can run trial decisions on contract agreement, and the interface would display the corresponding payoff for both retailer and supplier. Players are given at least 3 minutes to make a decision in actual game. On average, every experimental game lasts around 15 minutes. Besides the show-up fee ($0.75), each player was paid a bonus (ranged from $0.75 to $3.25) proportional to what he or she earned in the experiment. Since players can earn negative experimental payoffs, in that case, he or she will only get the show-up fee. In our experiment, every player earned $1.9 on average.

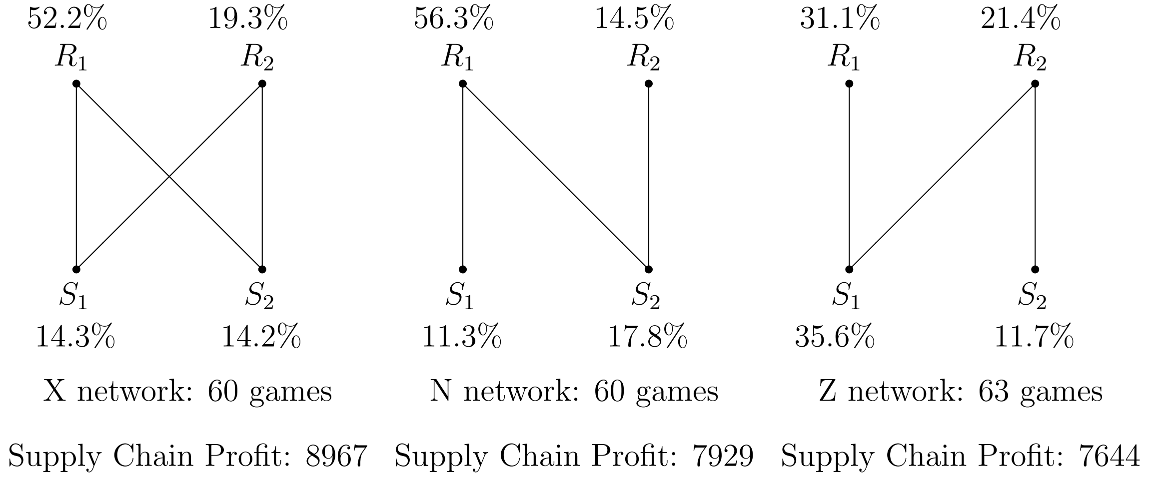
Experimental Results

Observational Result 1: Higher Perceived Value Firms Earn More in Contract Bargaining.

Figure 13 (or 14) respectively presents the experimental results of average bargaining payoff percentage under all treatments with (or without) price response heterogeneity. In Figure 14, under X network, our experimental results indicate that both retailers earn more bargaining payoff than both suppliers on average although theoretically all firms should earn the same amount shown in Figure 12. To statistically compare different roles' bargaining payoff under each treatment, we conduct both non-parametric Wilcoxon signed rank test and parametric paired-sample t-test. Table 7 summarizes the statistical results and the p-value of each test is shown as the first/second value in each cell respectively. As Part d of Table 7 shows, in the treatment of X network without price response heterogeneity, both parametric and nonparametric test results indicate that the bargaining payoff of each retailer is significantly higher than that of each supplier. In addition the results are consistent with the theoretical assumption that each retailer or supplier in the treatment should earn the same amount, which is 25% of the total supply chain network profit.

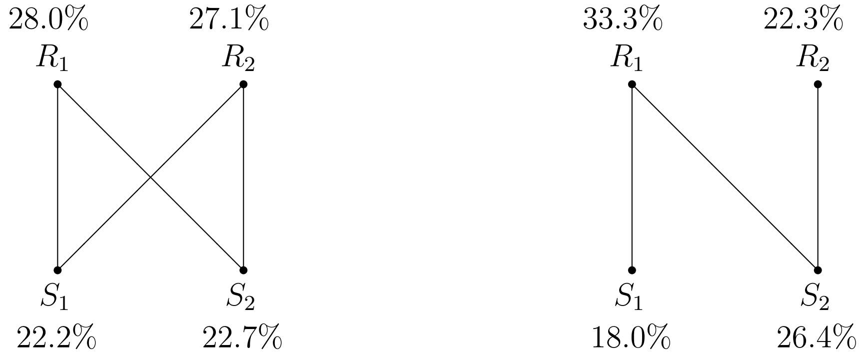
We speculate that both retailers in experiment may have a perception of having a higher bargaining power than both suppliers due to their role advantage although theoretically they should not (Brown 2005). In our setting, retailers stand between retail market and suppliers, and take the role of realizing the trade surplus of products for the supply chain, which may induce their perception of entirely owning it although they have to then split with supply partner. Similarly in Figure 13, under X network with price response heterogeneity, our experimental results also indicate that both S_1 and S_2 tend to earn less bargaining payoff than R_2 with the statistical support from both tests shown in Part a of Table 7 although theoretically they should earn the same amount. Thus, we conjecture that higher perceived value firms may earn more in contract bargaining due to their role advantages.

Figure 13: Experimental results of average bargaining payoff percentage under treatments with price response heterogeneity.



Note: in treatments with price response heterogeneity, $a = 100$, $b_1 = 0.25$, $b_2 = 0.5$, $c = 20$, $d = 80$, $n = 4$.

Figure 14: Experimental results of average bargaining payoff percentage under treatments without price response heterogeneity.



X network: 59 games

Supply Chain Profit: 5802

N network: 55 games

Supply Chain Profit: 5118

Note: in treatments without price response heterogeneity, $a = 100$, $b_1 = b_2 = 0.5$, $c = 20$, $d = 80$, $n = 4$.

Table 7: Statistical Tests on Bargaining Payoff Comparison of Different Roles: Nonparametric Wilcoxon Signed Rank Test vs Parametric Paired-sample t-test

	R1	R2	S1	S2
R1	NA	0.001 0.001	0.001 0.001	0.001 0.001
R2		NA	0.002 0.004	0.003 0.002
S1			NA	0.539 0.442
S2				NA

(a) X Network with PRH

	R1	R2	S1	S2
R1	NA	0.001 0.001	0.001 0.001	0.002 0.003
R2		NA	0.024 0.021	0.045 0.036
S1			NA	0.001 0.001
S2				NA

(b) N Network with PRH

	R1	R2	S1	S2
R1	NA	0.001 0.001	0.067 0.047	0.001 0.001
R2		NA	0.002 0.001	0.001 0.001
S1			NA	0.001 0.001
S2				NA

(c) Z Network with PRH

	R1	R2	S1	S2
R1	NA	0.397 0.354	0.002 0.001	0.015 0.025
R2		NA	0.033 0.021	0.036 0.025
S1			NA	0.590 0.576
S2				NA

(d) X Network without PRH

	R1	R2	S1	S2
R1	NA	0.001 0.001	0.001 0.001	0.002 0.004
R2		NA	0.061 0.042	0.052 0.058
S1			NA	0.001 0.001
S2				NA

(e) N/Z Network without PRH

Note: The first/second value in each cell represents the p-value from nonparametric Wilcoxon Signed Rank Test/Parametric Paired-sample t-test respectively.

Observational Result 2: More Connected Firms Earn More in Contract Bargaining.

In Figure 14, under N/Z network without price response heterogeneity, our experimental results indicate that the bargaining payoff on average is $\pi_{S_1} < \pi_{R_2} < \pi_{S_2} < \pi_{R_1}$ with the statistical support from both tests shown in Part e of Table 7 although theoretically all firms should earn the same amount. First of all, consistent with our first observational result, R_1 (or R_2) on average earns more than S_2 (or S_1) who has the same network links(s) in this treatment. Furthermore, we find that both S_1 and R_2's bargaining payoff is significantly less than what S_2 earns, which indicates that firms who connect with less supply chain partners may have a perception of having a lower bargaining power in contractual negotiation procedure and thus earn less in contract agreement. Given less supply chain connections but having role advantage compared to S_2, R_2 earns significantly lower than S_2, which indicates that the perception of bargaining power increase due to role advantage is *lower* than that of bargaining power decrease due to less supply chain connections within the network.

Similarly in Figure 13, under N network with price response heterogeneity, our experimental results indicate that the bargaining payoff on average is $\pi_{S_1} < \pi_{R_2} < \pi_{S_2} < \pi_{R_1}$ with the statistical support from both tests shown in Part b of Table 7 although theoretically all firms except R_1 should earn the same amount. Then, under Z network with price response heterogeneity in Figure 13, we predict that $\pi_{R_1} = \pi_{S_1}$ and $\pi_{R_2} = \pi_{S_2}$ in theory. However, our experiment results show that $\pi_{S_2} < \pi_{R_2} < \pi_{R_1} < \pi_{S_1}$ with the statistical support from both tests shown in part c of Table 7. In both treatments, we find consistent evidence that firms who connect with less supply chain partner tend to earn less payoff in contract bargaining, and further the perception of bargaining power change due to supply chain connections is higher than that due to role difference.

Observational Result 3: More Network Links, Higher Total Supply Chain Network Profit

Now we investigate the behavioral impact of network structures and price response heterogeneity on total supply chain network profit in our supply chain networks. Table 8 presents the descriptive statistics of total supply chain network profit in all treatments. First of all, total supply chain network profit in all treatments tends to be significantly lower than the theoretical prediction. With the statistical support from both non-parametric Wilcoxon test and parametric t-test (not published in the paper), we find that total supply chain profit under X network is significantly higher than that under other networks both with or without price response heterogeneity. Thus, we speculate that total supply chain network profit is higher under supply chain network with more network links although theoretically it should be the same under all networks.

In Table 8, we present profit lose due to different possible reasons under each treatment. First of all, mismatch between retailers and suppliers (e.g., R_1 contracts with S_2, or R_2 contracts with S_1) may lead to huge profit loss in N/Z networks but not X network due to no link between remaining firms in the network, which leads to 0 bargaining payoff for both firms. Furthermore, we find that profit lose caused by mismatch is not significantly different between N and Z network treatments with price response heterogeneity. Although N network has a lower profit lose compared to Z network each time when the "mismatch" situation happens, the probability of "mismatch" happening is higher under N network possibly because R_1 who can reach a higher partnership profit is more attractive to both suppliers. Therefore, with the compensating effects from both network structure and price response heterogeneity, our result is consistent with the assumption that profit lose is at the same level under both N and Z networks, which accounts for around 70% of the total supply chain network profit lose, and is much higher than any other possible reasons under each treatment.

Table 8: Total Supply Chain Profit Analysis

	Predicted Amount	Experimental Amount	Efficiency Percentage	Profit Loss % due to mismatch	Profit Loss % due to $w > c$	Profit Loss % due to $n > 1$ rounds	Profit Loss % due to no agreement
X network with PRH	9600	8967	93%	0%	53%	40.8%	6%
N network with PRH	9600	7929	82%	70%	16%	9%	6%
Z network with PRH	9600	7644	80%	73%	14%	9%	4%
X network without PRH	6400	5802	91%	0%	57%	36%	6%
N/Z network without PRH	6400	5118	80%	67%	20%	10%	3%

Other Miscellaneous Observation Results

Table 9 summarizes players' bargaining rounds in treatments either with or without price response heterogeneity (PRH). In our setting, the maximum possible bargaining round is 6 or 7 rounds with equal probability. However, only around 1% of the bargaining games can not reach contract agreement due to reaching the end of maximum possible rounds. Furthermore, different treatments show similar pattern on the distribution of bargaining rounds. Consistent with Charness et al. (2007), most of the games end in the first few rounds. Specifically, around 89% (or 95%) of the bargaining games on average end in the first two (or three) rounds.

Table 9: Bargaining Rounds Statistics

Treatment		Round						
		1	2	3	4	5	6	7
With PRH	X – AgreeEnd	68 (57%)	36 (30%)	6 (5%)	1 (1%)	3 (3%)	2 (2%)	3 (3%)
	X – NoAgreeEnd	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)
	N – AgreeEnd	65 (54%)	22 (18%)	8 (7%)	0 (0%)	0 (0%)	2 (2%)	0 (0%)
	N – NoAgreeEnd	20 (17%)	2 (2%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)	0 (0%)
	Z – AgreeEnd	75 (60%)	24 (19%)	3 (2%)	3 (2%)	3 (2%)	2 (2%)	0 (0%)
	Z – NoAgreeEnd	14 (11%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (2%)	0 (0%)
Without PRH	X – AgreeEnd	71 (60%)	27 (23%)	14 (12%)	3 (3%)	0 (0%)	2 (2%)	0 (0%)
	X – NoAgreeEnd	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)
	N/Z – AgreeEnd	67 (60%)	25 (22%)	1 (1%)	1 (1%)	1 (1%)	1 (1%)	0 (0%)
	N/Z – NoAgreeEnd	14 (13%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)
Total		394 (66%)	137 (23%)	32 (5%)	8 (1%)	7 (1%)	12 (2%)	6 (1%)

Table 10 then presents the descriptive statistics of contract agreements in all treatments. First of all, we show that agreed wholesale price (w) is significantly higher than production cost ($c = 20$), which contradicts with the theoretic prediction but is consistent with the double-marginalization phenomenon in previous experimental research (Ho and Zhang 2008). Furthermore, we compare agreed wholesale price (w) either between R_1 and R_2 partnerships within each treatment or of each partnership among treatments, but do not find significant differences in both ways with the statistical support from both Mann-Whitney test and two-sample t-test. Since we automate the order quantity decision for retailers in each treatment, the agreed order quantity in Table 10 is the optimized order quantity for each retailer on average.

Table 10: Descriptive Statistics of Contract Agreement in all treatments

	Agreed w for R_1 pair	Agreed w for R_2 pair	Agreed F for R_1 pair	Agreed F for R_2 pair	Agreed q for R_1 pair	Agreed q for R_2 pair
X network with PRH	28.95	30.71	465.08	622.68	142.1	69.29
N network with PRH	29.06	30.16	596.59	590.53	141.86	69.84
Z network with PRH	31.12	29.3	1403.06	845.33	137.76	70.7
X network without PRH	32.72	34.19	624.83	643.81	67.28	65.81
N/Z network without PRH	32.34	32.68	629.16	702.5	67.66	67.33

Behavioral Theory

We develop a new analytical theory to explain and predict firms behaviors in contract bargaining within two-sided supply chain networks. Our experimental findings have shown that firms who link with less potential partners or have less perceived value earn less in contract bargaining within two-sided supply chain networks, which clearly contradicts with the standard model predictions. Thus, we motivate our behavioral theory by considering the behavioral impact of network structure and perceived value difference. Specifically, we speculate that network position and value perception of each firm may induce *desperateness* in contract bargaining, and thus firms who at the disadvantageous situation in the supply network is willing to *sacrifice* part of the predicted contractual bargaining payoff to reach a contract agreement. Following this idea, we first set up hypotheses, formulate the new behavioral theory (referred to as the *desperateness theory*) and then test its predictive power.

Hypothesis 1: Value Desperateness

Within supply chain networks, firms who has less perceived value is desperate of making contract agreement, and thus is willing to sacrifice some bargaining payoff to reach the contract agreement in each bargaining round.

Hypothesis 2: Network Desperateness

Within supply chain networks, firms who link with less potential partners is desperate of making contract agreement, and thus is willing to sacrifice some bargaining payoff to reach the contract agreement in each bargaining round.

Hypothesis 3: Total Supply Chain Network Profit

Total supply chain profit is lower when the total desperateness level is higher within networks.

Desperateness Theory Formulation and Prediction

After capturing both network desperateness and value desperateness, we update firms' contract bargaining strategy within each supply chain network by following the simple rules:

Value Desperateness Rule: Within supply chain networks, due to farther away from retail market, suppliers are willing to sacrifice the amount of x bargaining payoff to reach the contract agreement in each bargaining round.

Network Desperateness Rule: Within supply chain networks, firms who link with less potential partners is willing to sacrifice the amount of y bargaining payoff to reach the contract agreement in each bargaining round.

Following the game setting in §3, we derive contracting bargaining strategy and payoffs based on our *Desperateness theory* and predict a unique behavioral equilibrium within each supply chain network. Theorem 2 shows the equilibrium results and all the proofs are presented in Appendix B. In general, firms should still reach the contract agreement in the first negotiation round by setting wholesale price at production cost (i.e., $w = c$) but allocate trade surplus through fixed fee F differently from the standard model prediction after incorporating the impact of network structure and perceived value differences. All the notations are summarized in Appendix A.

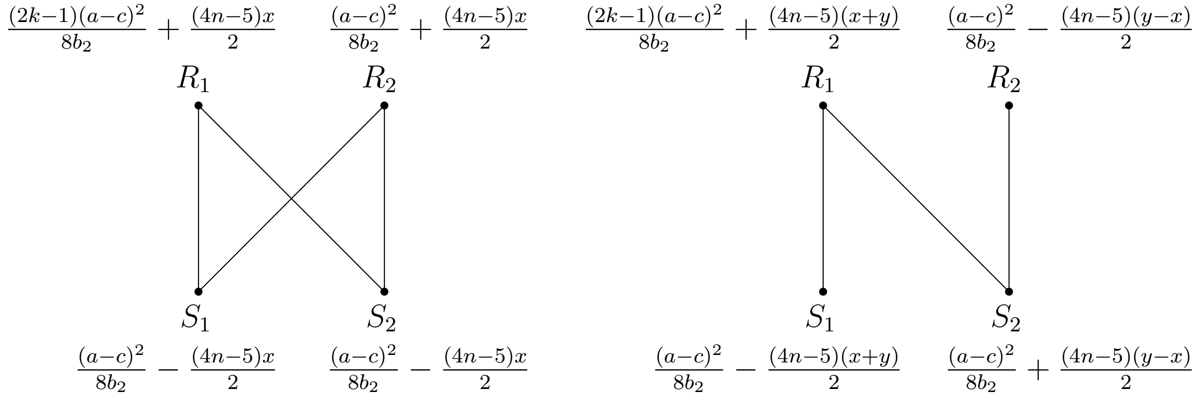
THEOREM 2:

(i) In X networks, the unique behavioral equilibrium predicts that both retailers propose a contract of $w^* = c$ *and* $F^* = \frac{(a-c)^2}{8b_2} - \frac{(4n-5)x}{2}$*, and both suppliers should accept the offer. With contract agreement, both retailers should order* $q_i^* = \frac{a-c}{2b_i}$ *from the supply partner before selling to the retail market.*

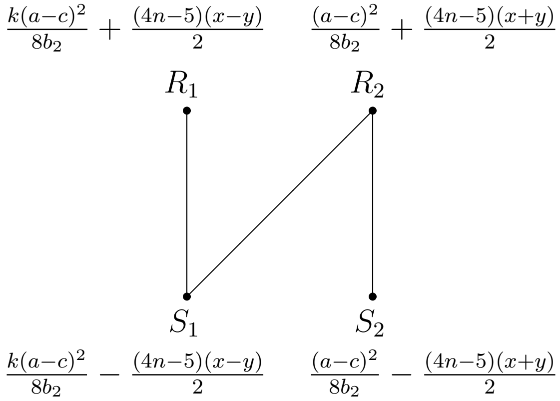
(ii) In N network, the unique behavioral equilibrium predicts that R_1 *should propose a contract of* $w^* = c$ *and* $F^* = \frac{k(a-c)^2}{8b_2} - \frac{(4n-5)(x+y)}{2}$*,* R_2 *should propose a contract of* $w^* = c$ *and* $F^* = \frac{(a-c)^2}{8b_2} + \frac{(4n-5)(y-x)}{2}$*, and* S_1 *and* S_2 *should accept the offer respectively. With contract agreement, both retailers should order* $q_i^* = \frac{a-c}{2b_i}$ *from the supply partner before selling to the retail market.*

(ii) In Z network, the unique behavioral equilibrium predicts that R_1 *should propose a contract of* $w^* = c$ *and* $F^* = \frac{k(a-c)^2}{8b_2} - \frac{(4n-5)(x-y)}{2}$*,* R_2 *should propose a contract of* $w^* = c$ *and* $F^* = \frac{(a-c)^2}{8b_2} - \frac{(4n-5)(x+y)}{2}$*, and* S_1 *and* S_2 *should accept the offer respectively. With contract agreement, both retailers should order* $q_i^* = \frac{a-c}{2b_i}$ *from the supply partner before selling to the retail market.*

Figure 15: General desperateness theory prediction of bargaining payoff under two-retailers-two-suppliers networks.



