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Chapter 3

SUPPLY CHAIN INTERMEDIATION:

A Bargaining Theoretic Framework

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1. Introduction

This chapter explores the theory of supply chain intermediation. Using a bargaining theoretic framework, we set out to examine why intermediaries exist, different forms they operate, and the way they influence supply chain efficiency. The notion of intermediary has its root in the economics literature, referring to those economic agents who coordinate and arbitrate transactions in between a group of suppliers and customers. Distinctions are often drawn between a "market maker" and a "broker" intermediary Resnick et al., 1998. The former buys, sells, and holds inventory (e.g., retailers, wholesales), while the latter provides services without owning the goods being transacted (e.g., insurance agents, financial brokage). Sarkar et al. (1995) offer a list of various intermediation services. They distinguish the services that benefit the customers (e.g. assistance in search and evaluation, needs assessment and product matching, risk reduction, and product distribution/delivery) and those that benefit the suppliers (e.g. creating and disseminating product information). Taking a step further, Spulber (1996) views intermediary as the fundamental building

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block of economic activities. He proposes the *intermediation theory of the firm* which suggests that the very existence of firms is due to the needs for intermediated exchange between a group of suppliers and customers. A firm is created when "the gains from intermediated exchange exceed the gains from direct exchange (between the supplier and the customer)." He also suggests that "with intermediated exchange, firms select prices, clear markets, allocate resources, and coordinate transactions." By this definition, firms *are* intermediaries which establish and operate markets.

Much of the earlier debate regarding the social/economic impact of Internet surrounds the possible "disintermediation" of traditional entities (c.f., Wigand and Benjamin 1996) and the formation of new intermediaries Kalakota and Whinston, 1997; Bollier, 1996. Disintermediation occur when an intermediary is removed from a transaction. The term was first used with regard to the financial services industry in the late 1960's to describe the trend for small investors to invest directly in financial instruments such as money market funds rather than through the traditional intermediary, a bank savings account Gellman, 1996. Popular discussions suggest that efficiencies in B2B e-commerce are obtained by disintermediation: that is, by cutting out "middlemen" and supplanting presumably costly intermediaries with direct transactions between the suppliers and buyers Hoffman, 1995; Imparato and Harari, 1995; Schiller and Zellner, 1994. On the other side of the debate, Fox (1999), Lu (1997a; 1997b), Crowston (1996), and Sarkar et al. (1995) show that intermediaries are still essential in electronic commerce, and argue that only the form of intermediation changes (reintermediation). Bailey (1998) suggests that both intermediation and disintermediation hypotheses are correct under different circumstances. He considers three basic transaction structures: *disintermediated* (direct exchange), *market* (where each intermediary carries all products from all suppliers, and the consumer only needs to visit one intermediary for these products), *hierarchy* (where each supplier chooses exactly one intermediary as in a distribution channel, and the consumer must choose among all intermediaries for different products). He shows that the preferred market structure to minimize transaction costs dependents on the number of suppliers. If the number is very small, a disintermediated market is preferred. As the number of suppliers increases, the market is preferred. After a point when the suppliers become numerous, the hierarchy is preferred.

The economics literature in market intermediation, agency theory, and bargaining theory offer rich and solid foundations for the study of intermediaries and their role in the supply chain. Spulber (1999) proposed the intermediary theory as a means to understanding market microstructure. The theory offers powerful explanation for why intermediaries exist, their advantage over direct exchange, and their roles in price setting, transaction costs, and the nature of competition. He suggests that markets reach equilibrium through strategic pricing and contracting by intermediaries. Intermediaries serve the critical functions of reducing transaction costs, pooling and diversifying risk, lowering costs of matching and searching, and alleviating adverse selection. Financial market literature also offers significant insights in the role of intermediation and market design. Campbell, et al. (1999) provides a comprehensive survey on the econometrics of financial markets. O'Hara (1995), and Frankel et al. (1996) offer significant insights of the theory of financial market microstructures. Harker and Zenios (2000) investigates main performance drivers in financial institutions and the roles of intermediations in that context.

Bargaining theory provides a powerful tool for the analysis of intermediaries. As stated above, the intermediary must offer intermediated trade that is no worse than the outcome expected from direct negotiation. Bargaining theory helps to characterize expected outcome from direct negotiation in various situations. In the seminal work of Nash (1950), he defines the bargaining problem as "two individuals who have the opportunity to collaborate for mutual benefits in more than one way. (p. 155)." There have been two main streams of research on bargaining theory: 1) axiomatic (cooperative game) models, and 2) strategic (non-cooperative game) models. Nash (1950 and 1953) lays the framework for the axiomatic Nash Bargaining Solution where he first defines the basic axioms that any bargaining solution should "naturally" satisfy, he then shows that the solution of the so called Nash product uniquely satisfies the stated axioms. Kalai and Smorodinsky (1975) replace a controversial axiom from the original Nash proposal and revise the unique solution. Binmore (1987) summarizes the efforts over the years that either relaxes or adds to the Nash axioms and gives further analysis of the Nash's bargaining model. An important characteristic of the axiomatic approach is that it leaves out the actual process of negotiations while focusing on the expected outcome based on prespecified solution properties. In this chapter, we will focus on non-corporative models of bargaining. Ståhl (1972) is among the first who investigates a noncooperative, sequential bargaining process by explicitly modelling bargaining as a sequence of offers and counter offers. Using the notion of sequential bargaining, Rubinstein (1982) lays out the framework for non-cooperative bargaining models. He proposes an alternating-offer bargaining procedure where the agents take turns in making offers and counter offers to one another until an agreement is reached. The agents face time-discounted gain (a "shrinking pie") which provide them the incentive to compromise. An intuitive comparison between the axiomatic and strategic bargaining theory can be found in Sutton, 1986.

A majority of the earlier bargaining literature focuses on bilateral bargaining with complete information. There is a significant and growing literature on sequential bargaining with incomplete information (c.f., Roth (1985), Wilson (1987)). In this setting, the players involve in the bargaining situation has only incomplete information about the opponent's valuation. Rubinstein (1985a,b) proposes an alternating-offer model with incomplete information where player-one's valuation is known but player-two's cost takes one of two values, with a certain probability. He develops the concept of sequential equilibrium and shows that many sequential equilibria may exist, unless additional assumptions are made about the player's beliefs. Myerson and Satterthwaite (1983) propose a mechanism design framework for bilateral bargaining where incomplete information is represented in the form of a distribution function with known supports. The mechanism design framework is more general than that of non-cooperative bargaining theory, and it provides a means to analyzing situations in multilateral settings. The latter has important implications in the context of supply chain intermediation, which we will also explore in this chapter.

The rest of the chapter is organized as follows: in Section 2, we define the scope and set up the context for the theory of supply chain intermediation. In Section 3, we outline a modelling framework starting from bilateral bargaining with complete information, to bilateral bargaining with incomplete information, then multilateral bargaining with incomplete information. In Sections 4 to 6 we discuss each of these models in some detail. In Section 7 we conclude the chapter by pointing to related work in the supply chain literature and outlining future research opportunities.

2. Supply Chain Intermediation

Many situations may arise in the supply chain where a group of suppliers and buyers find beneficial to seek the service of a third party agent as an *intermediary*. We may consider intermediaries in two broad categories: *transactional intermediaries* who improve the efficiency of a certain supply chain transactions (e.g., the wholesaler who facilitates the transactions between a group of manufacturers and retailers), and *informational intermediaries* who alleviate inefficiencies due to information asymmetry (e.g., an arbitrator, an auditor, an insurance agency). In either case, the intermediary must devise proper mechanisms (e.g., a long-term contract, a partnership agreement, auctions, etc.) to facilitate her operation. *Supply chain intermediation* refers to the coordination and arbitration functions provided by the intermediary. In the following, we summarize supply chain intermediation by the above categorization.