X network N network



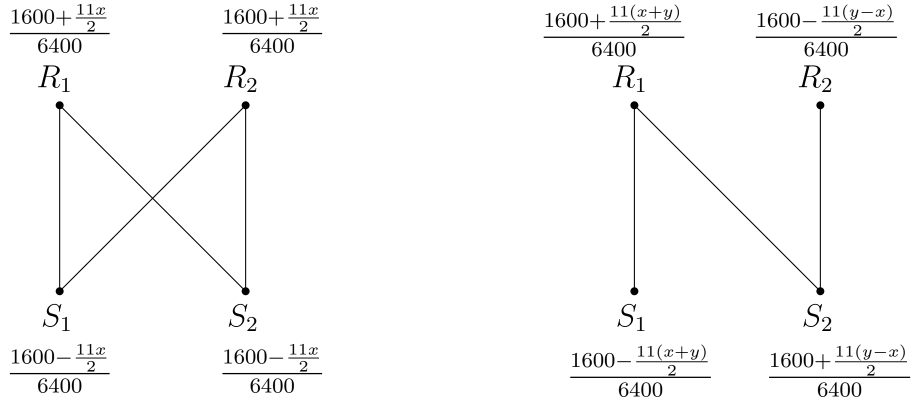
Z network

Figure 15 presents behavioral equilibrium bargaining payoff under all three supply chain networks following our *desperateness theory*. Augmented from the standard model, our *desperateness* model incorporates both value desperateness (i.e., x) and network desperateness (i.e., y) in contract bargaining. Specifically, in X network where all firms are well-connected, only value desperateness impacts the bargaining payoff and thus both retailers can benefit from it in contract bargaining with potential supply partners. However, in either N or Z networks, due to asymmetric network structure, not only value desperateness but also network desperateness has significant impacts on bargaining procedure and thus leads to different behavioral equilibrium bargaining payoff under all three supply chain networks.

Desperateness Theory Accurately Predicts Human Behaviors

We first estimate both value desperateness and network desperateness parameters in our *desperateness theory* given all other experimental parameter values. Figure 16 shows the *desperateness theory* prediction for two treatments without price response heterogeneity between retailers. First of all, in X network, our prediction indicates that both retailers earn more bargaining payoff compared to supplier partners due to their value desperateness, which is consistent with corresponding experimental results shown in Figure 14. By approximating that each retailer (or supplier) in X network earns 27.5% (or 22.5%) of total supply chain profit, we estimate the value desperateness parameter value (i.e., $x \approx 29.09$) given the experimental setting. Then, by comparing our *desperateness theory* prediction between X and N networks in Figure 16, we show that firms (either S_1 or R_2) who link with more potential partners earn more in contract bargaining due to their network desperateness, which is also consistent with our experiment results shown in Figure 14. With the estimation of x amount, we can simply derive the network desperateness parameter value (i.e., $y \approx 52.36$) given the experimental setting.

Figure 16: Desperateness theory prediction of bargaining payoff percentage under treatments without price response heterogeneity.

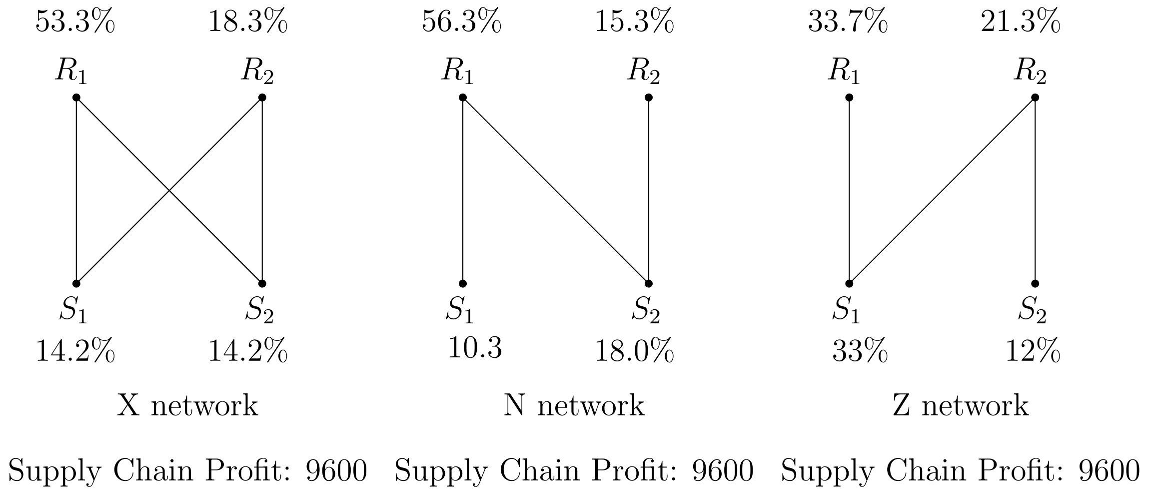


X network N network

Note: in treatments without price response heterogeneity, $a = 100$, $b_1 = b_2 = 0.5$, $c = 20$, $d = 80$, $n = 4$. Thus, $k = 1$, $w^* = 20$, $q_1^* = q_2^* = 80$, $V_1^* = V_2^* = 3200$, $\Pi_T^* = 6400$.

We then examine whether our *desperateness theory* can accurately predict behavioral phenomena in treatments with price response heterogeneity between retailers. With the estimation for both value desperateness and network desperateness parameter values above, Figure 17 presents our *desperateness theory* prediction under all these three treatments given our experimental setting. With a direct comparison with the corresponding experimental results shown in Figure 13, we find that our *desperateness theory* accurately predicts the direction and magnitude of our main observational results in experiment for all treatments. Also, our *desperateness theory* predicts that the total desperateness level in N and Z network is the same while is substantially higher than that in X network, which indicates that total supply chain network profit is highest in the supply chain network with lowest total desperateness level (i.e., X network) while is not significantly different between N and Z networks with same desperateness level. Rejecting the prediction from the standard model in §3 under all supply chain networks in favor of Hypotheses 1-3 provides the implications of *desperateness theory* in contract bargaining within supply chain networks.

Figure 17: Desperateness theory prediction of bargaining payoff percentage under treatments with price response heterogeneity given the desperateness parameters estimation.



Note: in treatments with price response heterogeneity, $a = 100$, $b_1 = 0.25$, $b_2 = 0.5$, $c = 20$, $d = 80$, $n = 4$. Thus, $k = 2$, $w^* = 20$, $q_1^* = 160$, $q_2^* = 80$, $V_1^* = 6400$, $V_2^* = 3200$, $\Pi_T^* = 9600$. Here, the estimation of desperateness parameters is $x = 29.09$ and $y = 53.36$.

Managerial Insights and Concluding Remarks

We theoretically and behaviorally explore the role of bilateral relationship in a multi-retailers-multi-suppliers supply chain system in which retailers negotiate supply contracts with their suppliers. We first build upon a contract bargaining model through transforming a traditional linear supply chain into a complex network of interactions and provide a general theoretic prediction. Since in behavioral literature, previous studies have shown sufficient evidence of behavioral regularities that are important but not captured by the game-theoretical predictions (e.g., Ho and Zhang 2008, Katok and Wu 2009, Kremer et al. 2010), we further investigate the behavioral phenomena in our setting via lab experiment. Our experimental data suggests systematic deviations from the theoretic benchmark and reveal behavioral regularities on contracting behaviors. In particular, we show that firms who link with more (or less) potential partners and/or who have more (or less) perceived values tend to earn more (or less) than expectation in games.

We then develop a new behavioral theory, referred to as *desperateness theory*, which explains and predicts contract bargaining behaviors in two-sided supply chain networks. In general, our *desperateness theory* predicts that firms who link with less potential supply chain partners or who have less perceived values are more desperate of making contract agreements, and thus need to “sacrifice” part of the contract bargaining payoffs when bargaining with the corresponding ”advantageous” firm(s) in each possible round. In addition, we also find evidence that the higher the total desperateness within the supply chain network, the lower the total supply chain network profit.

Our paper provides important managerial implications. First, supply chain network lens extends the scope of inquiry by accounting for both direct and indirect relationships among firms in contract bargaining. Specifically, when firms are choosing their supply chain partners, they should consider not only their own bilateral relationship with potential partners but also their competitors’ or their potential partners’ bilateral relations in the supply chain system for negotiating the best terms of trade. Second, behavioral leverage can arise in contract bargaining based on firm’s structural position and perceived value in supply chain network. Following our *desperateness theory*, firms can exploit their role or position advantages in supply chain networks to reach a better term of trade in contract bargaining, which indicates that firms should consider developing more connections with potential partners for the competitive advantage in the operational perspective. Third, the industries/governments need to be cautious when they set restrictions for negotiating and trading in the supply chain networks. It may increase total desperateness level in the supply chain network and thus lead to a substantial loss on total supply chain profit, which has been widely seen as global supply chain disruption phenomena especially during COVID-19 pandemic.

To the best of our knowledge, we are the first to integrate supply chain contracting with network negotiation and provide both theoretical and behavioral analyses to shed lights on contract bargaining behaviors in complex networks of interaction. This potentially opens up a new research area with many natural extensions. First, we investigate supply chain networks with balanced supply and demand. Future research can further explore other supply chain network structures in a similar context. Second, in this paper, supply chain contract takes the form of two-part tariff, future research can further explore other supply chain contracts and their impacts on contract bargaining outcomes from both theoretical and behavioral perspectives in a similar context. Finally, we have introduced a new behavioral theory to explain and predict contract bargaining behaviors in complex supply chain networks. Since this paper focuses on contract bargaining, we do not probe deeper into how it can impact firms' other decisions such as inventory decision. This also leaves opportunity for future research.

References

Adida E, DeMiguel V (2011) Supply chain competition with multiple manufacturers and retailers. *Operations Research* 59(1):156–172.

Aydin G, Heese HS (2015) Bargaining for an assortment. *Management Science* 61(3):542–559.

Bernstein F, Federgruen A (2005) Decentralized supply chains with competing retailers under demand uncertainty. *Management Science* 51(1):18–29.

Bimpikis K, Ehsani S, Ilkılıç R (2019) Cournot competition in networked markets. *Management Science* 65(6):2467–2481.

Bimpikis K, Fearing D, Tahbaz-Salehi A (2018) Multisourcing and miscoordination in supply chain networks. *Operations Research* 66(4):1023–1039.

Brown TC (2005) Loss aversion without the endowment effect, and other explanations for the wta–wtp disparity. *Journal of Economic Behavior & Organization* 57(3):367–379.

Cachon GP (2003) Supply chain coordination with contracts. *Handbooks in operations research and management science* 11:227–339.

Charness G, Corominas-Bosch M, Frechette GR (2007) Bargaining and network structure: An experiment. *Journal of Economic Theory* 136(1):28–65.

Corominas-Bosch M (2004) Bargaining in a network of buyers and sellers. *Journal of Economic Theory* 115(1):35–77.

Davis AM, Hyndman K (2019) Multidimensional bargaining and inventory risk in supply chains: An experimental study. *Management Science* 65(3):1286–1304.

Falkendal T, Otto C, Schewe J, Jägermeyr J, Konar M, Kummu M, Watkins B, Puma MJ

(2021) Grain export restrictions during covid-19 risk food insecurity in many low-and middle-income countries. *Nature Food* 2(1):11–14.

Feng Q, Lai G, Lu LX (2015) Dynamic bargaining in a supply chain with asymmetric demand information. *Management Science* 61(2):301–315.

Güth W, Schmittberger R, Schwarze B (1982) An experimental analysis of ultimatum bargaining. *Journal of economic behavior & organization* 3(4):367–388.

Ha AY, Tong S (2008) Contracting and information sharing under supply chain competition. *Management science* 54(4):701–715.

Haruvy E, Katok E, Pavlov V (2020) Bargaining process and channel efficiency. *Management Science* .

Ho TH, Zhang J (2008) Designing pricing contracts for boundedly rational customers: Does the framing of the fixed fee matter? *Management Science* 54(4):686–700.

Kalkanci B, Chen KY, Erhun F (2011) Contract complexity and performance under asymmetric demand information: An experimental evaluation. *Management science* 57(4):689–704.

Katok E, Wu DY (2009) Contracting in supply chains: A laboratory investigation. *Management Science* 55(12):1953–1968.

Korpeoglu CG, Körpeoğlu E, Cho SH (2020) Supply chain competition: A market game approach. *Management Science* .

Kremer M, Minner S, Van Wassenhove LN (2010) Do random errors explain newsvendor behavior? *Manufacturing & Service Operations Management* 12(4):673–681.

Leider S, Lovejoy WS (2016) Bargaining in supply chains. *Management Science* 62(10):3039–

3058.

Long X, Nasiry J (2015) Prospect theory explains newsvendor behavior: The role of reference points. *Management Science* 61(12):3009–3012.

Nakkas A, Xu Y (2019) The impact of valuation heterogeneity on equilibrium prices in supply chain networks. *Production and Operations Management* 28(2):241–257.

Neelin J, Sonnenschein H, Spiegel M (1988) A further test of noncooperative bargaining theory: Comment. *The American Economic Review* 78(4):824–836.

Netessine S, Zhang F (2005) Positive vs. negative externalities in inventory management: Implications for supply chain design. *Manufacturing & Service Operations Management* 7(1):58–73.

Ochs J, Roth AE (1989) An experimental study of sequential bargaining. *The American Economic Review* 355–384.

Özer Ö, Zheng Y, Chen KY (2011) Trust in forecast information sharing. *Management Science* 57(6):1111–1137.

Rubinstein A (1982) Perfect equilibrium in a bargaining model. *Econometrica: Journal of the Econometric Society* 97–109.

Shih WC (2020) Global supply chains in a post-pandemic world: Companies need to make their networks more resilient. here's how. *Harvard Business Review* 98(5):82–89.

Weg E, Rapoport A, Felsenthal DS (1990) Two-person bargaining behavior in fixed discounting factors games with infinite horizon. *Games and Economic Behavior* 2(1):76–95.

Weng ZK (1995) Channel coordination and quantity discounts. *Management science* 41(9):1509–1522.

Wu DY, Chen KY (2014) Supply chain contract design: Impact of bounded rationality and individual heterogeneity. *Production and Operations Management* 23(2):253–268.

Wu OQ, Chen H (2010) Optimal control and equilibrium behavior of production-inventory systems. *Management Science* 56(8):1362–1379.

Appendix

Appendix A: Notations

Model Parameters	
c	per-unit production cost
d	per-round negotiation cost
t	contract negotiation round
n	retailer's potential number of proposal round
p	per-unit retail price
a	linear price function intercept
b_i	linear price function coefficient for retailer i
k	price response heterogeneity multiplier
Behavioral parameters	
x_1	value desperateness in each bargaining round for retailer 2
x_2	value desperateness in each bargaining round for supplier 1 and supplier 2
y	network desperateness in each bargaining round
Decision variables	
w	per-unit wholesale price
F	fixed fee
q_i	order quantity of retailer i
Profits	
π_{R_i}	retailer i's profit
π_{S_i}	supplier i's profit
V_i	retailer i partnership profit
Π^T	total supply chain network profit

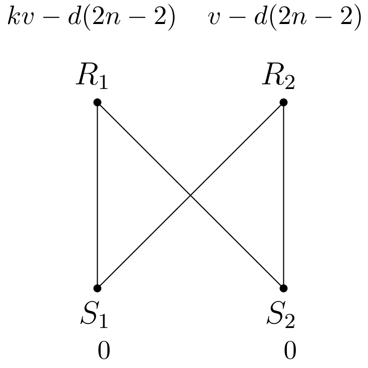
Appendix B: Proofs

Let x_1 and x_2 denote value desperateness level of R_2 (or both S_1 and S_2) relative to R_1 in each bargaining round where $0 \leq x_1 \leq x_2$; and let y (where $y \geq 0$) denote network desperateness level of each firm who only links with one potential partner in the network relative to full-connected firm(s) in each bargaining round. In each of supply chain network game, there are at most $2n-1$ rounds of bargaining, where n represents retailer's potential number of proposal rounds and $n \geq 2$. If the game proceeds to Round $2n-2$, there is a 50% chance that the game ends after that round or the next round $2n-1$, which is a common knowledge for each firm remaining in the network. All firms who can not reach a contract agreement during the game will get 0 reservation amount. As Lemma 3 of my first essay shows, if R_1 (or R_2) reaches the contract agreement with supply partner in the first bargaining round, then $V_1^* = \frac{k(a-c)^2}{4b_2}$ (or $V_2^* = \frac{(a-c)^2}{4b_2}$) and we denote $v = \frac{(a-c)^2}{4b_2}$ throughout the appendix. Now, we employ backward induction to find a behavioral equilibrium in each supply chain network game after incorporating desperateness concepts.

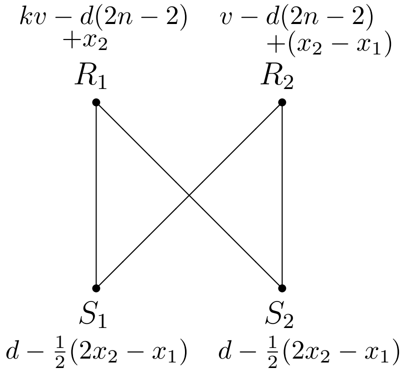
(i) X network

In X network, both R_1 and R_2 can bargain with S_1 and S_2 and vice versa. For R_1 and R_2, they are indifferent of bargaining and trading with S_1 or S_2 who has same desperateness level in each bargaining round. Then for S_1 and S_2, although both of them would prefer bargaining with R_2 due to less disadvantage in terms of desperateness in each bargaining round, one supplier with 50% chance can contract with R_2 while the other supplier would contract with R_1 who offers the same contract proposal. The backward induction starts from Round $2n-1$ as shown below and is based on the assumption that every player's bargaining payoff in each bargaining round is greater than or equal to the reservation amount.

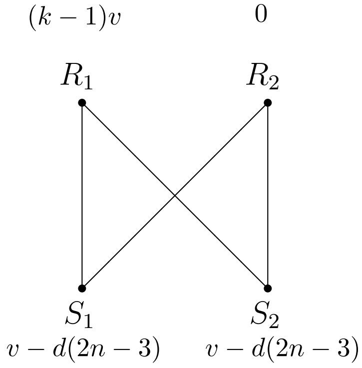
Round $2n-1$



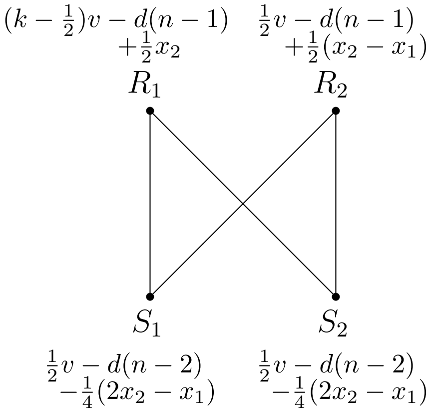
Round $2n-2$ (from $2n-1$)



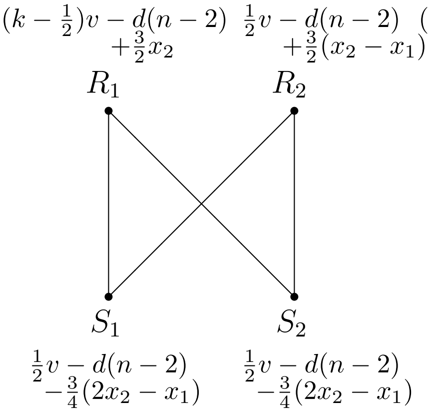
Round $2n-2$ (last round)



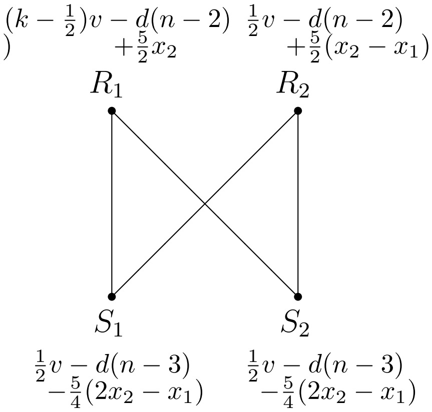
Round $2n-2$ (expected)



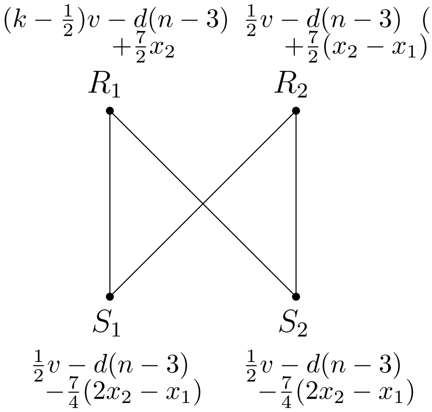
Round $2n-3$



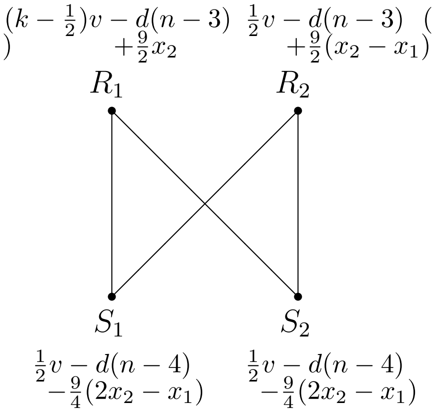
Round $2n-4$



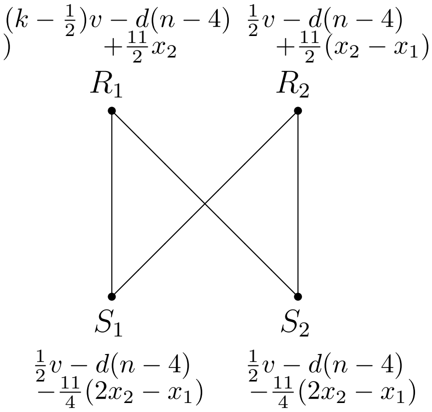
Round $2n-5$



Round $2n-6$

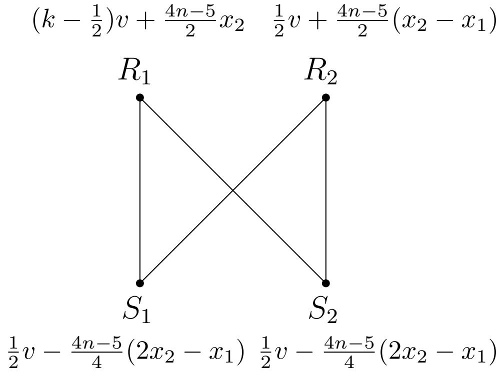


Round $2n-7$



In our experiment design, we allow 7 bargaining rounds at most, which indicates that $n=4$. By substituting $n=4$ into the theoretical prediction of Round $2n-7$, we find the behavioral equilibrium in our experiment setting. Figure 18 presents the generalized behavioral equilibrium bargaining payoff in X network by incorporating desperateness concepts. Notice that if $x_1 = x_2 = y = 0$, the result corresponds to the subgame perfect Nash equilibrium; if $x_1 = 0$, it corresponds to a simplified version of desperateness theory prediction.

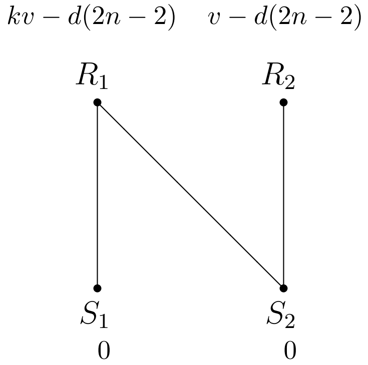
Figure 18: Behavioral Equilibrium Bargaining Payoff in X Network



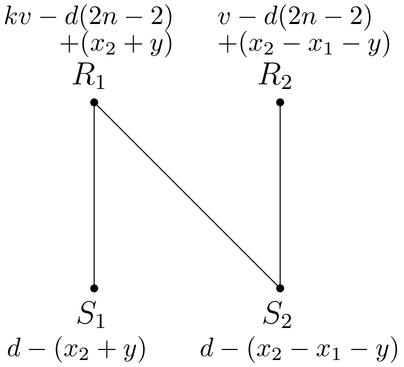
(ii) N network

In N network, S_1 can only bargain with R_1, and R_2 can only bargain with S_2 due to no bilateral relationship with other potential partner in the supply chain network. For R_1, although he links with both suppliers, he would prefer bargaining with S_1 due to her higher desperateness level in each bargaining round. Then for S_2, although she links with both retailers, she would prefer bargaining with R_2 because of his higher desperateness level in each bargaining round. The backward induction starts from Round $2n-1$ as shown below and is based on the assumption that every player's bargaining payoff in each bargaining round is greater than or equal to the reservation amount.

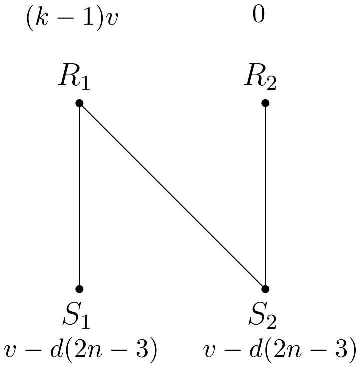
Round $2n-1$



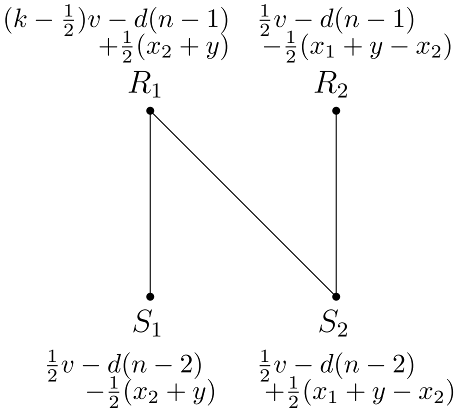
Round $2n-2$ (from $2n-1$)



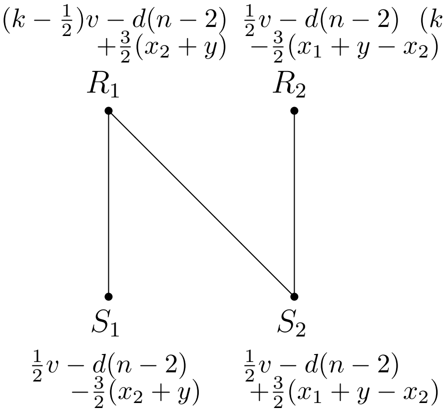
Round $2n-2$ (last round)



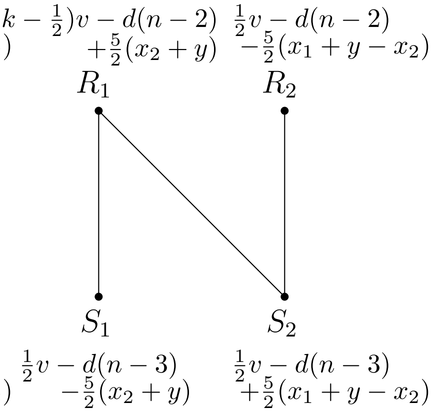
Round $2n-2$ (expected)



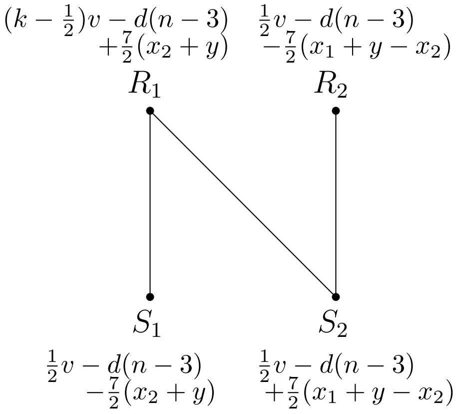
Round $2n-3$



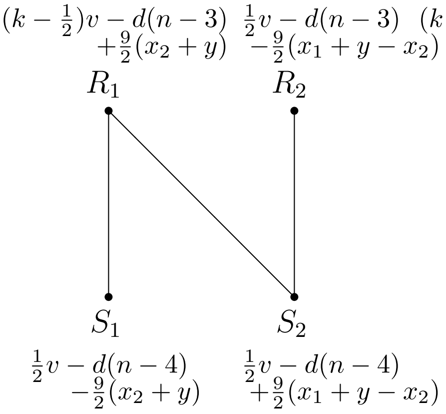
Round $2n-4$



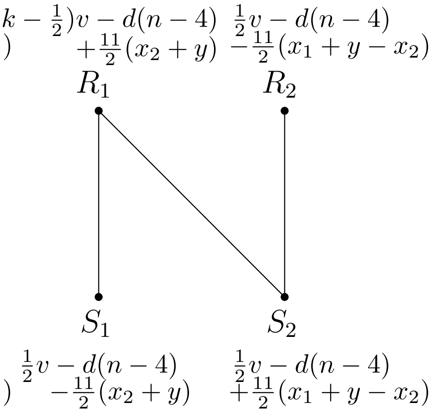
Round $2n-5$



Round $2n-6$

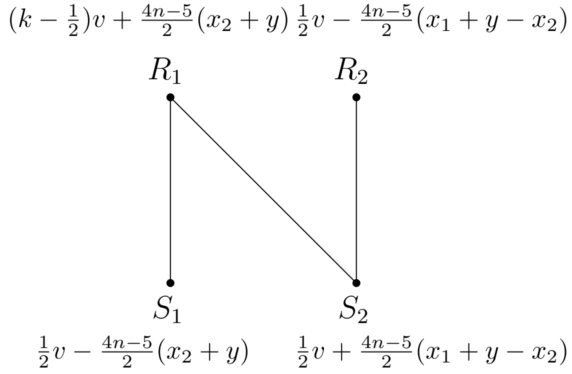


Round $2n-7$



In our experiment design, we allow 7 bargaining rounds at most, which indicates that $n = 4$. By substituting $n = 4$ into the theoretical prediction of Round $2n-7$, we find the behavioral equilibrium in our experiment setting. Figure 19 presents the generalized behavioral equilibrium bargaining payoff in N network by incorporating desperateness concepts. Notice that if $x_1 = x_2 = y = 0$, the result corresponds to the subgame perfect Nash equilibrium; if $x_1 = 0$, it corresponds to a simplified version of desperateness theory prediction.

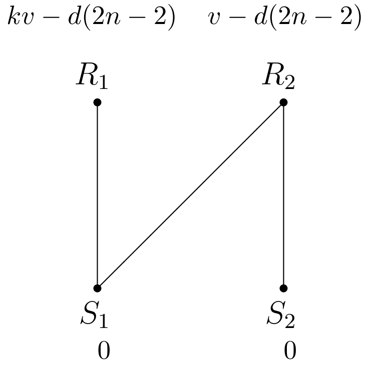
Figure 19: Behavioral Equilibrium Bargaining Payoff in N Network



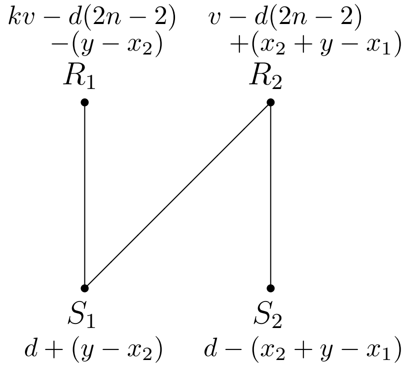
(iii) Z network

In Z network, R_1 can only bargain with S_1, and S_2 can only bargain with R_2 due to no bilateral relationship with other potential partner in the supply chain network. For S_1, although she links with both retailers, she would prefer bargaining with R_1 by assuming $y > \frac{1}{2}x_1$. Then for R_2, although he links with both suppliers, he would prefer bargaining with S_2 because of her higher desperateness level in each bargaining round. The backward induction starts from Round $2n - 1$ as shown below and is based on the assumption that every player's bargaining payoff in each bargaining round is greater than or equal to the reservation amount.

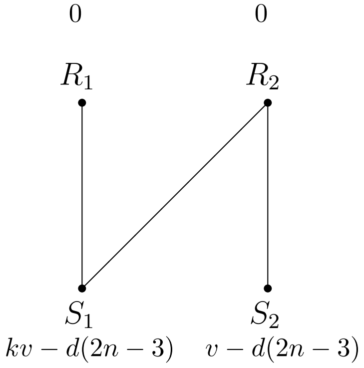
Round $2n-1$



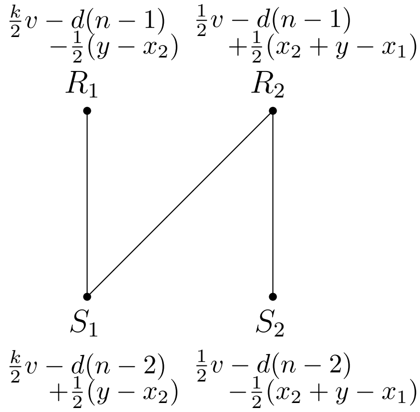
Round $2n-2$ (from $2n-1$)



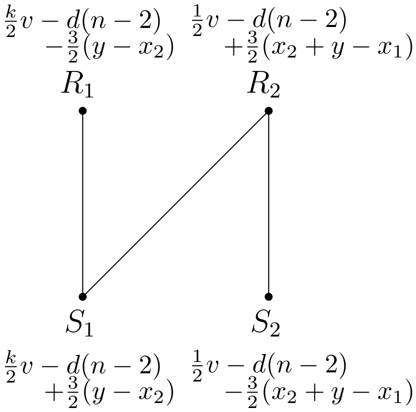
Round $2n-2$ (last round)



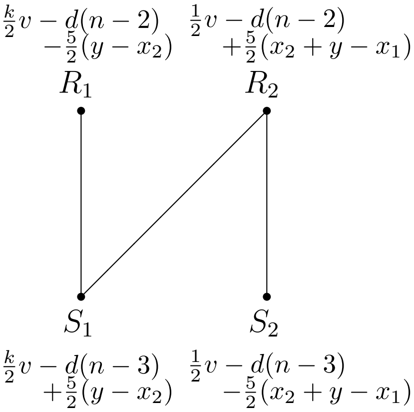
Round $2n-2$ (expected)



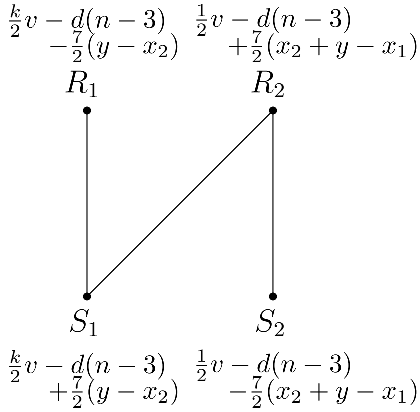
Round $2n-3$



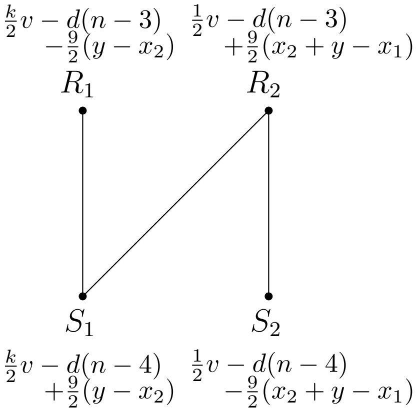
Round $2n-4$



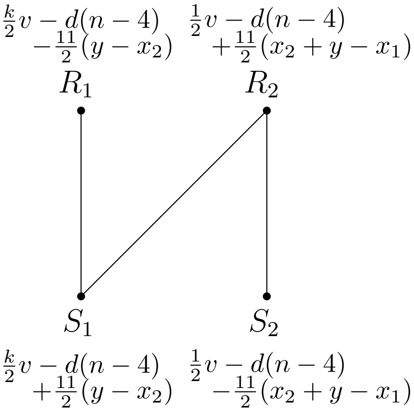
Round $2n-5$



Round $2n-6$

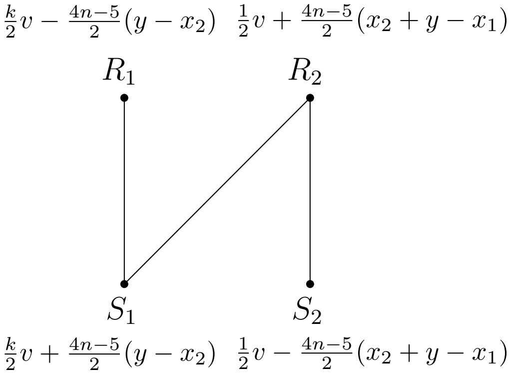


Round $2n-7$



In our experiment design, we allow 7 bargaining rounds at most, which indicates that $n = 4$. By substituting $n = 4$ into the theoretical prediction of Round $2n-7$, we find the behavioral equilibrium in our experiment setting. Figure 20 presents the generalized behavioral equilibrium bargaining payoff in Z network by incorporating desperateness concepts. Notice that if $x_1 = x_2 = y = 0$, the result corresponds to the subgame perfect Nash equilibrium; if $x_1 = 0$, it corresponds to a simplified version of desperateness theory prediction.

Figure 20: Behavioral Equilibrium Bargaining Payoff in Z Network



Essay 3: Buyer-Side Supply Chain Contract Auction

Introduction

Auction is a common used mechanism for firms to allocate contracts to downstream supply chain and channel partners. That is, downstream business partners will bid for the right to contract with a supplier to sell (and often also provide value-adds) its products. It is typically used by big suppliers to pick one downstream channel partner when using multiple downstream channel partners is inefficient or undesirable for other business reasons. For instance, Wilmar International, an S&P500 company, sells biodiesel by auctioning off supply contracts to buyers such as P&G and Shanghai Jahua Corporation. In each short cycle, Wilmar only picks one buyer due to the capacity limit of biodiesel and the complicated contract compliance process. Another typical example can be found in the distribution industry. Marc Jacobs auctions off exclusive distribution agreements to one fashion group distributor in each local market. The licensing industry also provides good examples. Disney auctions off rights to produce and sell products (e.g. video games or toys) of their IP, often, to a single or small number of firms to maintain local monopolies. In this case, Disney provides IP rights, as opposed to physical supplies but the basic characteristics of the setting are the same.

Surprisingly, this type of mechanisms, referred to as the right-to-sell contract auction in the rest of the paper, is understudied in the literature despite its popularity. That is not to say auction is not studied in the supply chain literature. Notably, previous studies (e.g., Chen 2007, Duenyas et al. 2013) have extensively investigated the reverse auction for a retailer to select suppliers. The right-to-sell contract auction is substantially different from the reverse auction, aside from the reversal of the roles of the auctioneer and the bidder, and from the straight-forward private value auctions. First of all, the value of the contract is uncertain, and more importantly, impacted by both supplier and retailers' actions. Furthermore, unique and prominent to this setting, how the contract is auctioned off can substantially impact both supplier and retailers' decisions from both theoretical and behavioral perspectives. In this paper, we focus on the contract and auction mechanisms that are popular in practice. The contract takes the form of two-part tariff as it is commonly used in both theory and practice (Weng 1995, Cachon 2003). Meanwhile, first-price sealed bid auction has wide applications as well among industries such as by agricultural companies to sell agricultural and sideline products or by design companies to sell exclusive distribution agreements.

To allocate a two-part tariff by a first-price sealed bid auction, we have three possible configurations and call them the "Bid-on-F", "Bid-on-W" and "Bid-on-Both" configurations respectively. In the Bid-on-F configuration, the supplier first sets a wholesale price, and, subsequently, after observing the wholesale price, the retailers submit bids for the fixed fee through a first-price sealed bid auction. Similarly, in the Bid-on-W configuration, the supplier first sets a fixed fee, and, subsequently, after observing the fixed fee, the retailers submit bids for the wholesale price through a first-price sealed bid auction. Lastly, in the Bid-on-Both configuration, the retailers submit two-attribute bids, which includes a wholesale price and fixed fee pair. The Bid-on-Both auction requires the design of a winner determination policy that involves two attributes (fixed fee and wholesale price). Since there is no real world guidance on this issue, and a full theoretical analysis would dilute focus from the more practical scenario, we decide to leave the Bid-on-Both auction out of the scope of this paper and focus on evaluating and comparing the Bid-on-F and Bid-on-W auction.

To fully explore the implication of this tandem auction-contracting scenario, we model the retailers as newsvendors to capture the double marginalization incentive problem and the uncertainties in managing inventory. Both are important operations considerations that drives contracting, and hence auction behaviors. In addition, retailers have the option to reject the contract and decide not to participate in the auction. The complexity of the full setting, as well as the complexity associated with the behavioral operations perspective, is part of the reasons why we limit the scope of the study to two simpler auctions. The main research question is deceptively simple. Which auction, Bid-on-F or Bid-on-W, is better from the supplier's (or supply chain's) perspective? Besides that, we also investigate the conditions that encourage participation, and how the auction impact subsequent operations decisions, from a behavioral perspective.

In this study, we employ a combination of game theoretic analysis, human subject experiments and behavioral modeling. Analytical analysis provides a baseline of behavior from the rational perspective. Specifically, we find that the incentives to participate in the Bid-on-F and Bid-on-W auctions can be significantly different. In particular, under the right conditions, retailers should participate regardless of type in the Bid-on-F auction but, in general, only some types should participate in the Bid-on-W auction. Further, we find that supplier should always prefer the Bid-on-W auction but it is more profitable to apply Bid-on-F auction from the supply chain perspective.