Transactional Intermediary. Consider supply chain transactions from the customers, retailers, wholesaler/distributor, manufacturer, to the raw material suppliers. Each supply chain player can be viewed as a intermediary between her upstream suppliers and downstream customers. Over the long run, a supply chain player is only engaged when she creates value from such intermediation, she would be disengaged (disintermediated) otherwise. For instance, in a three-tier supply chain with retailers, wholesalers, and manufacturers, the wholesaler serves as an intermediary between the retailers and the manufacturers. Operationally, the wholesaler may create value by holding inventory for the manufacturers such that just-in-time delivery could be made to the retailers. Over time, the wholesaler may help reducing the manufacturer's risk by aggregating demands from multiple retailers, or reducing the retailer's shortage risk by offering alternative products from multiple manufacturers. Over the long-run, a certain manufacturers, wholesalers, and retailers may form strategic alliance to further improve efficiency by streamlining their transactions electronically, by joint forecasting and inventory planning, etc. While providing the service as an intermediary, the wholesaler incurs intermediation costs (i.e., overhead plus her own profit) for the manufacturers and retailers. As market condition changes, the intermediation costs may not be justified by the reduction in transaction costs when comparing to direct exchange, or an alternative form of intermediation. In this case, disintermediation and/or reintermediation will eventually occur, i.e., a retailer may choose a new intermediary, say, a buy-side procurement auction for some of her products, while ordering directly from the manufacturer for other products. In general, a transactional intermediary may serve the following functions:

- reducing uncertainty by setting and stabilizing prices,
- reducing the costs associated with searching and matching,
- providing immediacy by holding inventory or reserving capacity, and
- aggregating supply or demand to achieve economy of scale.

Informational Intermediary. While at the transactional level a supply chain may operate with a high level of transparency, at the tactical and strategic level it typically operates under incomplete or asymmetric information. Financial incentives represented by the buyer's willingness-to-pay level and the supplier's opportunity cost tend to be private information subject to distortion. The buyer and supplier may both have outside options that influence their bargaining positions, therefore their valuations. This information asymmetry could significantly complicate the supplier-buyer interaction, leading to inefficiency known as adverse selection (i.e., players making misinformed decisions due to information distortion). This creates the needs for a third-party trust agent (an informational intermediary) who either acts as a broker between the trading parties, or as an arbitrator who regulates the trade in some way. In either case, the intermediary may devise mechanisms that elicit private information from the players, thereby improving trade efficiency. Similar to a transactional intermediary, an informational intermediary incurs her own costs and must create (net) value in order to justify her existence. In general, we may characterize informational intermediation as follows:

- avoiding adverse selection by administrating coordination mechanisms,
- creating a trusted institution thereby reducing the needs for direct negotiation, thus the transaction overhead, and
- synthesizing dispersed information to reduce information asymmetry.

If one is curious about the utilities of supply chain intermediary theory, it may be helpful to consider the perspective of a supply chain "integrator." A supply chain integrator represents the leader of a vertically integrated supply chain, or a certain collective effort in the supply chain to improve overall efficiency. To the supply chain integrator, the transactional and information intermediaries are strategic instruments who can be used to improve a certain aspect of supply chain efficiency. For instance, the integrator may want to instigate different classes of service in the supply chain, where a buyer may set up "preferred" status for a certain subset of suppliers. A preferred supplier is given a guaranteed sourcing percentage (of a product) in exchange for better quality and favorite pricing. However, neither the supplier nor the buyer is willing to share information openly. Thus, the buyer may have no way to verify if the quality and pricing offered by a particular supplier is truly favorable (relative to other buyers), and the supplier may have no way to verify the sourcing split the buyer actually uses (across all suppliers). In this case, the integrator may create an informational intermediary to facilitate the preferred supplier program. The intermediary is to make sure that the buyer correctly ranks the suppliers based on her established criteria, and the preferred supplier program satisfies basic requirements of an efficient mechanism.