There is a large literature documenting and explaining how human decision makers deviate from game theoretic predictions in operations settings (please see Donohue et al. (2018) for more details). Hence, we conduct human subject experiments to provide empirical evidence of actual behavior. Unsurprisingly, our experimental data suggest systematic deviations from the theoretical benchmark and reveal behavioral regularities on contract auctioning behaviors. First, suppliers earn a higher expected profit under Bid-on-F auction which is contrary to the theoretical predictions. Second, suppliers tend to set the wholesale price too high under the Bid-on-F auction but set the fixed fee too low under Bid-on-W auction. Third, retailers tend to over-participate and overbid in almost all experiments. Last but not least, we find significant over-ordering for winning retailers. This last result contradicts the famous and consistent "pull-to-center" effect (e.g., Schweitzer and Cachon 2000, Bostian et al. 2008, Katok and Wu 2009).

The most logical explanation of why the "pull-to-center" is no longer in effect is that the auction in the first stage of our setting substantially impacts the subsequent newsvendor behavior, which is also the primary difference between our setting and settings of most newsvendor research. Along this line, the most promising hypothesis is that the result of the auction changes the reference point of the winning retailer and thus he needs to make at least that much from the subsequent newsvendor setting. We develop a behavioral model to validate this explanation. We employ a quantal response framework (McKelvey and Palfrey 1998, Su 2008, Chen et al. 2012) and incorporate the reference point idea following prospect theory (Tversky and Kahneman 1992). We test this model against several alternate explanations and find this model explains the data the best. Overall, this study sheds light on the contract auction mechanism design from supplier's perspective in decentralized supply chain structures.

In the following sections, we first review the relevant literature in §2. Then, we present a standard game-theoretic analysis for both Bid-on-F and Bid-on-W auctions in §3. We describe our experimental design in §4 and provide experimental results and statistical analysis in §5. We develop behavioral models in §6 and summarize our main findings by highlighting the managerial implications in §7.

Literature Review

Our paper sits in the intersection of the literature of first-price sealed bid auction, supply chain contracting, and newsvendor decision problem. The economics literature of first-price sealed-bid auction (hereafter FPSBA) studies the characteristic and impact of FPSBA in competition. Previous theoretical works have examined the optimal bidding prices in FPSBA (Klemperer (1999) provides a thorough survey). Meanwhile, experimental studies show that bidders tend to overbid in FPSBA experiments due to risk aversion (Cox et al. 1988), joy of winning (Crawford and Iriberri 2007) or aversion to regret (Engelbrecht-Wiggans and Katok 2008). One key difference between our paper and studies in literature is that we investigate auctioning off a supply chain contract instead of a private value item through FPSBA. Specific to the operations management field, previous research (e.g., Chen 2007, Duenyas et al. 2013, Huang et al. 2019) theoretically studies the buyer's optimal procurement strategy through auctioning off supply contracts among suppliers. In those papers, each supplier is privately informed of his/her constant marginal production cost without supply uncertainty, and thus the value of the supply contract is privately known by each bidder (i.e., supplier). Different from the previous procurement auction studies, we stand from supplier's perspective and investigate right-to-sell contract auction mechanisms with both theoretical and behavioral analysis. Although each bidder (i.e., retailer) has private information about his/her marginal processing cost, the value of the supply chain contract is still uncertain since each retailer is viewed as a newsvendor who is facing demand uncertainty.

Also related is the broad research on supply chain contracting. Earliest stream of papers in this literature aims to design coordinated supply chain contracts that strategically improves the supply chain efficiency (see Cachon (2003) for a review) although the related behavioral studies have shown some deviations (e.g., Lim and Ho 2007, Katok and Wu 2009). Our paper different from the above studies is that the contract terms are not decided by one party (i.e., supplier), but determined by both the supplier and the winning retailer in a competitive scenario. Specifically, in our right-to-sell contract auction, supplier first determines one contract term, pass to each retailer, and then the other contract term is determined by the highest bid among participating retailers in the auction competition. Previous research also investigate the bargaining procedure in supply chain contracting. For instance, Davis and Hyndman (2018) uses multidimensional bargaining between one retailer and one supplier when setting a wholesale price contract. Haruvy et al. (2020) investigates the effect of bargaining on the performance of either a wholesale price contract or a two-part tariff by allowing the supplier to make concessions when negotiates with a retailer. In our context, we consider a competitive scenario where retailers who have private processing cost, and thus choose to apply contract auction mechanism for supplier.

Another related stream of literature is the newsvendor decision problem in the operations management field. Numerous newsvendor experiments, starting from Schweitzer and Cachon (2000), have shown that quantity decisions made by experimental newsvendors systematically deviate from the optimal order quantity and tend to be biased towards the mean demand, which is called “pull-to-center” effect. Schweitzer and Cachon (2000) provides possible explanations such as anchoring and insufficient adjustment heuristic. Su (2008) finds a random component within newsvendors’ order quantity decisions by using “bounded rationality model". More recently, Wu and Chen (2014) integrates the standard newsvendor setting with several types of supply chain contracts. However, in our setting, not every retailer can reach the newsvendor decision stage. They have to first compete through auction mechanism for supply chain contract, and only the winning retailer can order quantity from the supplier as a newsvendor. In our paper, we investigate whether and how the fundamental setting difference can substantially affect the newsvendor behaviors.

In summary, we integrate supply chain contracting with auction mechanism to study sales problem for suppliers who face newsvendor-type retailers in competition, which is commonly applied in industries but is still underexplored in the literature. Our contributions to the literature of contract auctions is to investigate the right-to-sell contract auction in which uncertain contract valuation is determined by both supplier and retailers' decisions, and to provide important operational implications of both mechanism designer and bidders' behaviors from both theoretical and behavioral perspectives. To the best of our knowledge, we are the first to investigate the right-to-sell contract auction and provide guidances for upstream firms in a decentralized supply chain system.

Game Theoretic Analysis

We consider a supply chain system with one supplier and multiple retailers who auction off supply chain contract for the right of ordering and selling products from the supplier before observing the market demand. A supply contract takes the form of a wholesale price of W per unit and a fixed transfer fee of F (i.e., two-part tariff) due to its wide application in both theory and practice (Weng 1995, Cachon 2003). In general, we investigate and compare two types of right-to-sell contract auctions referred to as the Bid-on-F auction and the Bid-on-W auction. Figure 21 (or 24) presents game structure of Bid-on-F auction (or Bid-on-W auction) respectively. The contract auction mechanism starts from *Supplier's Decision Stage*. Specifically, in the Bid-on-F auction, the supplier (denoted as "she") first sets a wholesale price W before each of retailers (denoted as "he") considers to bid on the fixed fee F, after observing the wholesale price. While in the Bid-on-W auction, the supplier first sets a fixed fee F before each of retailers considers to bid on the wholesale price W given they know the fixed fee.

Then in *Retailer's Auction Stage*, we use first-price sealed bid auction (FPSBA) due to its wide application in procurement auction (Kokott et al. 2019) and explicitly model whether a retailer decides to participate in the auction in our setting. Notice that not participating is not the same as entering a bid of zero. If more than one retailer participate, following FPSBA, one with the highest bid wins. If more than one retailer participate with the highest bid, one will be randomly picked as the winning retailer. If only one retailer participates, he wins the contract. If no retailer participates, the supplier and all retailers receive zero profit. After each retailer submits their bid or decide not to participate in auction, the winning retailer moves to the next stage, referred as the "newsvendor stage" while all other retailers end the game with 0 profit.

Finally, in the *Newsvendor Stage*, the winning retailer, who is viewed as a newsvendor and face uncertain demand, can decide on purchase amount of the product (i.e., Q) from the supplier before selling them to the retail market. The retail price of each ordered product (P) is exogenously given. For each retailer, if he wins the auction, besides the contract payment to the supplier, he has a private processing cost C_i for each ordered product. While C_i is private information to retailer i, we assume that the distribution of C_i is a common knowledge, which is in-line with the traditional private value auction literature (e.g., Vickrey 1981, Myerson 1981). To keep the model tractable, we further assume that all the C_i are drawn from an independent and identical uniform distribution F, with $C_i \sim U[C_l, C_h]$. In addition, the market demand (D) is assumed to follow a uniform distribution G, where $D \sim U[d_l, d_h]$. and is a common knowledge for all players. Market demand realizes at the end of the newsvendor stage after all the decisions are made. If the realized demand is less than the order quantity, the unsold products have no salvage value for the winning retailer. Thus, in both auctions, with a contract agreement, supplier's profit is $\pi_S = W \cdot Q + F$ while winning retailer's profit is $\pi_{R_i} = P \cdot \min\{Q, D\} - (W + C_i) \cdot Q - F$, where both supplier and retailers are assumed to be expected profit maximizers and rationality is common knowledge.

1. Bid-on-F Auction

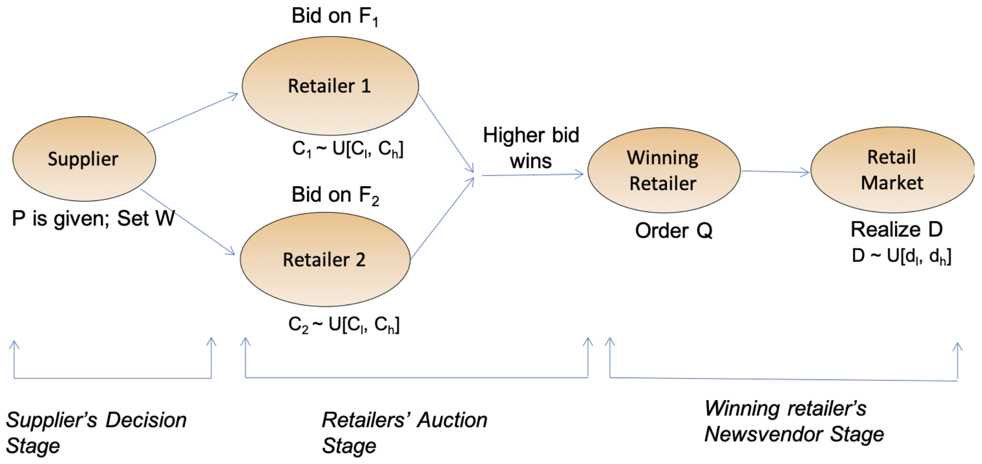


Figure 21: Game Structure of Bid-on-F Auction

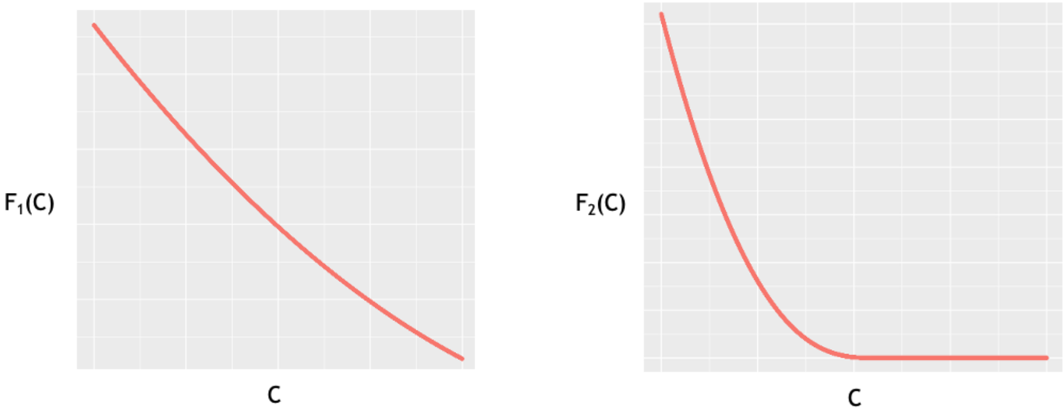
To solve the equilibrium of Bid-on-F auction, we employ backward induction and thus our theoretic analysis starts from the *Newsvendor Stage*. If at least one retailer participates and wins the auction, with the contract agreement, his expected profit ($E(\Pi_{R_i})$) in the

Newsvendor Stage can be expressed as a function of order quantity (Q) given retail price (P), demand distribution ($D \sim U[d_l, d_h]$), contract agreement terms (W and F) and private processing cost (C_i):

$$\begin{aligned} E(\Pi_{R_i}) &= E(P \cdot \min{(Q, D)}) - W \cdot Q - C_i \cdot Q - F \\ &= P \cdot Q - P \cdot \int_{d_l}^{Q} G(y)dy - W \cdot Q - C_i \cdot Q - F \\ &= -\frac{P}{2(d_h - d_l)} \cdot (Q - \frac{d_h P - (d_h - d_l)C_i - (d_h - d_l)W}{P})^2 + \frac{(d_h - d_l)(P - C_i - W)^2}{2P} \\ &\quad + (P - C_i - W) \cdot d_l - F \end{aligned} \tag{1}$$

In (1), we derive the winning retailer i's expected profit as a quadratic function of order quantity Q. More specifically, the parabola for (1) is openning downward since we assume $P > 0$ and $d_h > d_l \geq 0$, and the vertex of the parabola is $\frac{d_h P - (d_h - d_l)C_i - (d_h - d_l)W}{P}$ (we call it VT hereafter). Since Q is assumed to be within the range of $[d_l, d_h]$, we clarify whether VT is within that accessible range before we can summarize the corresponding optimal order quantity Q^* and the optimal expected profit $E^*(\Pi_{R_i})$ for the winning retailer i. First, we can easily verify that $VT < d_h$ always stands given the nonnegative parameters. Then, if $d_l < VT < d_h$ (equivelantly if $P - C_i - W > 0$), given the characteristic of our quadratic function, we can find that $Q^* = \frac{d_h P - (d_h - d_l)C_i - (d_h - d_l)W}{P}$ and $E^*(\Pi_{R_i}) = \frac{(d_h - d_l)(P - C_i - W)^2}{2P} + (P - C_i - W) \cdot d_l - F$. Under this scenario, given $P - C_i - W > 0$, retailer i should participate in auction since his optimal expected profit before paying the bid fee F is always positive if he wins the auction. On the other hand, if $VT \leq d_l < d_h$ (equivelantly $P - C_i - W \leq 0$), we can find that $Q^* = d_l$ and $E^*(\Pi_{R_i}) = (P - C_i - W) \cdot d_l - F$. Under this scenario, given $P - C_i - W \leq 0$, retailer i should not participate in auction since his optimal expected profit before paying the bid fee F is nonpositive if he wins the auction, which is worse than nonparticipation. In general, under Bid-on-F auction, each retailer i should only participate in auction when $P - C_i - W > 0$.

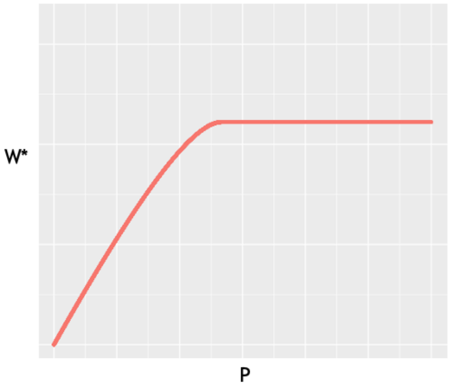
Figure 22: Retailer's Equilibrium Bidding Strategy $F^*(C)$



(a) High profit margin scenario **(b)** Low profit margin scenario

Next, we move to the *Auction Stage*. First of all, at this stage, W has been determined by the supplier given P is exogenously known and C_i is privately known by each retailer i and is generated from a uniform distribution $[C_l, C_h]$. Given the participation condition, we classify three possible scenarios before we solve for the equilibrium bidding strategy $F^*(C)$. In high profit margin scenario, when $P - W > C_h$ (i.e., $P - W - C_i > 0$ for every C_i), each retailer should participate. In low profit margin scenario, when $C_l \leq P - W \leq C_h$, we further seperate into two subcases. If $C_l \leq C_i < P - W$, the retailer i should participate. Otherwise, the retailer i should not participate. In negative profit margin scenario, if $P - W < C_l$ (i.e., $P - W - C_i < 0$ for every C_i), each retailer should not participate. All the theoretical derivations and proofs are presented in Appendix A. Figure 22 qualitatively shows retailer's equilibrium bidding strategy $F^*(C)$ under either high or low profit margin scenario. First of all, in high profit margin scenario, $F_1^*(C)$ drops to 0 until C_i increases to the upper limit C_h, which indicates that every retailer should participate in auction and the bidding amount $F_1^*(C)$ should decrease with C_i because of smaller profit space left for the retailer i. However, in low profit margin scenario, the equilibrium bidding strategy $F_2^*(C)$ drops to 0 once C_i increases to $P-W$. For the retailers whose $C_i \geq P-W$, they should not participate as shown in Part (b) of Figure 22.

Figure 23: Supplier's Equilibrium Contract Term Decision $W^*(P)$



Finally, we come to the supplier's *Decision Stage*. All the theoretical derivation and proofs are presented in Appendix A. Figure 23 presents qualitative pattern of supplier's equilibrium contract term decision $W^*(P)$ as a function of exogenously given retail price P. In general, W^* follows a threshold strategy depending on the magnitude of the retail price P. Specifically, when retail price P is below the thereotical threshold, supplier should set wholesale price higher when retail price P increases for squeezing more profit from the retailers. This corresponds to low profit margin scenario where only some retailers should participate. However, when retail price P is above the theoretical threshold, the wholesale price set by the supplier does not depend on P. It corresponds to the high profit margin scenario where every retailer should participate in auction under this scenario and supplier tend to squeeze retailer's profit from their bids instead of setting a higher W amount.

2. Bid-on-W Auction

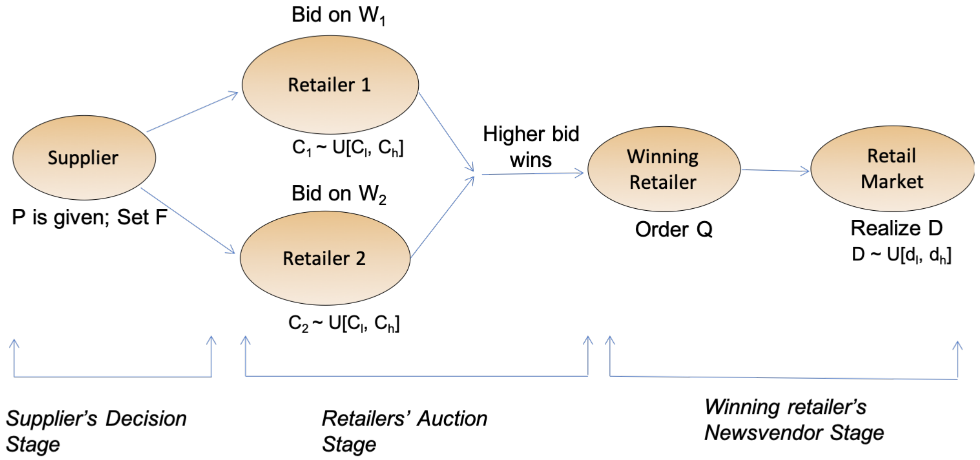
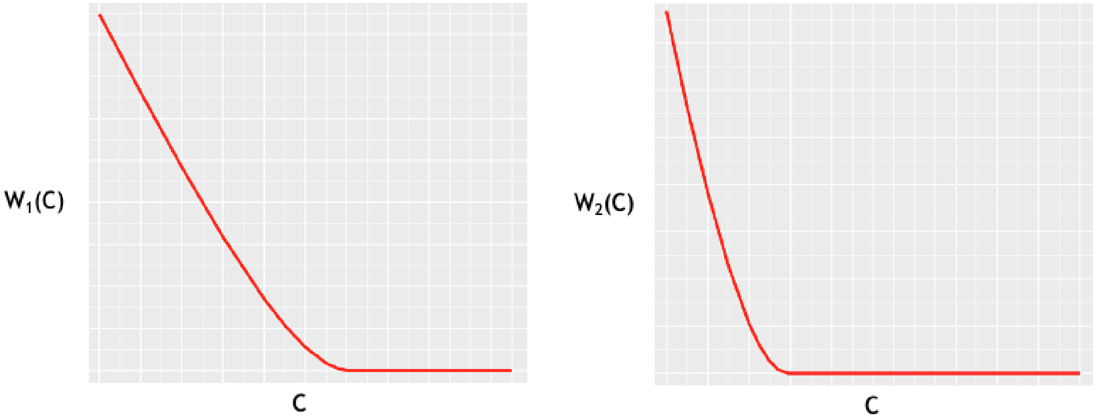


Figure 24: Game Structure of Bid-on-W Auction

In Bid-on-W auction, our theoretic analysis for the *Newsvendor Stage* shown in (1) still applies since both contract terms have been specified in the two-part tariff after the supplier and the winning retailer reach a contract agreement. Then, to determine the participation condition in Bid-on-W auction, we first classify winning retailer's optimal order quantity decision into two cases and calculate the corresponding expected profit: (1) when $d_hP-(d_h-d_l)C_i \leq 0$ (i.e., $C_i \geq \frac{d_h}{d_h-d_l}P$), the optimal $Q^* = d_l$ and $E^*(\Pi_{R_i}) = -\frac{d_l^2P}{2(d_h-d_l)} - F < 0$. In this case, retailer simply should not participate in auction. (2) When $d_hP-(d_h-d_l)C_i > 0$ (i.e., $C_i < \frac{d_h}{d_h-d_l}P$), we further separate into two subcases: (I) if $\frac{(d_h-d_l)(P-C_i-W)^2}{2P} + (P-W-C_i)\cdot d_l - F > 0$ (i.e., $C_i < \frac{d_h}{d_h-d_l}P - \sqrt{(\frac{d_lP}{d_h-d_l})^2 + \frac{2PF}{d_h-d_l}}$ by setting $W=0$), retailer i whose C_i is within this range should participate. The optimal $Q^* = \frac{d_hP-(d_h-d_l)C_i-(d_h-d_l)W}{P}$ and $E^*(\Pi_{R_i}) = \frac{(d_h-d_l)(P-C_i-W)^2}{2P} + (P-W-C_i)\cdot d_l - F$; (II) if $\frac{(d_h-d_l)(P-C_i-W)^2}{2P} + (P-W-C_i)\cdot d_l - F \leq 0$ (i.e., $\frac{d_h}{d_h-d_l}P - \sqrt{(\frac{d_lP}{d_h-d_l})^2 + \frac{2PF}{d_h-d_l}} \leq C_i < \frac{d_h}{d_h-d_l}P$ by setting $W=0$), retailer i whose C_i is within this range should not participate. In general, under Bid-on-W auction, each retailer i should only participate in auction when $C_i < C_T = \frac{d_h}{d_h - d_l} P - \sqrt{(\frac{d_l P}{d_h - d_l})^2 + \frac{2PF}{d_h - d_l}}$.

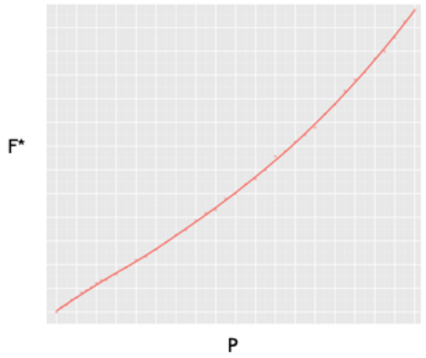
Figure 25: Retailer's Equilibrium Bidding Strategy $W^*(C)$



(a) High profit margin scenario **(b)** Low profit margin scenario

Next, we move to the *Auction Stage*. Different from the Bid-on-F auction, participating retailers auction off the wholesale price W within the two-part tariff given fixed fee F has been determined by the supplier. First of all, given the participation condition (i.e., C_T), we classify three possible scenarios before solving for the equilibrium bidding strategy $W^*(C)$. In high profit margin scenario, when $C_T \geq C_h$, each retailer should participate. In low profit margin scenario, when $C_l < C_T < C_h$, we separate into two subcases. If $C_l \leq C_i \leq C_T < C_h$, the retailer i should participate. Otherwise, the retailer i should not participate. In negative profit margin scenario, when $C_T < C_l$, each retailer should not participate. Due to no closed form equilibrium solution, we provide numerical analysis for Bid-on-W auction shown in Appendix B. Figure 25 qualitatively shows retailer's equilibrium bidding strategy $W^*(C)$ under either high or low profit margin scenario. First of all, in both high and low profit margin scenarios, $W^*(C)$ drops to 0 once C_i increases to C_T which is less than C_h. It indicates that supplier in Bid-on-W auction tends to squeeze retailer's profit by setting a higher F amount and thus leads to a low participation rate in both scenarios. Specifically, as Figure 25 shows, retailer whose $C_i > C_T$ should not participate the auction in both high and low profit margin scenario.

Figure 26: Supplier's Equilibrium Contract Term Decision $F^*(P)$



Finally, we come to the supplier's *Decision Stage*. Figure 26 presents qualitative pattern of supplier's equilibrium contract term decision $F^*(P)$ as a function of exogenously given retail price P. Different from Bid-on-F auction, the supplier's equilibrium contract term decision $F^*(P)$ in Bid-on-W auction does not follow a threshold strategy. In general, as Figure 26 shows, supplier should always set fixed fee higher when retailer pirce P increases for squeezing more profit from the retailers. With numerical analysis given different retail price levels, we find that supplier should always set F relatively high and leads to the scenario that only some retailers should participate in the auction shown in Figure 25.

Experimental Design and Predictions

(1) Experimental Design and Procedures

In this section, we conducted human-subject experiments to examine the behavioral regularities in contract auctions. Specifically, we investigate how the contract auction mechanisms together with retail price of the purchased products can behaviorally impact firms' contracting behaviors and profit performance. In §3, our theoretic analysis predicts that both contract auction mechanisms and retail price level can drastically change on firms' supply chain contracting behaviors in competition. In Bid-on-F auction, the equilibrium strategy is a threshold strategy. Specifically, when retail price P is below the threshold, the wholesale price W set by the supplier increases with retail price P which prevents the retailers with higher C_i from participating the auction. However, when retail price P is above the threshold, the wholesale price W no longer increases with retail price P which in turn encourages all retailers to participate in the auction. In contrast, in Bid-on-W auction, the fixed fee F set by the supplier increases with retail price rapidly which always prevents the retailers with higher C_i from participating the auction in both low and high profit margin scenarios.

Following existing literature (Schweitzer and Cachon 2000, Katok and Wu 2009, Wu and Chen 2014), we use the following experimental parameters. We assume that each retailer's per-unit processing cost (C_i) follows a discrete uniform distribution where $C_i \sim U[0, 100]$, and the market demand (D) follows another discrete uniform distribution where $D \sim U[0, 50]$. The upper limit of two discrete uniform distributions is intentionally set different for a better clarification. Given the experimental parameters, we first derive the threshold of equilibrium strategy (i.e., $P = \frac{400}{3}$) in Bid-on-F auction and choose $P = 80$ and $P = 180$ at each side of the threshold to represent the low and high profit margin scenario respectively under both auctions. Table 11 summarizes our experiment design and reports both the number of participating subjects (N) and the round of experimental games (R) played in each treatment. Each participant can only join in one treatment and was randomly assigned either as a supplier or a retailer in the first experimental game. The role was fixed in the remaining games and a supplier and two retailers were randomly matched in each game.

Table 11: Experiment Design and Sample Size

	P = 180	P = 80
Bid-on-F auction	N = 21 R = 25	N = 21 R = 36
Bid-on-W auction	N = 15 R = 36	N = 21 R = 32

In each game, supplier first determines either the per-unit wholesale price (W) or the fixed transfer fee (F) in Bid-on-F auction or Bid-on-W auction respectively given retail price of purchased products and distribution information of each retailer's processing cost and market demand. After that, each retailer will be invited to participate the auction given all the information above. With privately informed per-unit processing cost (C_i), each retailer privately decides whether to participate the auction and how much to bid if he decides to participate. If both participate, the retailer who offers a higher bid wins the auction; if one participates, the retailer who participates wins the auction; if no one participates, each player will get 0 profit. Then, only the winning retailer has the decision right to order products from the supplier while the other retailer end the game with 0 profit. Market demand realizes after all the decisions are made.

All experiment implementations are summarized as follows. After arriving at the behavioral lab, all the participants were required to read the experimental instructions prepared by the experimenter. Then, experimenter read aloud instructions to ensure common knowledge and show the participants how to appropriately use the software (Z-Tree). Before games start, participants can ask the experimenter any relevant questions. While during the game, participants are not allowed to communicate with others. The experiment ended either when each participant played 40 experimental games or the treatment conducted for 90 minutes. All participants were undergraduate or graduate students from a university located at the Southwest of United States. Previous research in behavioral literature have documented that students and managers tend to perform in a similar manner in various supply chain contexts (e.g., Croson and Donohue 2006, Bolton et al. 2012). For each participant, besides the \$5 show-up fee, he/she was paid a bonus proportional to what he/she earned in the experiment. The average earnings per participant was \$15.

(2) Experimental Predictions and Hypotheses

Table 12: Theoretical Prediction of Profit Performance Given Experimental Parameters

Expected Profit	Bid-on-F auction		Bid-on-W auction	
Retail Price	P = 180	P = 80	P = 180	P = 80
Supplier	2015	434	2042	470
Retailer	448	130	376	109
Supply Chain	2910	694	2794	688

Note that: $C_i \sim U[0, 100]$ and $D \sim U[0, 50]$.

Table 12 summarizes the theoretical predictions on profit performance in each contract auction treatment given experimental parameters. By comparing the profit performance between two contract auctions in each profit margin scenario, we predict that supplier's expected profit is higher under Bid-on-W auction in both low and high profit margin scenarios and summarize as *Hypothesis 1*, which indicates that supplier should prefer Bid-on-W auction to Bid-on-F auction theoretically.

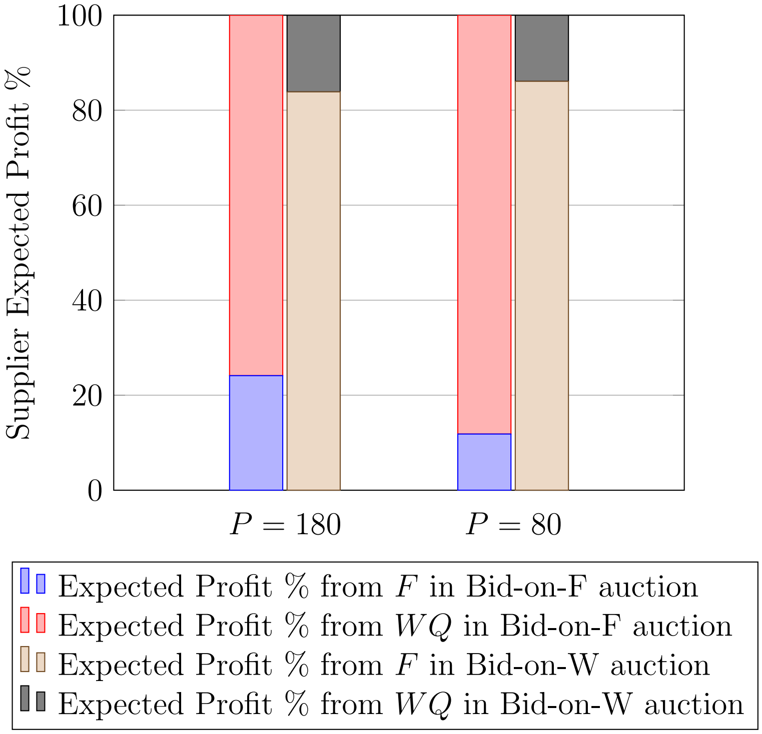
Hypothesis 1: Profit Performance

Supplier achieves higher expected profit under the Bid-on-W auction compared to the

Bid-on-F auction in both low and high profit margin scenarios.

To uncover the profit performance in each contract auction, we analyze the impact of firms' contracting decisions in prediction on supplier's expected profit. Figure 27 shows the composition of suppliers' expected profit in prediction for each treatment. Orange bar (or blue bar) represents the expected profit from WQ (or from F) respectively. Specifically, in both profit margin scenarios, supplier's expected profit in Bid-on-F auction is mostly from WQ while her expected profit in Bid-on-W auction is mostly from F, which indicates that supplier should always exploit the contract term that under her control to extract more profit in each contract auction.

Figure 27: Composition of Supplier Expected Profit in Prediction



Further, in Bid-on-F auction, a higher wholesale price W set by the supplier leads to a lower bid on fixed fee F by retailers and also decreases winning retailer's optimal order

Table 13: Theoretical Prediction of Supplier's Contract Term Decision Given Experimental Parameters

Supplier Decision	Bid-on-F auction		Bid-on-W auction	
Retail Price	P = 180	P = 80	P = 180	P = 80
Wholesale Price W	33.33	24.28	-	-
Fixed Fee F	-	-	2067	828

Note that: $C_i \sim U[0, 100]$ and $D \sim U[0, 50]$.

quantity shown in (1). While, in Bid-on-W auction, a higher fixed fee F set by the supplier leads to a lower bid on wholesale price W by retailers, but reversely increases winning retailer's optimal order quantity, which can help improve supplier's expected profit and is more preferable to that in Bid-on-F auction when at least one retailer participates. In *Hypothesis 2*, we compare supplier's contract term decision between contract auctions and summarize the theoretical predictions in Table 13.

Hypothesis 2: Supplier's Contract Term Decision

In both Bid-on-F and Bid-on-W auctions, supplier should set contract term higher in high profit margin scenario than in low profit margin scenario.

Table 14: Theoretical Prediction of Retailer's Participation Decision Given Experimental Parameters

Retailer Decision	Bid-on-F auction		Bid-on-W auction	
Retail Price	P = 180	P = 80	P = 180	P = 80
Expected Participation %	100%	55.72%	58%	28.5%

Note that: $C_i \sim U[0, 100]$ and $D \sim U[0, 50]$.

Besides supplier's contract term decision, retailers' participation decision can also have a significant impact on suppliers' expected profit in each contract auction. Table 14 presents the theoretical prediction of retailers' expected participation rate in both contract auctions under each profit margin scenario. We find that expected participation rate in Bid-on-F auction should be higher than that in Bid-on-W auction under both low and high profit margin scenarios, and summarize it as *Hypothesis 3*.

Hypothesis 3: Retailer's Participation Decision

Retailer's participation rate is higher under the Bid-on-F auction compared to the Bid-on-W auction in both low and high profit margin scenarios.

The underlying reason is intuitive. In Bid-on-W auction, supplier should set a high fixed fee F which leads to the case that only some retailers would participate the auction in both low and high profit margin scenarios, and that the expected participation rate is lower than that of Bid-on-F auction. As to its impact on supplier's expected profit, as long as at least one retailer participates the auction, supplier can ensure the payment from winning retailer according to the contract agreement instead of getting 0 profit in each contract auction. Thus, the probability that neither of retailers would participate the auction is not that high in Bid-on-W auction although its frequency is still relatively higher than that in Bid-on-F auction, which does not hinder the supplier from generating a higher expected profit in Bid-on-W auction theoretically.

Table 15: Theoretical Prediction of Winning Retailer's Quantity Decision Given Experimental Parameters

Winning Retailer Decision	Bid-on-F auction		Bid-on-W auction	
Retail Price	P = 180	P = 80	P = 180	P = 80
Expected Order Quantity	26.85	17.64	39.88	39.38

Note that: $C_i \sim U[0, 100]$ and $D \sim U[0, 50]$.

When a retailer wins from the auction, he has the decision right to purchase products from the supplier as a newsvendor. In (1), we show that winning retailer's optimal order quantity is $Q^* = \frac{d_h P-(d_h-d_l)C-(d_h-d_l)W}{P}$ in both Bid-on-F and Bid-on-W auctions, which indicates that the wholesale price W should impact the optimal order quantity Q^* in a same manner while the fixed fee F has no impact in both contract auctions. Table 15 presents the theoretical prediction of retailers' expected order quantity in both contract auctions under each profit margin scenario. We find that winning retailer's expected order quantity in Bid-on-F auction should be lower than that in Bid-on-W auction under both low and high profit margin scenarios since the wholesale price set by supplier in Bid-on-F auction is higher than that auctioned off by retailers in Bid-on-W auction. We summarize it as *Hypothesis 4*.

Hypothesis 4: Winning Retailer's Order Quantity Decision

Winning retailer's expected order quantity is higher under the Bid-on-W auction compared to the Bid-on-F auction in both low and high profit margin scenarios.

Previous experimental research (e.g., Schweitzer and Cachon 2000, Bostian et al. 2008, Katok and Wu 2009) have documented the well-known "pull-to-center" effect in numerous newsvendor experiments, which indicates that newsvendors tend to order quantities between the optimal amount and the mean demand in the experiments. However, in our setting, different from the standard newsvendor problem, not every retailer can reach the newsvendor decision stage since only the retailer who wins from the auction can order products from the supplier as a newsvendor. Thus, we also investigate whether and how our new setting will affect the newsvendor's order quantity behavior.

Experimental Results

(1) Observational Result 1: Suppliers earn more profit in Bid-on-F auction than in Bid-on-W auction.

Figure 28: Supplier's Profit Performance in Experiment

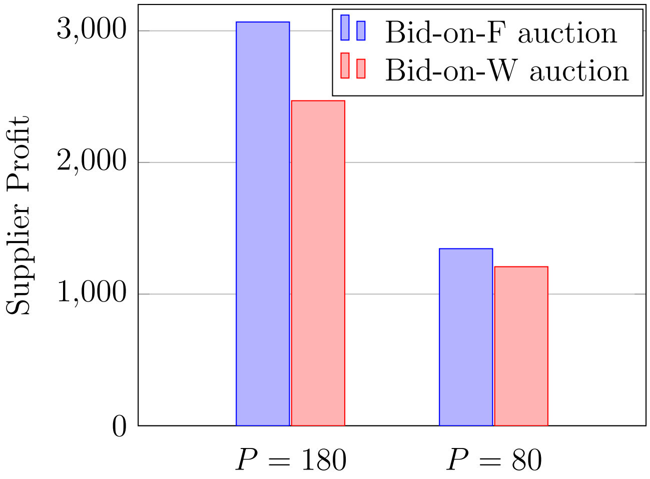
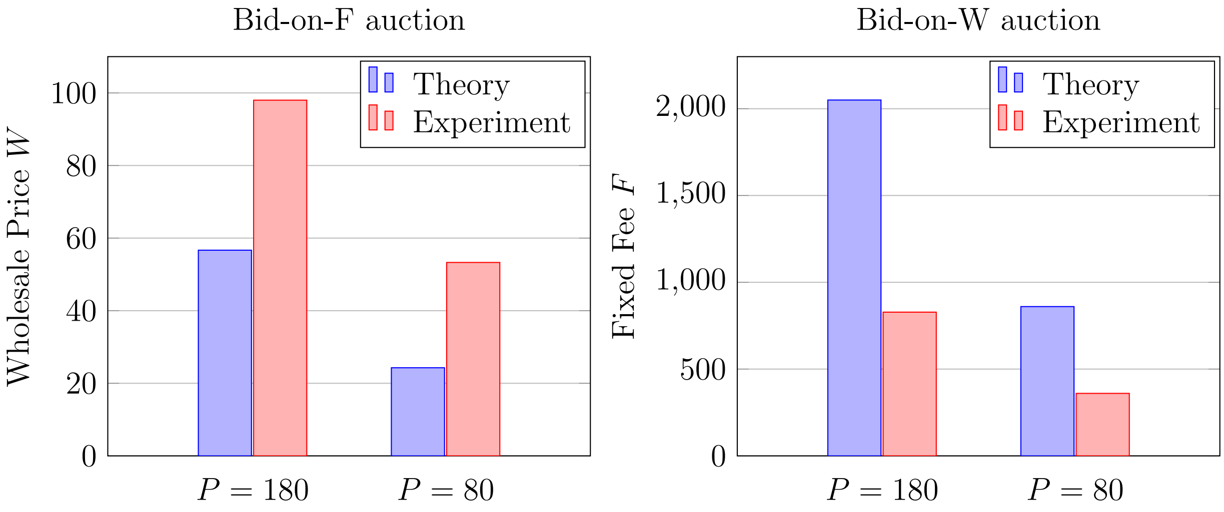


Figure 28 summarizes the profit performance in all treatments and shows that suppliers earn a higher average profit in Bid-on-F auction than in Bid-on-W auction under both low and high profit margin scenarios. Both the nonparametric Mann-whitney test and the parametric two-sample t-test results shown in Appendix C agree on making the inference that supplier's profit performance in Bid-on-F auction is significantly higher. Thus, **Hypothesis 1 is rejected and supplier should choose Bid-on-F auction under both low and high profit margin scenarios** based on our experimental results, which contradicts with the theoretical prediction. We speculate that the underlying behaviors, fully investigated below, from both supplier and retailers have a significant impact on the supplier's profit performance in experiment under each contact auction.

(2) Observational Result 2: Suppliers overset wholesale price W in Bid-on-F auction while underset fixed fee F in Bid-on-W auction.