As another example, suppose the leader of a vertically-integrated supply chain is to explore new strategies to integrate her Internet and traditional retail channels. The Internet channel operates most efficiently using *drop shipping*, where the wholesaler stocks and owns the inventory and ships products directly to the customers at the retailers' request (see Chapter 14). On the other hand, retailers in the traditional distribution channels must stock and own their inventory for shelf display. To successfully integrate the two channels, it may be necessary to replace the existing wholesaler with a new intermediary (reintermeidation), who implements mechanisms that reconcile the conflicting goals and different operational requirements of the two channels. In this context, the new intermediary plays a critical role, addressing issues ranging from demand management and inventory ownership, to stocking decision rights.

More generally, the supply chain integrator may consider strategically placing intermediaries in the supply chain to improve efficiency. To be economically viable, an intermediary must create intermediated trades that are more profitable than (1) direct exchange between the suppliers and buyers, and (2) other competing forms of intermediary. The intermediary creates value by improving transaction efficiency and/or reducing the effects of information asymmetry, while creating a system surplus that benefit all players involved. The value-creation is accomplished by overcoming obstacles that hamper profitable trades and by preventing inefficient trades from taking place. In the following section, we establish the basic framework for supply chain intermediary theory, focusing on the roles of the intermediary in dividing system surplus and regulating trades.

3. Supply Chain Intermediary Theory

3.1 The Basic Settings

To establish a framework for supply chain intermediary analysis, we focus on the economic incentives of three types of players: suppliers, buyers, and intermediaries. All players are self interested, profit seeking, and risk neutral. In the simplest form, each supplier has an opportunity cost s, each buyer has a willingness to pay level v that could be public or private information depending on the model assumptions. The intermediary offers an asked price w to the supplier and a bid price p to the buyer while creating a non-negative bid-ask spread $(p - w)$ to support her operation. The intermediary has the authority to determine whether a particular trade is to take place using control β. Adopting some mechanism $\Gamma(\beta, p, w)$, the intermediary optimizes her own profit.

The setting above describes the key elements we use to define supply chain intermediation. To further characterize supply chain intermediation in different settings and scopes, we consider models distinguished by two main factors: information symmetry (complete vs. incomplete information), and cardinality of interaction (bilateral vs. multilateral). Under the multilateral setting, we further distinguish vertically integrated channels and matching markets. This characterization suggests the following simple taxonomy that we will use to structure the remainder of the chapter.

Supply Chain Intermediation Models:

1. Complete Information

- Bilateral Bargaining (Section 4)

2. Incomplete Information

- Bilateral Bargaining (Section 5)

- Multilateral Trade (Section 6)
  - Vertical Integration (Section 6.1)
  - Markets (Section 6.2)

As hinted above, all supply chain intermediation models discussed in this chapter assume a profit-maximizing intermediary. The intermediary, either serving as a mediator or an arbitrator, always has an explicit interest in profit. This assumption provides a simple and unifying view between supply chain coordination and intermediation. Simply stated, the intermediary must ensure that sufficient system surplus is generated from the intermediated trade such that (1) the players are no worse off participating in the trade compared to their other options, (2) in the case of incomplete information, the player has the incentive to reveal her true valuations, and the trade is ex post efficient, and (3) the player receives non-negative profit. When any of the above conditions are not satisfied, the intermediary has the option of calling off the trade. In a more generalized case, the intermediary may choose to subsidize a short-term trade (violating condition (3)) for long-term profit, but we do not consider this extension. Thus, after providing necessary funds in support of the trade, the intermediary keeps the remaining system surplus. The profitability of the intermediary symbolizes the strength of intermediated trade, while the opposite signals the eventual fate of disintermediation. This draws contrast to the existing supply chain coordination literature, where the system surplus is divided among the players depending on the coordination mechanism (e.g., the specific form of a contract), the result typically favors the leader of the channel who has the first-move advantage.

We will introduce an analytical model for each of cases listed above. The models help to characterize the role of intermediation, to determine when should they exist, and to understand how could they extract profit while sustaining the trade efficiency. For the incomplete information cases we need to make use of the *mechanism design* framework and the *revelation principle*, which we will briefly summarize in the following section. In Section 3.3 we will summarize the settings of the four supply chain intermediation models.

3.2 Mechanism Design and the Revelation Principle

To carry out transactions at a lower cost, the intermediary must design an efficient mechanism that offers the service. We now introduce a mechanism design framework to characterize the main components of supply chain intermediation. Consider the base model of *bilateral* bargaining under *incomplete information*. There is a significant literature on strategic sequential bargaining models with incomplete information. Roth (1985) and Wilson (1987) provide excellent surveys of this literature. A subset of the literature is concerned about the design of mechanisms that carry out the bargaining process. This mechanism design literature contributes two important concepts that are fundamental to bargaining analysis with incomplete information. First, the *revelation principle* Myerson, 1979 states that regardless of the actual mechanism constructed by the intermediary, given the Bayesian-Nash equilibrium outcome of the mechanism we can construct an equivalent direct mechanism where the buyer and the supplier reveal their respective valuation to the intermediary, and the intermediary determines if the trade is to take place. This allows the study of a large class of bargaining games without the need to specify each of the games in detail. Second, *ex post efficiency* requires that when all the information is revealed, the players' payoffs resulting from the bargaining process are Pareto efficient. It can be shown that if there exists a bargaining mechanism where the corresponding bargaining game has a Bayesian-Nash Equilibrium that generates an ex post efficient outcome, then the bargaining mechanism can be ex post efficient. A mechanism is *incentive compatible* if it is the best strategy for the players to reveal their true valuations. It is *individually rational* if the players are no worse-off participating in the game than not participating. In summary, when putting into a mechanism design framework, it is sufficient for the supply chain intermediary to consider a direct revelation mechanism that is *incentive compatible*, *individually rational*, and *ex post efficient*. In other words, regardless of the actual mechanism being constructed, it is sufficient to consider a direct mechanism as follows:

Step 1. To the intermediary, the buyer reveals her valuation v. The supplier reveals her valuation s.

Step 2. Based on the players' reports, the intermediary specifies a mechanism $\Gamma(\beta, p, w)$ as follows:

a. The intermediary determines $\beta(s, v)$ which specifies if the current trade is to take place:
$\beta(s, v) \quad = 1,$ if a certain creiteria are satisfied
$\qquad\qquad = 0,$ Otherwise.

b. If the trade is to take place ($\beta(s, v) = 1$), the intermediary collects asked price p from the buyer and pay the bid price w to the supplier. The intermediary determines the bid-ask spread (p, w) to maximize a certain well-fare function, subject to *incentive compatibility*, and *individually rationality* constraints.

c. If the trade is not to take place ($\beta(s, v) = 0$), the players take their outside options.

In general, the intermediary ensures that mechanism $\Gamma(\beta, p, w)$ is ex post efficient while balancing the budget (otherwise, the intermediary is to call off the trade). The above procedure offers a general mechanism design framework for supply chain intermediation. In the following section, we use this framework to consider a few different settings.

3.3 Models of Supply Chain Intermediation

We summarize four basic models for supply chain intermediation according to the taxonomy established earlier. The simplest model is the complete information case based on bilateral bargaining with complete information. This is followed by three incomplete information cases. Figure 3.1 illustrates the schematics for the four different models of supply chain intermediation.