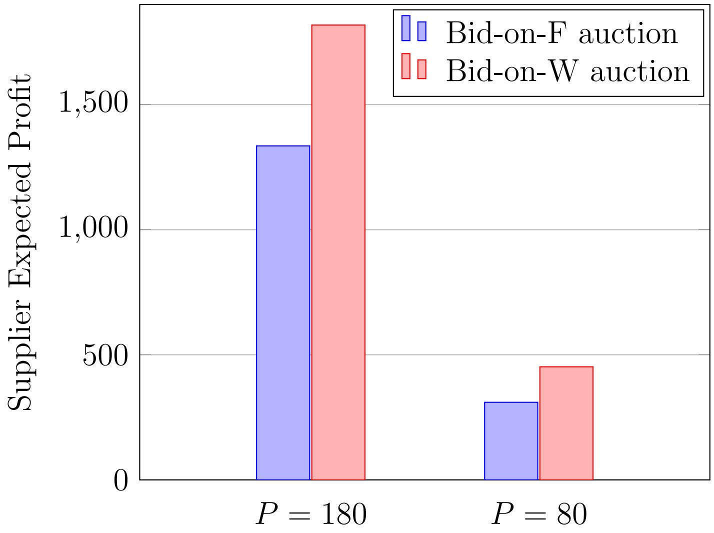
Figure 29: Supplier Contract Term Decision in Bid-on-F and Bid-on-W Auction



In Bid-on-F auction, supplier first sets wholesale price W before she invites the retailers for auction. Figure 29 shows that, in Bid-on-F auction, the theoretical prediction (i.e., blue bar) of wholesle price W is much lower than the corresponding experimental results (i.e., red bar) in both low and high profit margin scenarios. To statistically examine it, we use both the nonparameteric Wilcoxon Signed Rank Test and the parametric paired sample t-test. Both test results (with $< 0.1\%$ p-value) agree on making the above inference that **suppliers overset wholesale price W in Bid-on-F auction at both low and high profit margin scenarios.** We also find that wholesale price W substantially increases when we move from the low to the high profit margin scenario, which indicates that **Hypothesis 2 is supported in Bid-on-F auction**. In general, our experimental results in Bid-on-F auction indicates that suppliers would like to push further to exploit more payoffs from the contract term W in their control although it will increase the probability of retailers' rejection of auction participation in rationality.

In contrast, in Bid-on-W auction, supplier first sets fixed fee F before the auction invitation. Figure 29 shows that, in Bid-on-W auction, the theoretical prediction (i.e., blue bar) of fixed fee F is much higher than the corresponding experimental results (i.e., orange bar) in both low and high profit margin scenarios. Again, we statistically examine it with both the nonparameteric Wilcoxon Signed Rank Test and the parametric paired sample t-test. Both test results (with $< 0.1\%$ p-value) agree on making the above inference that **suppliers underset fixed fee F in Bid-on-W auction at both low and high profit margin scenarios.** Contrary to Bid-on-F auction, our experimental results in Bid-on-W auction indicates that suppliers are more willing to sacrifice some payoffs from the contract term F in their control to increase the probability of having at least one participating retailer and ensure the F amount. Besides that, we also find that fixed fee F substantially increases when moving from the low to the high profit margin scenario, which indicates that **Hypothesis 2 is supported in Bid-on-W auction**.

Figure 30: Supplier Expected Profit Given Experimental Contract Term Decisions



Further, we investigate how suppliers' contract term decisions impact their expected profit in both contract auctions at each profit margin level. Figure 30 decomposes suppliers' expected profit into two parts (i.e., $W \cdot Q(W)$ and F) given their experimental contract term decision by assuming that retailers' participation decision and winning retailer's order quantity decision are rational. We find that on average suppliers earn more profit in both $W \cdot Q(W)$ and F parts under Bid-on-W auction compared to Bid-on-F auction at each profit margin scenario, which indicates that **suppliers' expected profit is higher in Bid-on-W auction after incorporating their contract term behaviors in experiment.**

(3) Observational Result 3: Retailers overparticipate and overbid in both Bid-on-F auction and Bid-on-W auction generally.

Figure 31: Retailer's Participation Decision in Bid-on-F and Bid-on-W Auctions

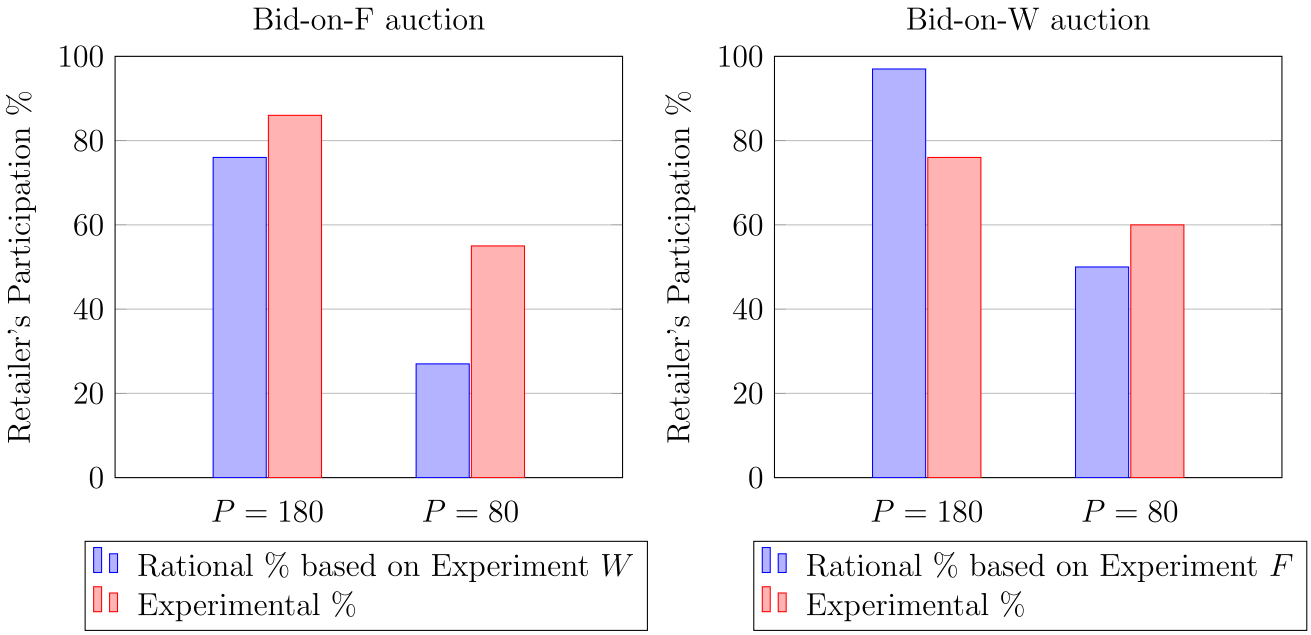
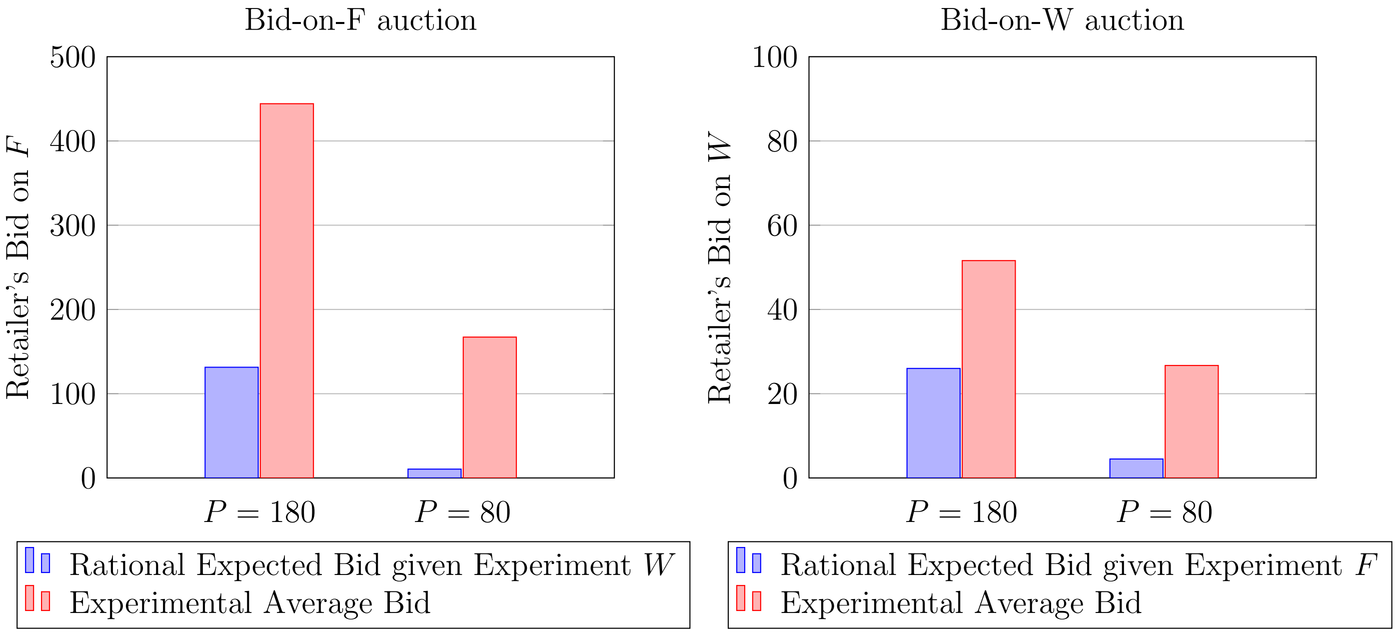


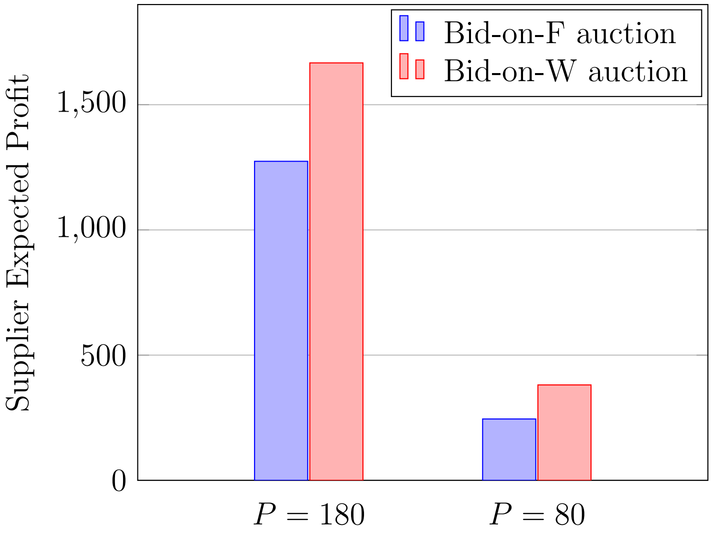
Figure 31 shows retailers' participation rate in both Bid-on F auction and Bid-on-W auction at each profit margin scenario. The blue/red bar in each treatment represents for rational participation rate based on experimental contract term decision/experimental participation rate respectively. By comparing the red bar with the blue bar in each treatment, we show that **in Bid-on-F auction, retailers overparticipate in both low and high profit margin scenarios; while in Bid-on-W auction, the retailers tend to underparticipate (or overparticipate) in the high (or low) profit margin scenario.** To statistically examine it, we use both the nonparametric Mann-Whitney test and the parametric two sample t-test. Both test results agree that the experimental participation rate in Bid-on-F auction is significantly higher (with $< 0.1\%$ p-value) than that in Bid-on-W auction at high profit margin scenario, while at low profit margin scenario, the experimental participation rate in Bid-on-F auction is significantly less than that in Bid-on-W auction at 10% significance level. Thus, **Hypothesis 3 is rejected.**

Figure 32: Retailer's Bidding Decision in Bid-on-F and Bid-on-W Auctions



Further, we summarize participating retailers' bidding decisions in Figure 32. The blue/red bar in each treatment represents for rational expected bid given experimental contract term decision/experimental average bid respectively. Since the red bar is substantially higher than the blue bar in each treatment, we find that **retailers overbid fixed fee F in Bid-on-F auction and overbid wholesale price W in Bid-on-W auction at both low and high profit margin scenarios.** To statistically examine it, we use both the nonparametric Wilcoxon Signed Rank Test and the parametric paired sample t-test. Both test results (with $< 0.1\%$ p-value) agree on make the above inference. Overparticipation and overbidding behaviors in first-price sealed-bid auction has been documented in numerous previous research and the possible explanations can be risk aversion (Cox et al. 1988), joy of winning (Crawford and Iriberri 2007) or regret in auctions (Engelbrecht-Wiggans and Katok 2008). While, for the underparticipation behavior shown in one treatment of Bid-on-W auction, we speculate that retailers may concern about the high fixed fee payment (F) set by the suppliers, and thus some are not willing to participate in the auction.

Figure 33: Supplier Expected Profit Given Experimental Contract Term, Participation and Bidding Decisions



We also investigate the impact of retailers' participation and bidding decisions on suppliers' expected profit in both contract auctions at each profit margin level. Notice that supplier gets 0 profit if neither of retailers participates the auction while benefits from retailers' overbidding behaviors when at least one retailer participates. Figure 33 shows suppliers' expected profit given their experimental contract term decisions, retailers' experimental participation and bidding decisions by assuming that the winning retailers order quantity decisions are rational. We find that, in both low and high profit margin scenarios, **suppliers' expected profit is higher in Bid-on-W auction after incorporating contract term, participation and bidding behaviors in experiment.**

(4) Observational Result 4: Winning retailers overorder and the "pull-to-center" effect does not hold in both Bid-on-F and Bid-on-W auctions.

Figure 34: Retail's Order Quantity Decision in Bid-on-F and Bid-on-W Auctions

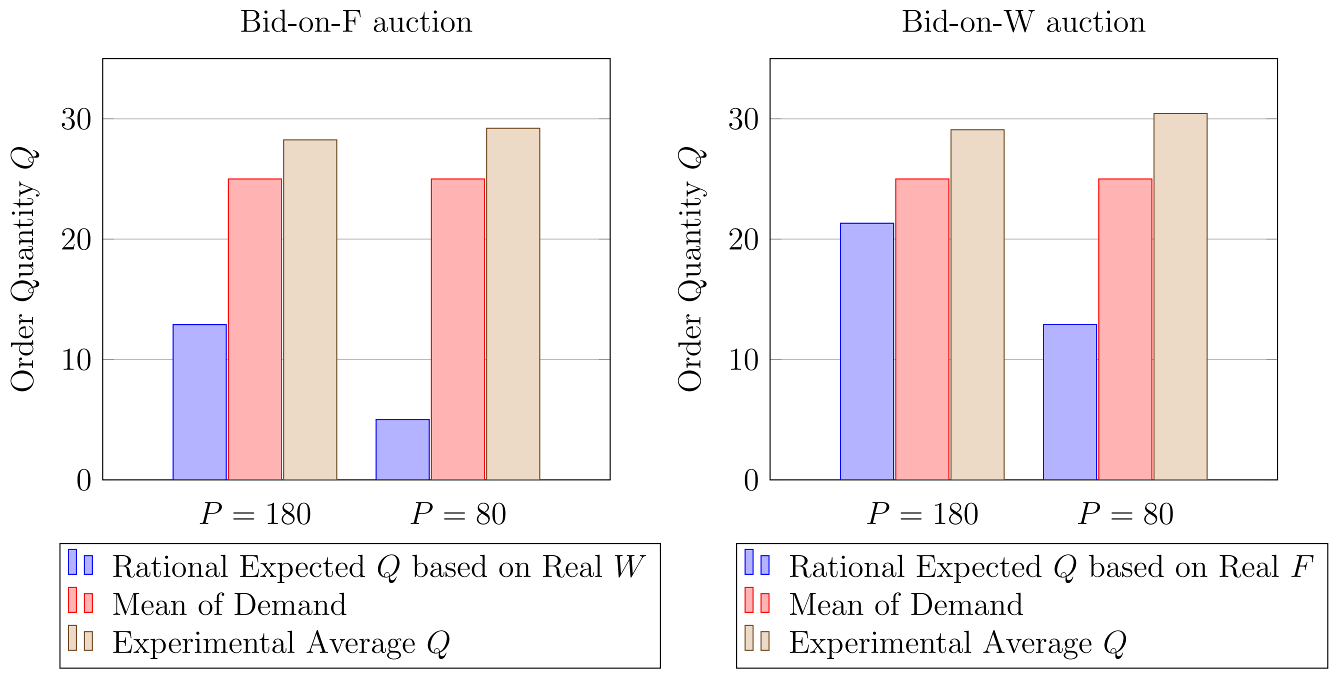


Figure 34 shows winning retailers' order quantity decision in both Bid-on-F auction and Bid-on-W auction at each profit margin scenario. The blue/red/brown bar in each treatment represents for rational expected order quantity based on experimental contract term, participation and bidding decisions/mean of demand/experimental average order quantity respectively. The mean of demand is 25 in each treatment since we assume that market demand is uniformly distributed between 0 and 50. First of all, we find that, in each treatment, the experimental average order quantity is substantially higher than the rational expected order quantity given experimental decisions in previous stages, which is supported by both the nonparametric Wilcoxon signed rank test and paired sample t-test, and indicates that **winning retailers order substantially more than prediction in both Bid-on-F and Bid-on-W auction.**

We also compare the rational expected order quantity given experimental decisions (or experimental order quantity) between Bid-on-F and Bid-on-W auction at each profit margin scenario by using both nonparametric Mann-Whitney Test and the parametric two sample t-test. Both tests agree that rational expected order quantity in Bid-on-W auction is higher while the experimental order quantity is not substantially different between contract auctions, which indicates that **the level of overorder behaviors in Bid-on-F auction is higher and Hypothesis 4 is rejected**.

Supplier can always benefit from winning retailers' overorder behaviors and a higher level of the overorder behaviors can bring substantial profit for the supplier. As Figure 28 and Figure 33 shows, suppliers' expected profit is higher in Bid-on-F auction after we further incorporate winning retailers' overorder behaviors while Bid-on-W auction is still better before that, which indicates that **winning retailers' overorder behaviors have a significant impact on supplier's profit in contract auction and can change supplier's contract auction mechanism preference contradictorily with the theoretical pre-**

diction. Thus, we further explore winning retailer's order quantity behaviors in our setting to uncover the behavioral regularities.

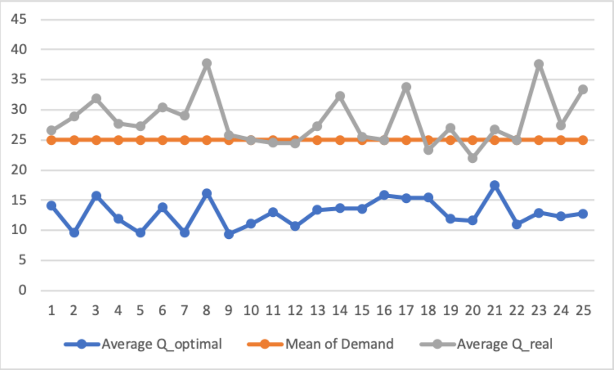


Figure 35: Order Quantity Decision in High-Profit Margin Treatment under Bid-on-F Auction

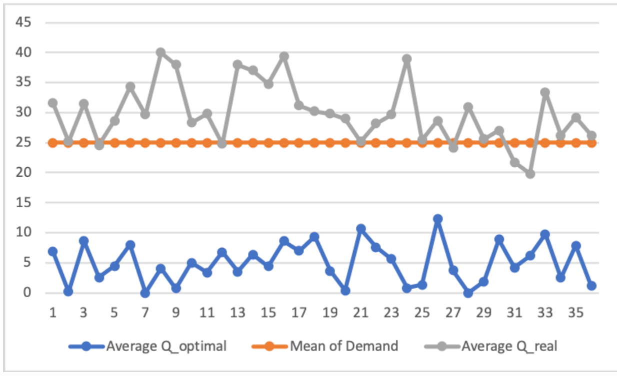


Figure 36: Order Quantity Decision in Low-Profit Margin Treatment under Bid-on-F Auction

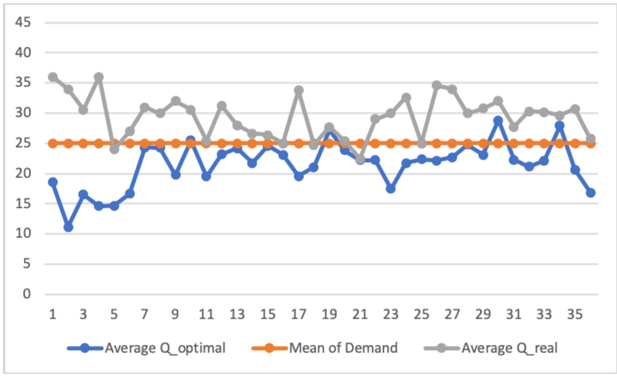


Figure 37: Order Quantity Decision in High-Profit Margin Treatment under Bid-on-W Auction

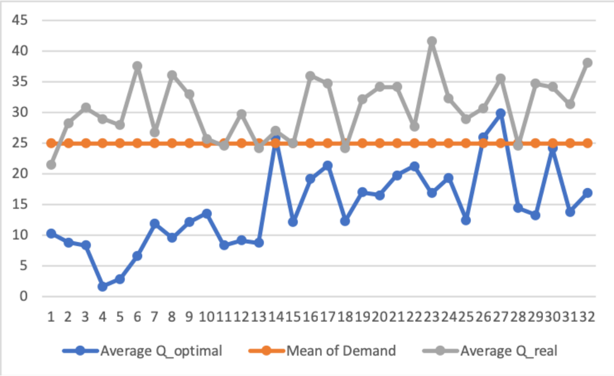


Figure 38: Order Quantity Decision in Low-Profit Margin Treatment under Bid-on-W Auction

Previous experimental research on the newsvendor problem (e.g., Schweitzer and Cachon 2000) found that newsvendors' experimental order quantity tends to locate between the expected profit-maximizing order quantity and the mean demand at an aggregate level, which is widely known as the "pull-to center" effect. To examine the newsvendor behaviors in our setting, Figure 35-38 shows winning retailers' order quantity decision in both Bid-on-F and Bid-on-W auction at each profit margin scenario. The blue/orange/grey dot represents for the rational expected order quantity based on other experimental decisions/mean of demand/experimental average order quantity in each round of experimental games respectively. If the "pull-to-center" effect occurs in our experiment, the grey line of dots should generally locate between the blue line of dots and the orange line of dots. However, our experimental results show that winning retailers set their order quantity above that range in most rounds, which indicates that **the "pull-to-center" effect does not hold in each treatment of our experiment.**

This new experimental phenomenon may come from the crucial difference between our setting and the standard newsvendor problem. In our setting, not every retailer but only the winning retailer can order products from the supplier as a newsvendor. We speculate that contract auction competition among retailers can substantially impact winning retailers' order quantity behaviors and thus we break the "pull-to-center" effect shown in numerous newsvendor experiments (e.g., Schweitzer and Cachon 2000, Bostian et al. 2008, Katok and Wu 2009). To examine it, we first investigate the impact of the agreed contract terms and winning retailer's private processing cost on their order quantity decision in each treatment with a fixed-effect regression model. Table 16 summarizes the regression results where dependent variable is winning retailers' real order quantity and the independent variables are agreed fixed fee F, wholesale price W and their private processing cost C_i. We also use round dummies to control for the time effect. Due to the limited space, we don't list in the table.