1. In **bilateral bargaining with complete information** (Figure 3.1-(a)), the supplier's opportunity cost is s and the buyer's willingness to pay is v. The intermediary determines if the trade is to take place (β) based on the cost information. If so, she collects asked price p from the buyer and pay bid price w to the supplier. The intermediary determines β, p, w to maximize a certain function subject to individual rationality (see Section 4).

2. In **bilateral bargaining with incomplete information** (Figure 3.1-(b)), the supplier and the buyer hold private information $s \in [s_1, s_2], v \in [v_1, v_2]$ as defined above with ex ante distributions $F(s)$ and $G(v)$, respectively. The intermediary decides if the trade is to take place ($\beta(s, v)$). If so, she collects $p(s, v)$ from the buyer and pay $w(s, v)$ to the supplier. The intermediary determines β, p, w to maximize a certain function subject to incentive compatibility, individual rationality, and ex post efficiency (see Section 5).

3. In **multilateral trade with vertical integration** (Figure 3.1-(c)) there is one supplier and m buyers (bidders). Each bidder i holds private information about her valuation $v_i \in [a_i, b_i]$ which is known to the others in the form of distribution function $G_i : [a_i, b_i] \to [0, 1]$. Each bidder i reports her valuation v_i to the intermediary, the supplier reports her opportunity cost s. Given s and the vector of the reported valuations $v = (v_1, ..., v_m)$, the intermediary determines the probability $\beta_i(s, v)$ that bidder i will get the object (i.e., determines which bidder gets the object), collect the amount $p_i(s, v)$ from each bidder i, and pay $w(s, v)$ to the supplier. The intermediary determines (β, p, w) to maximize a certain function subject to incentive compatibility and individual rationality (see Section 6.1).

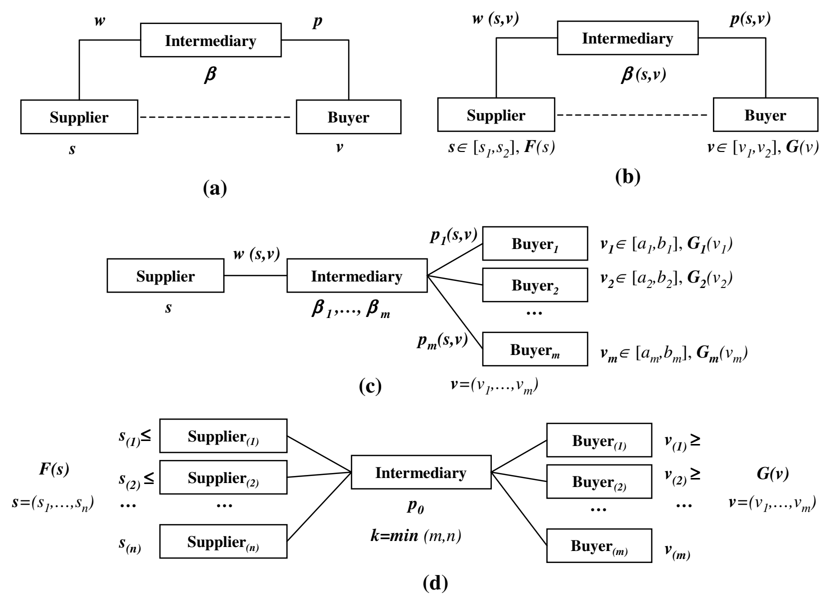

Figure 3.1. Models of Supply Chain Intermediation

4. In **multilateral trade with markets** (Figure 3.1-(d)) there are m buyers and n suppliers, each buyer i has a private valuation v_i for a single unit of good, and each supplier j has a privately known cost s_j for the good she sells. It is the common believe of all traders that each buyer's value is distributed according to $G(v)$, and each supplier's cost is distributed according to $F(s)$. The buyers and the suppliers report their valuations to the intermediary, who finds the efficient trade quantity $k \leq \min(m, n)$ and determines the market clearing price p_0 subject to budget balanceness (see Section 6.2).