In both treatments of Bid-on-F auction, the significantly positive coefficient of fixed fee F suggests that a higher bid on fixed fee F leads to a higher order quantity amount although theoretically it should not impact. While, the insignificant coefficient of wholesale price W indicates that wholesale price W set by the supplier does not significantly impact winning

Table 16: Regression Results for All Treatments in Bid-on-F/Bid-on-W Auction

Order Quantity	Bid-on-F auction		Bid-on-W auction	
	P = 180	P = 80	P = 180	P = 80
Fixed Fee F	0.0157*** (0.0035)	0.0552*** (0.0167)	-0.0015 (0.0029)	0.0012 (0.0027)
Wholesale Price W	0.0013 (0.0243)	-0.0767 (0.0459)	-0.0768* (0.0374)	0.2526*** (0.0543)
Processing Cost C_i	-0.0607* (0.0242)	-0.0858** (0.0320)	-0.1353*** (0.0325)	-0.0060 (0.0366)
Intercept	27.11*** (5.11)	21.03** (7.21)	35.62*** (6.00)	31.38*** (4.71)
Observations	167	199	165	189
Adjusted R^2	0.4172	0.3267	0.3050	0.3172

Note that: $^{***}\, p < 0.001$; $^{**}\, p < 0.01$; $^{*}\, p < 0.05$. Standard error is in parenthesis.

retailer's order quantity although theoretically it should negatively affect. Meanwhile, in both treatments of Bid-on-W auction, the insignificant coefficient of fixed fee F and the significant coefficient of wholesale price W seems to be more comparable to the theoretical prediction in (1). However, winning retailers are either underreacting or positively reacting to their bid on wholesale price W in high or low profit margin scenario, which also leads to the overorder behaviors as in Bid-on-F auction. Thus, our statistical results confirms that **contract auction competition has a significant impact on winning retailers' order quantity behaviors since their order quantities significantly react to their bid in both contract auctions.**

(5) Experimental Results Discussion

Among all of our experimental findings, some are consistent with the previous findings in auction literature such as the overbidding behavior and the underlying reasoning has been widely explored. Some seem to be contradict with the previous findings. For instance, we find a strong pattern across all treatments of winning retailers' overorder behaviors, which breaks the well-known and robust "pull-to-center" effect shown in numerous newsvendor experiments and triggers the change of suppliers' contract auction mechanism preference contradictorily with the theoretical prediction. We find that contract auction competition can have a significant impact on winning retailers' order behaviors and further investigate the underlying behavioral regularities. We speculate that each contract auction changes the reference point of each winning retailer after he bids and commits to the contract agreement. He may view his commitment as a pre-investment and expect to make at least that much from the subsequent order quantity stage. If we follow this idea and apply prospect theory in our setting (Tversky and Kahneman 1992, Long and Nasiry 2014), the winning retailers are more likely to view themselves in the lose domain due to the overbidding behaviors, and thus tend to overorder quantities because of risk seeking in that domain. To validate it against several alternate explanations, in section 6, we develop a behavioral model for each potential explanation and compare the predictive power.

Behavioral Model and Estimation

We motivate the behavioral model by two main experimental observations in the *Newsvendor Stage*. First, winning retailers' order quantity decisions are noisy shown in Figure 35-38. This suggests bounded rationality and we model it through the quantal response framework. (McKelvey and Palfrey 1998, Su 2008, Chen et al. 2012). Second, we have identified a strong pattern of overorder behaviors in all treatments, which leads to the fact that the "pull-to-center" is no longer in effect in our setting. Following Schweitzer and Cachon (2000), we consider different potential explanations including risk preference, loss preference, reference dependent risk preference, and satisfying target behaviors. We model each potential explanation under the quantal response framework by implementing utility modification. With the structural estimation of the behavioral parameter(s) under each behavioral model, we then use model selection techniques to find the most convincing explanation among alternatives.

(1) Bounded Rationality

McKelvey and Palfrey (1998) introduced a quantal response idea which incorporates bounded rationality into game-theoretic analysis. Following this idea, given the agreed contract terms (both W and F), the winning retailer's quantal response probability, following a standard logit formulation, of choosing the order quantity q is given by:

$$P_w(q|W,F) = \frac{exp(\beta Eu(\Pi_R(q|W,F)))}{\sum_{q \in Q} exp(\beta Eu(\Pi_R(q|W,F)))}$$

where β is the bounded rationality parameter for all winning retailers' order quantity decision and the level of β represents the extent of their bounded rationality. As Chen et al. (2012), we use a common parameter β and leave the individual-level heterogeneity of bounded rationality for future research. At one extreme, when $\beta \to 0$, the winning retailer randomly chooses the order quantity amount from all alternatives with no intelligence and equal probabilities. At the other extreme, when $\beta \to +\infty$, the winning retailer chooses the order quantity that can maximize his expected payoff. $Eu(\Pi_R(q|W,F))$ denotes the winning retailer's expected utility modified from (1) by incorporating any potential behavioral explanation of overorder quantity behavior. Here, we use a summation, as opposed to an integration, in the formulation because we restrict the decision space to be discrete in the experiments. There is no known method to find a closed form solution for the quantal response framework and we use numerical methods to evaluate $P_w(q|W, F)$.

(2) Potential Explanations of Overorder Behavior

Schweitzer and Cachon (2000) considered potential behavioral explanations for newsvendors' order quantity behaviors in experiment and ruled out most of them due to the inconsistency with the well-known "pull-to-center" effect. Different from previous studies on newsvendor experiments, our study finds that the "pull-to-center" is no longer in effect and indicates that contract auction competition can have a significant impact on winning retailers' order behaviors. Following Schweitzer and Cachon (2000), we test potential behavioral explanations such as risk preference, loss preference, reference dependent risk preference and satisfying behavior. Appendix D provides the formulation summary of behavioral models.

In risk preference model, we speculate that the winning retailers may have risk preference instead of risk neutral when ordering products. Specifically, we build up an exponential utility function, where γ is the winning retailers' risk preference parameter. When $\gamma > 0$ (or $\gamma < 0$), the winning retailers are risk-averse (or risk-seeking) since $u^{''}(\Pi_R) < 0$ (or $u^{''}(\Pi_R) > 0$). Since a risk-averse/risk-seeking player orders less/more than the normative benchmark (Eeckhoudt et al. 1995), we speculate that the winning retailers are risk-seeking if we follow this idea to match with the overorder behaviors in our setting.

Then in reference dependent risk preference model, we speculate that the winning retailers may present different risk preferences when facing potential losses and gains. We use p_1 and p_2 to stand for the risk preference parameter in the gain and loss domain respectively. When $p_i > 0$ (or $p_i < 0$), the winning retailers are risk averse (or risk seeking) over the corresponding domain. Our experimental findings show that winning retailers in both contract auctions are more likely to face losses instead of gains given possible demand realization due to the overbidding behaviors. Thus, if winning retailers are risk-averse/risk-seeking over the gain/lose domain following prospect theory (Kahneman and Tversky 1979), they will order more than necessary as newsvendors.

Other than risk preference, the winning retailers may exhibit loss preference when they order products. Specifically, l_1 stands for the loss preference parameter. Schweitzer and Cachon (2000) demonstrated that, when $l_1 > 1$ (or $0 < l_1 < 1$), players are loss-averse (or loss-seeking) and order less (or more) than the profit-maximizing quantities. Thus, if we follow the loss preference idea to match with the overorder behaviors in our setting, the winning retailers are generally loss-seeking for some reasons.

Finally, instead of optimizing expected profit, we speculate that the winning retailers may switch their goals to satisfy a target when ordering products. Specifically, the winning retailers may be satisfied if they can earn the "pre-investment" amount in auction competition with some extra profit through ordering and selling products. In our formulation, γ represents the satisfying parameter, which measures the utility changes when probability of satisfying the target changes. We measure the "Extra Payoff" with different versions. One standard version is Extra Payoff $= A_0 + A_1 \cdot c_i$, since we speculate that when c_i increases, the "Extra Payoff" amount set by the winning retailer i may systematically decrease.

(3) Estimation and Results

We estimate behavioral models with the standard maximum likelihood estimation (MLE) method. As in the experiment, we discretize the decision space to integers and limit the q

decision range matching with the demand distribution. By incorporating quantal response framework together with utility adjustment according to possible behavioral explanations, our behavioral models, with different sets of behavioral parameters (e.g., $\theta = (\beta, P1, P2)$), allow us to calculate the probability of observing the decisions. The loglikelihood function can be expressed as: $L(\theta) = \sum[log(P_w(q|W, F))]$.

Table 17, as an illustration, shows the estimation results of different behavioral models in which the behavioral parameters can maximize the loglikelihood and best fit for the data collected from the treatment of high profit margin scenario in Bid-on-F auction. Since the qualitative pattern is the same across all treatments, we show estimation results for other treatments in Appendix E. First of all, to statistically test whether each behavioral parameter has a significant impact on the performance of the behavioral model, we perform the likelihood ratio test. Specifically, we set each behavioral parameter at 0 and get the loglikelihood of the restricted model based on MLE technique. Then, we compute the test statistic $\chi^2 = 2(l_{full} - l_{reduced})$ which follows a χ^2 distribution with one degree of freedom. Thus, the critical value is $\chi^2_1(0.99) = 6.64$ at 1% significance level. In each behavioral model, we find that the test statistics of each behavioral parameter exceed the critical value which indicates its significant impact in each behavioral model.

Expected profit model in Table 17 shows the estimation result of the standard quantal response model without utility modification. We find that β is significantly positive but is still far less than ∞, which indicates that the winning retailers are bounded rational. Then, in the following columns of Table 17, we estimate behavioral models that further incorporates different potential explanations of winning retailers' overorder behaviors. To formally compare the estimation performance of different behavioral models, we apply both

Table 17: Estimation Results of High-Profit Margin Treatment in Bid-on-F Auction

Parameters	Expected Profit	Risk Preference	Loss Preference	Reference Dependent Risk Preference	Reference Dependent Risk Preference (Loss)
β	0.00041	0.0013	0.00473	0.0095	0.00563
γ	-	-0.00037	-	-	-
l_1	-	-	0.1189	-	-
P_1	-	-	-	0.00051	-
P_2	-	-	-	-0.00275	-
P_L	-	-	-	-	-0.00163
Loglikelihood	-1003.611	-986.15	-955.07	-929.81	-945.06
AIC	2009.22	1976.30	1914.13	1865.61	1894.12
BIC	2012.78	1983.41	1921.24	1876.27	1901.23

Note that: All behavioral parameters are significant at 1% level.

Akaike information criterion (AIC) and Bayes information criterion (BIC) which aims to penalize the additional degree of freedom within different behavioral models compared to the standard quantal response model.

Both AIC and BIC agree on the conclusion that the reference dependent risk preference model (with lowest values) provides a superior explanation of the data among alternatives for all treatments. The coefficient of parameter P_1 and P_2 is significantly positive and negative in all treatments, which indicates that winning retailers are risk averse/seeking in the gain/loss domain consistently with the key idea of prospect theory (Kahneman and Tversky 1979). Our estimation results provide strong evidence that prospect theory together with bounded rationality are crucial factors to be considered in our contract auction settings for helping explain the behavioral regularities. Specifically, contract auction competition can change the winning retailers' reference point and substantially impact their subsequent order quantity behaviors. They possibly view their bids as pre-investments and are more likely to perceive themselves in the lose domain due to the overbidding behaviors. Thus, following prospect theory, they tend to overorder quantities because of risking-seeking preference in the lose domain. Also, possibly due to the cognitive limitations of their minds, the time limitation of making decisions or other reasons, winning retailers are bounded rational when ordering products.

Managerial Insights and Concluding Remarks

This paper examines a sale problem with one supplier and multiple potential retailers who hold private information and compete on contracting with the supplier. We theoretically and experimentally analyze two contract auction mechanisms, named as Bid-on-F (or Bid-on-W) auction - under an operational setting where a supplier first sets a wholesale price of each potential selling product (or the fixed payment) and potential retailers, after observing it, decide whether to participate the respective auction and how much to bid on the fixed payment (or the wholesale price) if participate. The winning retailer who offers a higher bid can order products from the supplier based on an uncertain market demand, which will be realized after all decisions.

Our experimental data suggests systematic deviations from the theoretical benchmark, and reveals behavioral regularities that can be crucial in supply chain contracting under competitive scenarios. In particular, we find that suppliers tend to overset wholesale price (or underset fixed fee) in Bid-on-F (or Bid-on-W) auction and retailers tend to overparticipate and overbid generally in both contract auctions. Further, the contract auction behaviors can have a significant impact on the subsequent winning retailers' order quantity behaviors which break the well-known "pull-to-center" effect in numerous newsvendor experiments (e.g., Schweitzer and Cachon 2000, Bostian et al. 2008, Katok and Wu 2009), and leads to a higher average profit for suppliers in Bid-on-F auction compared to Bid-on-W auction contradictorily with the theoretical prediction. We believe that understanding and applying the consequence of contract auction is important.

Motivated by winning retailers' noisy and excessive order behaviors, we develop a behavioral model built upon quantal response framework, which further incorporates reference dependent risk preference. We show that bounded rationality plays an important role in both contract auctions possibly due to the setting complexity or cognitive limitation of subjects. We verify that contract auction behaviors can substantially impact winning retailers' subsequent order quantity decisions through changing their reference point. Due to the overbidding behaviors, they are more likely to perceive themselves in the lose domain and tend to overorder quantities because of risk-seeking preference in the lose domain following prospect theory. We explore several alternative explanations, such as risk aversion, loss aversion, satisfying target, and confirm that our behavioral model provides the best predictive power.

To the best of our knowledge, we are the first to examine the supply chain contract auctions from both theoretical and behavioral standpoints, under a newsvendor setting with private information. We believe that our research provides implications of understanding the contract auction mechanisms/behaviors and there are ample opportunities to extend this work. In this study, we focus on the "seller's market" and explore supply chain contracting with buyer-side competition. One natural extension is to look into "buyer's market" and investigate the procurement contract auction mechanisms/behaviors in a similar context. In addition, in this paper, the contract and auction takes the form of two-part tariff and first-price sealed bid auction respectively. It would be interesting to investigate other combinations of contract and auction format applied in business. Finally, we have found a significant behavioral impact of supply chain competition on subsequent market decisions in a contract auction setting. There is an opportunity to investigate if this impact also occurs in other competitive scenarios such as bilateral negotiations.

References

Bolton GE, Ockenfels A, Thonemann UW (2012) Managers and students as newsvendors. *Management Science* 58(12):2225–2233.

Bostian AA, Holt CA, Smith AM (2008) Newsvendor pull-to-center effect: Adaptive learning in a laboratory experiment. *Manufacturing & Service Operations Management* 10(4):590–608.

Cachon GP (2003) Supply chain coordination with contracts. *Handbooks in operations research and management science* 11:227–339.

Chen F (2007) Auctioning supply contracts. *Management Science* 53(10):1562–1576.

Chen Y, Su X, Zhao X (2012) Modeling bounded rationality in capacity allocation games with the quantal response equilibrium. *Management Science* 58(10):1952–1962.

Cox JC, Smith VL, Walker JM (1988) Theory and individual behavior of first-price auctions. *Journal of Risk and uncertainty* 1(1):61–99.

Crawford VP, Iriberri N (2007) Level-k auctions: Can a nonequilibrium model of strategic thinking explain the winner's curse and overbidding in private-value auctions? *Econometrica* 75(6):1721–1770.

Croson R, Donohue K (2006) Behavioral causes of the bullwhip effect and the observed value of inventory information. *Management science* 52(3):323–336.

Davis AM, Hyndman K (2018) Multidimensional bargaining and inventory risk in supply chains: An experimental study. *Management Science* .

Donohue K, Katok E, Leider S (2018) *The handbook of behavioral operations* (John Wiley & Sons).

Duenyas I, Hu B, Beil DR (2013) Simple auctions for supply contracts. *Management Science* 59(10):2332–2342.

Eeckhoudt L, Gollier C, Schlesinger H (1995) The risk-averse (and prudent) newsboy. *Management science* 41(5):786–794.

Engelbrecht-Wiggans R, Katok E (2008) Regret and feedback information in first-price sealed-bid auctions. *Management Science* 54(4):808–819.

Haruvy E, Katok E, Pavlov V (2020) Bargaining process and channel efficiency. *Management Science* 66(7):2845–2860.

Huang H, Liu L, Parker G, Tan Y, Xu H (2019) Multi-attribute procurement auctions in the presence of satisfaction risk. *Production and Operations Management* 28(5):1206–1221.

Kahneman D, Tversky A (1979) Prospect theory: An analysis of decision under risk. *Econometrica* 47(2):263–292.

Katok E, Wu DY (2009) Contracting in supply chains: A laboratory investigation. *Management Science* 55(12):1953–1968.

Klemperer P (1999) Auction theory: A guide to the literature. *Journal of economic surveys* 13(3):227–286.

Kokott GM, Bichler M, Paulsen P (2019) First-price split-award auctions in procurement markets with economies of scale: An experimental study. *Production and Operations Management* 28(3):721–739.

Lim N, Ho TH (2007) Designing price contracts for boundedly rational customers: Does the number of blocks matter? *Marketing Science* 26(3):312–326.

Long X, Nasiry J (2014) Prospect theory explains newsvendor behavior: The role of reference points. *Management Science* 61(12):3009–3012.

McKelvey RD, Palfrey TR (1998) Quantal response equilibria for extensive form games. *Experimental economics* 1(1):9–41.

Myerson RB (1981) Optimal auction design. *Mathematics of operations research* 6(1):58–73.

Schweitzer ME, Cachon GP (2000) Decision bias in the newsvendor problem with a known demand distribution: Experimental evidence. *Management Science* 46(3):404–420.

Su X (2008) Bounded rationality in newsvendor models. *Manufacturing & Service Operations Management* 10(4):566–589.

Tversky A, Kahneman D (1992) Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and uncertainty* 5(4):297–323.

Vickrey W (1981) Optimal auctions. *The American Economic Review* 71(3):381–392.

Weng ZK (1995) Channel coordination and quantity discounts. *Management science* 41(9):1509–1522.

Wu DY, Chen KY (2014) Supply chain contract design: Impact of bounded rationality and individual heterogeneity. *Production and Operations Management* 23(2):253–268.