4. Bilateral Bargaining with Complete Information

We now present a simple supply chain intermediary model based on the setting of bilateral bargaining with complete information. There is one supplier who is to provide a certain product to a buyer. The supplier produces (or acquires) the product at a unit cost of s. The buyer is willing to pay v for each unit of the good. The supplier and the buyer may choose to trade directly, in which case a transaction cost T incurs. Suppose there are positive net gains π^d

from the trade, then:

$$\pi^d = v - s - T > 0. \tag{3.1}$$

Suppose that an intermediary can purchase the goods from the supplier at unit price w and sell it to the buyer at unit price p, while incurring a transaction cost of K. The intermediary posts the bid-asked prices based on a certain criteria. Based on the posted price, the supplier and buyer may choose to trade directly, or through the intermediary. Clearly the intermediated trade will occur if and only if it offers a lower transaction cost, i.e., $K \leq T$. For a typical trade, the sequence of events is as follows:

Step 1. The intermediary makes a binding offer of an asked price p and a bid price w.

Step 2. After observing p and w, the buyer and the supplier decide whether to trade directly with one another, or to accept the intermediary's offer.

Step 3. If the supplier and buyer are to transact via the intermediary, trade takes place at p and w with a transaction cost of K. If they trade directly, they must bargain over the allocation of the gain π^d, while incurring a transaction cost T.

The above posted price model can be described in the form of a direct mechanism as specified in Section 3.2, where the intermediary determines if the trade is to take place based on the following criteria:

$$\begin{aligned} \beta(s, v) &= 1, \quad \text{if } v \geq p \text{ and } w \geq s \\ &= 0, \quad \text{Otherwise.} \end{aligned}$$

This simple model captures the basic decisions faced by the supplier and the buyer: to use direct, or intermediated trade based on the unit price. In the former case, the supplier and the buyer must split the net gain through bilateral bargaining. Suppose the bargaining results in a split $\alpha \in [0, 1]$, such that the buyer receives $\alpha \cdot \pi^d$ and the supplier receives $(1 - \alpha) \cdot \pi^d$. In order for the intermediary to attract the supplier and the buyer to the intermediated trade, she must offer an asked price p and a bid price w such that

$$v - p = \alpha \cdot \pi^d \tag{3.2}$$

$$w - s = (1 - \alpha) \cdot \pi^d \tag{3.3}$$

The intermediary sets the bid-ask spread $(p - w)$, which is equal to the transaction cost T according to (3.2) and (3.3):

$$(p - w) = (v - \alpha \cdot \pi^d) - ((1 - \alpha) \cdot \pi^d - s) = v - s - \pi^d = T \tag{3.4}$$

The intermediary's profit is generated from the bid-ask spread after taking out the transaction cost, i.e., $(p - w - K) = T - K$. Thus, the intermediary can only extract profit if she could offer a more efficient transaction with $K < T$.

In the following section, we present a supply chain bargaining model which further characterizes how the system surplus (the gain of trade π^d) is divided, and how the players' bargaining power influence the surplus division.

4.1 Bilateral Bargaining to Divide the System Surplus

One important function for the intermediary is to provide a shortcut to the otherwise lengthy, and possibly costly negotiations between the supplier and the buyer, while at the same time achieving the expected benefit brought by direct bargaining. Bilateral bargaining provides the basis for an intermediary to design an efficient trade and to determine a bid-ask spread that is sufficiently attractive from the players' perspectives.