Appendix

Appendix A: Theoretical Derivation of Bid-on-F Auction

In Bid-on-F auction, we derive that retailer i should participate only when $C_i > P - W$. Given $C_i \sim U[C_l, C_h]$, (1) if $P - W \geq C_h$, both retailer should participate; (2) if $C_l < P - W < C_h$, retailer i with $C_i > P - W$ should participate; (3) if $P - W \leq C_l$, neither retailer should participate.

Scenario 1: if $P - W \geq C_h$

In this scenario, both retailers should participate the auction and the winning retailer i's optimal expected profit is $E^*(\Pi_{R_i}) = \frac{(d_h - d_l)(P - C_i - W)^2}{2P} + (P - C_i - W) \cdot d_l - F_i$. To derive a Bayesian Nash equilibrium, we suppose retailer j adopts the bidding strategy $F(\cdot)$ and assume that $F(\cdot)$ is strictly decreasing and differentiable. Then for a given value of C_i, retailer i's optimal bid F_i solves

$$\max_{F_i} E^*(\Pi_{R_i}) \cdot Prob(F_i > F(C_j) | C_j < P - W)$$

$$\rightarrow \max_{F_i} E^*(\Pi_{R_i}) \cdot Prob(F^{-1}(F_i) < C_j < P - W)$$

$$\rightarrow \max_{F_i} E^*(\Pi_{R_i}) \cdot [1 - \frac{F^{-1}(F_i) - C_l}{C_h - C_l}]$$

To find the symmetric Bayesian Nash equilibrium strategy $F(\cdot)$, we first solve the first-order condition for retailer i's optimization problem and then substitute $F_i = F(C_i)$ into the first-order condition, which yields the differential equation:

$$\frac{\mathrm{d}F(C_i)}{\mathrm{d}C_i} = -\frac{1}{C_i - C_h} \cdot F(C_i) + \frac{\frac{(d_h - d_l)(P - C_i - W)^2}{2P} + (P - C_i - W)d_l}{C_i - C_h}$$

By solving the above equation with initial value at: $C_i \to C_h$, $F(C_i) \to \frac{(d_h-d_l)(P-C_h-W)^2}{2P} + (P - C_h - W)d_l$, we find the Bayesian Nash equilibrium bidding strategy in Scenario 1:

$$\begin{aligned} F_1^*(C) =& \frac{1}{6P}(-d_l(C_h^2 - 3P^2 + 3W^2 + 3WC + C^2 + C_h(3W + C)) \\ &+ d_h(C_h^2 + 3P^2 + 3W^2 + 3WC + C^2 - 3P(2W + C) + C_h(-3P + 3W + C))) \end{aligned}$$

Then for supplier, given retailers' equilibrium bidding strategy $F_1^*(C)$ and winning retailer's optimal order quantity decision $Q^*(C) = \frac{d_hP-(d_h-d_l)C-(d_h-d_l)W}{P}$, supplier's expected profit can be expressed as:

$$\begin{aligned} E(Supplier) &= \int_{C_l}^{C_h} (W \cdot Q^*(C) + F_1^*(C)) \cdot 2 \cdot f_x(C) \cdot (1 - F_x(C))dC \\ &= \int_{C_l}^{C_h} (W \cdot Q^*(C) + F_1^*(C)) \cdot 2 \cdot \frac{1}{C_h - C_l} \cdot (1 - \frac{C - C_l}{C_h - C_l})dC \end{aligned}$$

We derive the first-order condition with respect to W for supplier's optimization problem and then calculate her best response of wholesale price to retailers' bidding strategy in scenario 1: $W_1^*(P) = \frac{C_h-C_l}{3}$. Further, we can derive E(Supplier), E(Retailers) and E(Supply Chain) given equilibrium strategies of both supplier and retailers. The equations are as follows:

$$\begin{aligned} E(Supplier) &= \int_{C_l}^{C_h} (W_1^*(P) \cdot Q^*(C|W_1^*(P)) + F_1^*(C|W_1^*(P))) \cdot 2 \cdot f_x(C) \cdot (1 - F_x(C))dC \\ E(Retailers) &= \int_{C_l}^{C_h} E^*(\Pi_R|(W_1^*(P), F_1^*(C|W_1^*(P))) \cdot 2 \cdot f_x(C) \cdot (1 - F_x(C))dC \\ E(Supplier) &= E(Supplier) + E(Retailers) \end{aligned}$$

Given $P - W \geq C_h$ in scenario 1 and $W_1^*(P)$, supplier should prefer scenario 1 when $P \geq \frac{4C_h - C_l}{3}$.

Scenario 2: If $C_l < P - W < C_h$

In this scenario, retailer i should participate the auction only when $C_i < P - W$. Given retailer i should participate and wins the auction, his optimal expected profit $E(\Pi_{R_i})^*$ is the same as in Scenario 1. Otherwise, retailer i should not participate the auction, which leads to 0 profit.

Given $C_i < P - W$, to derive the Bayesian Nash equilibrium of retailer i, we suppose retailer j adopts the bidding strategy $F(\cdot)$ when he should participate the auction (i.e., $C_j < P - W$) and assume that $F(\cdot)$ is strictly decreasing and differentiable. Then for a given value of C_i, retailer i's optimal bid F_i solves

$$\max_{F_i} E(\Pi_{R_i})^* \cdot [Prob(F_i > F(C_j)|C_j < P - W) \cdot Prob(C_j < P - W)$$

$$+ Prob(\text{retailer } i \text{ can win}|C_j \geq P - W) \cdot Prob(C_j \geq P - W)]$$

$$\rightarrow \max_{F_i} E(\Pi_{R_i})^* \cdot [\frac{Prob(F^{-1}(F_i) < C_j < P - W)}{Prob(C_j < P - W)} \cdot Prob(C_j < P - W) + Prob(C_j \geq P - W)]$$

$$\rightarrow \max_{F_i} E^*(\Pi_{R_i}) \cdot [1 - \frac{F^{-1}(F_i) - C_l}{C_h - C_l}]$$

The process of solving first-order condition for retailer i's optimization problem yields the same differential equation as in Scenario 1. Then, by solving this equation with initial value at: $C_i \rightarrow P - W$, $F(C_i) \rightarrow 0$, we derive the Bayesian Nash equilibrium bidding strategy

$F(C_i)$ in Scenario 2:

$$F_2^*(C) = \frac{(P - W - C)^2(d_h(P - W - C) + d_l(2P + W + C))}{6P(C_h - C)}$$

For supplier, given retailer should participate only when $C < P - W$, participating retailers' equilibrium bidding strategy $F_2^*(C)$ and winning retailer's optimal order quantity decision $Q^*(C) = \frac{d_hP-(d_h-d_l)C-(d_h-d_l)W}{P}$, supplier's expected profit can be expressed as:

$$\begin{aligned} E(\mathit{Supplier}) &= \int_{C_l}^{P-W} (W \cdot Q^*(C) + F_2^*(C)) \cdot 2 \cdot f_x(C) \cdot (1 - F_x(C))dC \\ &= \int_{C_l}^{P-W} (W \cdot Q^*(C) + F_2^*(C)) \cdot 2 \cdot \frac{1}{C_h - C_l} \cdot (1 - \frac{C - C_l}{C_h - C_l})dC \end{aligned}$$

As scenario 1, we derive the first-order condition with respect to W for supplier's optimization problem and then calculate her best response of wholesale price to retailers' bidding strategy in this scenario: $W_2^*(P)$. Due to the long length of $W_2^*(P)$ equation, we do not explicitly present. Further, we can derive E(Supplier), E(Retailers) and E(Supply Chain) given equilibrium strategies of both supplier and retailers in this scenario. The equations are as follows:

$$E(\mathit{Supplier}) = \int_{C_l}^{P-W_2^*(P)} (W_2^*(P) \cdot Q^*(C|W_2^*(P)) + F_2^*(C|W_2^*(P))) \cdot 2 \cdot f_x(C) \cdot (1 - F_x(C))dC$$

$$E(\mathit{Retailers}) = \int_{C_l}^{P-W_2^*(P)} E^*(\Pi_R|(W_2^*(P), F_2^*(C|W_2^*(P))) \cdot 2 \cdot f_x(C) \cdot (1 - F_x(C))dC$$

$$E(\mathit{Supplier}) = E(\mathit{Supplier}) + E(\mathit{Retailers})$$

Given $C_l < P - W < C_h$ in scenario 2 and $W_2^*(P)$, supplier should prefer scenario

2 when $C_l < P < \frac{4C_h - C_l}{3}$**.**

Scenario 3: If $\boldsymbol{P - W \leq C_l}$

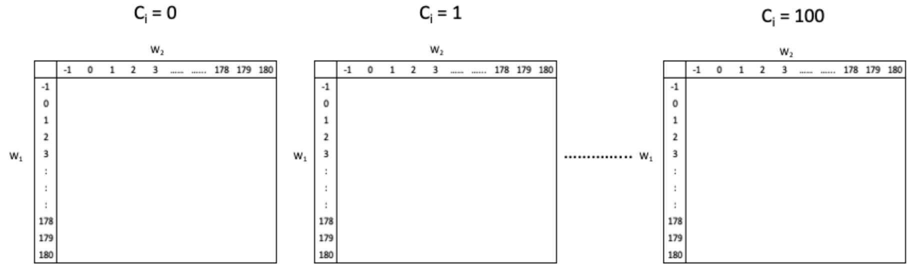
In this scenario, neither retailer should participate, which generates 0 profit for all players. Thus, when $P \leq C_l$, there is simply no trade between supplier and any of potential retailers due to negative profit margin. On the other hand, when $P > C_l$, supplier would not set W at a level which leads to Scenario 3.

Appendix B: Numerical Analysis of Bid-on-W Auction

Our numerical analysis is based on the standard iterative best response method implemented on R language and starts from retailers' decisions stages. In Bid-on-W auction, retail price P is exogenously given and fixed fee F is set by the supplier before she invites two retailers to the auction. We name two retailers as R_1 and R_2 respectively. To compare with the theoretical prediction of Bid-on-F auction, we use the same numerical setting in which we assume that $C_i \sim U[C_l, C_h]$ and $D \sim U[d_l, d_h]$.

First of all, we form a list of R_1's utility matrices according to his possible private cost C_1. In each utility matrix, row represents R_1's possible actions W_1 while column represents R_2's possible actions W_2. Figure 39 provides an illustration of this step in Bid-on-W auction when $P = 180$, $C_1 \sim U[0, 100]$ and $D \sim U[0, 50]$. Specifically, given the contract term F set by the supplier, both R_1 and R_2 can decide either not to participate in the auction (represented as -1 in the matrix) or bid W amount for each ordered product where $0 \leq W \leq P$. Thus, given each combination of W_1 and W_2, we can calculate R_1's utility in each matrix based on his processing cost C_1.

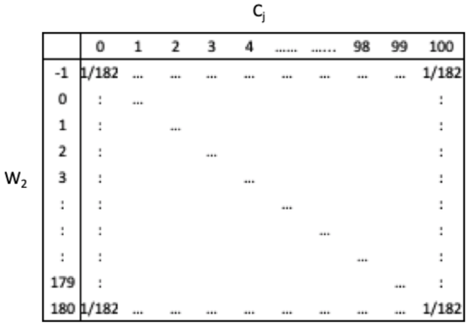
Figure 39: A list of R_1's utility matrices ($W_1 \cdot W_2$) based on his processing cost C_1



In next step, we first construct R_2's decision strategy and then calculate R_1's best response to R_2's decision strategy based on the list of R_1's utility matrices. Figure 40 provides an example of R_2's decision strategy when $P = 180$ and $C_2 \sim U[0, 100]$. Specifically, row represents R_2's possible actions (W_2) and column represents his possible private cost (C_2). In each column, if we assume that R_2 chooses his possible actions W_2 randomly with equal probability, the value of each cell would be $\frac{1}{P+2}$. Then, by performing matrix multiplication between R_1's list of utility matrices and R_2's strategy matrix, we derive a new list of matrices, in which each matrix provides R_1's utility with specific private cost C_1 given different combinations of his possible action W_1 and R_2's processing cost C_2. Figure 41 provides an illustration when $P = 180$, $C_1 \sim U[0, 100]$, $C_2 \sim U[0, 100]$ and $D \sim U[0, 50]$. Then, we calculate the average of each row in each matrix and combine all columns to form a new matrix ($W_1 \cdot C_1$), which represents R_1's expected utility under each combination of his possible action W_1 and processing cost C_1 given R_2's decision strategy. By assuming that retailers are fully rational, R_1 should choose the W_1 action/actions in each column that can maximize his expected utility. Thus, to form R_1's best response strategy given R_2's decision strategy, we further build up a new matrix (i.e., R_1's decision strategy) based on R_1's expected utility matrix by letting the cell with highest amount in each column equals to 1 and all other cells equal to 0 (in the case that only one cell in each column contains the maximum value).

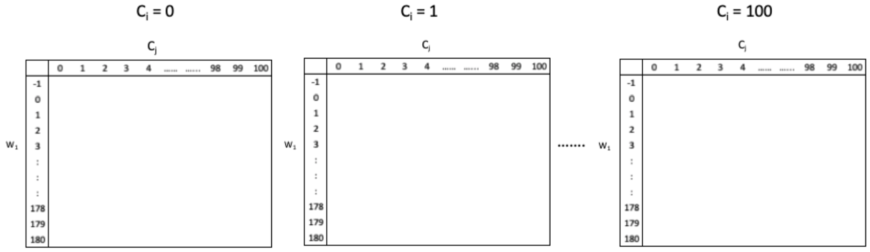
With the above two steps, we perform numerical analysis for the equilibrium bidding strategy of both retailers through finding the fixed point that neither of them has incentive to deviate. Specifically, we iteratively perform the whole process of step 1 and 2 for both retailers until their decision strategies are closely approaching to each other. Then, the corresponding decision strategy of both retailers, shown in Figure 25, can be viewed as an approximation of the symmetric Bayesian Nash equilibrium in Bid-on-W auction.

Figure 40: R_2's decision strategy matrix (W_2 * C_2)



		C_j									
		0	1	2	3	4	......	......	98	99	100
	-1	1/182	...	...	...	...	...	...	...	...	1/182
	0	:	...								:
	1	:		...							:
	2	:			...						:
W_2	3	:				...					:
	:	:					...				:
	:	:						...			:
	:	:							...		:
	179	:								...	:
	180	1/182	...	...	...	...	...	...	...	...	1/182

Figure 41: A list of R_1's expected utility matrices (W_1 * C_2) based on his processing cost C_1



With the approximation of retailers' equilibrium bidding strategy, we further calculate the supplier's contract term decision (i.e., fixed fee F) that can maximize her expected profit. Intuitively, if she sets a small F amount, both buyers would possibly participate while it may not maximize her expected profit since she can ensure the F amount as long as one retailer participates the auction. However, if she requires a very high F amount, it increases the probability that neither retailers would participate the auction which leads to 0 profit for herself. In our numerical analysis, through enumerating supplier's expected profit given all possible F amounts and locating the F amount that can maximize her expected profit, we summarize supplier's equilibrium contract term decision $F^*(P)$ as a function of the exogenous retail price P in Bid-on-W auction shown in Figure 26.

Appendix C: Statistical Analyses for Profit Performances

Table 18: Statistical tests about profit performance between experimental results and theoretical predictions in each treatment

Part a: Supplier Profit Performance (greater than)	Bid-on-F auction		Bid-on-W auction	
Retail Price	P=180	P=80	P=180	P=80
Wilcoxon Signed Rank Test	<0.001	<0.001	<0.001	<0.001
Paired Sample t-test	<0.001	<0.001	<0.001	<0.001

Part b: Retailer Profit Performance (less than)	Bid-on-F auction		Bid-on-W auction	
Retail Price	P=180	P=80	P=180	P=80
Wilcoxon Signed Rank Test	<0.001	<0.001	<0.001	<0.001
Paired Sample t-test	<0.001	<0.001	<0.001	<0.001

Part c: Supply Chain Profit Performance (less than)	Bid-on-F auction		Bid-on-W auction	
Retail Price	P=180	P=80	P=180	P=80
Wilcoxon Signed Rank Test	0.0052	<0.001	0.0012	<0.001
Paired Sample t-test	0.0137	<0.001	<0.001	<0.001

Table 19: Statistical tests about profit performance between low and high profit margin scenarios in both Bid-on-F and Bid-on-W auctions

Supplier Profit Performance	Bid-on-F auction	Bid-on-W auction
Mann-Whitney Test	<0.001	<0.001
Two Sample t-test	<0.001	<0.001

Retailer Profit Performance	Bid-on-F auction	Bid-on-W auction
Mann-Whitney Test	<0.001	<0.001
Two Sample t-test	0.039	0.0012

Supplier Chain Profit Performance	Bid-on-F auction	Bid-on-W auction
Mann-Whitney Test	<0.001	<0.001
Two Sample t-test	<0.001	<0.001

Appendix D: Formulation Summary of Behavioral Models

Risk Preference Model	$u(\pi) = \begin{cases} \frac{1-e^{-r\pi}}{r} & \text{if } r \neq 0 \\ \pi & \text{if } r = 0 \end{cases}$
Reference Dependent Risk Preference Model	$u(\pi) = \begin{cases} \frac{1-e^{-p_1\pi}}{p_1} & \text{if } \pi > 0 \text{ and } p_1 \neq 0 \\ \pi & \text{if } \pi > 0 \text{ and } p_1 = 0 \\ \frac{1-e^{-p_2\pi}}{p_2} & \text{if } \pi \leq 0 \text{ and } p_2 \neq 0 \\ \pi & \text{if } \pi \leq 0 \text{ and } p_2 = 0 \end{cases}$
Loss Preference Model	$u(\pi) = \begin{cases} \pi & \text{if } \pi \geq 0 \\ l_1 \cdot \pi & \text{if } \pi < 0 \end{cases}$
Satisfying Target Model	$u(\pi) = \pi + \gamma \cdot \text{Prob(Satisfying Target)}$ $\begin{aligned} \text{Prob(Satisfying Target)} &= \text{Prob}(p \cdot min(q, d) - (w + c)q - F - \text{Extra Payoff} > 0) \\ &= 1 - \frac{(w + c)q + F + \text{Extra Payoff}}{50 \cdot p} \quad \text{if } q > \frac{F + \text{Extra Payoff}}{p - w - c} \\ &= 0 \quad \text{otherwise} \end{aligned}$

Appendix E: Estimation Results for different treatments

Table 20: Estimation Results of Low Profit Margin Treatment in Bid-on-F

Parameters	Expected Profit	Risk Preference	Loss Preference	Reference Dependent Risk Preference	Reference Dependent Risk Preference (Loss)
β	0.00026	0.00042	0.00410	0.00634	0.005
γ	-	-0.001	-	-	-
l_1	-	-	-0.067	-	-
P_1	-	-	-	0.00071	-
P_2	-	-	-	-0.0325	-
P_L	-	-	-	-	-0.009
Loglikelihood	-463.24	-463.43	-455.81	-446.27	-451.37
AIC	928.48	930.85	915.62	898.54	906.74
BIC	931.26	936.4	921.16	906.85	912.28

Note that: All behavioral parameters are significant at 1% level.

Table 21: Estimation Results of High Profit Margin Treatment in Bid-on-W

Parameters	Expected Profit	Risk Preference	Loss Preference	Reference Dependent Risk Preference	Reference Dependent Risk Preference (Loss)
β	0.0007	0.001	0.00145	0.0094	0.00184
γ	-	-0.00018	-	-	-
l_1	-	-	0.3499	-	-
P_1	-	-	-	0.0023	-
P_2	-	-	-	-0.0044	-
P_L	-	-	-	-	-0.00062
Loglikelihood	-1055.26	-1047.36	-1044.22	-1002.08	-1034.59
AIC	2112.53	2098.73	2092.43	2010.15	2073.17
BIC	2116.13	2105.94	2099.64	2020.97	2080.38

Note that: All behavioral parameters are significant at 1% level.

Table 22: Estimation Results of Low Profit Margin Treatment in Bid-on-W

Parameters	Expected Profit	Risk Preference	Loss Preference	Reference Dependent Risk Preference	Reference Dependent Risk Preference (Loss)
β	0.00028	0.00049	0.0016	0.01244	0.00164
γ	-	-0.00056	-	-	-
l_1	-	-	-0.0424	-	-
P_1	-	-	-	0.00354	-
P_2	-	-	-	-0.0597	-
P_L	-	-	-	-	-0.007
Loglikelihood	-754.19	-752.37	-748.23	-736.25	-747.69
AIC	1510.38	1508.73	1500.46	1478.51	1499.37
BIC	1513.64	1515.25	1506.97	1488.28	1505.89

Note that: All behavioral parameters are significant at 1% level.