Economists (c.f., Rubinstein and Wolinsky, 1985, 1990) use models of bargaining and searching to present markets as decentralized mechanisms with pairwise interactions of buyers and suppliers. In this context, intermediaries could either increase the likelihood of matching, or improve the terms of trade relative to direct exchange. Rubinstein (1982) lays out an alternating offer bargaining procedure where the agents face time-discounted gain, and in each iteration, an agent must decide to either (1) accept the opponent's offer (in which case the bargaining ends), or (2) propose a counter offer. Binmore and Herrero (1988) propose a third option where an agent may decide to leave the current negotiation and opt for her "outside options" (e.g., previously quoted deals). Ponsati and Sakovics (1998) also consider outside options as part of the Rubinstein model. Muthoo (1995) considers outside options in the form of a search in a bargaining search game. An important aspect of the extended bargaining model is to allow the possibility for the negotiation to breakdown. Binmore et. al (1986) study a version of the alternating offer model with breakdown probability. In this model, there is no time pressure (time-discounted gain), but there is a probability that a rejected offer is the last offer made in the game, meaning that the negotiation breaks down.

The supply chain literature takes a different perspective on supplier-buyer interaction. The most well known model of pairwise supplier-buyer interaction is in supply chain contracting. The scope of the contract is typically limited to the two agents involved in the negotiation at a particular point in time with the assumption that they have agreed to coordinate via some form of contract. Cachon (2002) describes the typical sequence of events as follows: "the supplier offers the retailer a contract; the retailer accepts or rejects the contract; assuming the retailer accepts the contract, the retailer submits an order quantity, q, to the supplier; the supplier produces and delivers to the retailer before the selling season; season demand occurs; and finally transfer payments are made between the firms based upon the agreed contract. If the retailer rejects the contract, the game ends and each firm earns a default payoff." A typical goal for supply chain contracting is to design "channel coordinated" contracts (i.e., contracts where the players' Nash equilibrium coincides with the supply chain optimum), while at the same time satisfies *individual rationality* and *incentive compatibility* constraints. So long as that is the case, the agents are thought to be justified to accept the contract terms. The channel surplus created by the coordination contract is split arbitrarily, typically in favor of the "leader" who initiates the contract design.

The above approach encounters two basic problems when considered in the broader context of supply chain coordination: (1) there is no guarantee that either agent involved in the current negotiation should necessarily accept the "channel coordinated" contract when other outside options are easily accessible, and (2) rather than settling for a predetermined split of the channel surplus, both players may desire to negotiate for a (hopefully) larger share of the surplus. Outside options play a role here, shaping the agent's perception of her bargaining power. Ertogral and Wu (2001) show that the dynamics of supplier-buyer contract negotiation would change fundamentally if the agents were to enter a repeated, alternating-offer bargaining game on the contract surplus, and the equilibrium condition for the bargaining game may not coincide with contract stipulation. The bargaining model offers an alternative view of supply chain interaction as follows: first, contract negotiation is generalized to a *bilateral bargaining* over the expected channel surplus; second, instead of assuming the contract terms would be accepted in one offer, an alternating-offer bargaining process takes place before a final agreement is reached; third, the players' corresponding bargaining power, not the pre-determined contract stipulation, determines the ultimate split of the channel surplus. As we will argue throughout this chapter, the viewpoints offered by supply chain intermediary theory and bargaining theory broaden the scope for supply chain coordination and allow for additional versatility in modelling.

In the following section, we model the pair-wise supply chain interaction as a bilateral bargaining game with complete information. We will summarize main results derived in Ertogral and Wu (2001), and introduce a bargaining theoretic perspective which help to analyze the tradeoff between direct and intermediated exchanges.

4.2 A Bilateral Supply-Chain Bargaining Model

Consider a bargaining situation between a pair of suppliers and buyers who set out to negotiate the terms associated with a certain system surplus, say $\pi = \pi^d$. The supplier and the buyer are to make several offers and counter offers before settling on a final agreement. Before entering negotiation, the supplier and buyer each have recallable outside options W_s and W_b, respectively. We limit the definition of outside options to tangibles known at the point of negotiation, e.g., negotiations a player previously carried out with other agents in the market, which she could fall back on. Intangibles such as an anticipated future deal is not considered an outside option. We assume that the total maximum surplus generated from the current trade is greater than or equal to the sum of the outside options. This is reasonable since otherwise at least one of the players will receive a deal worse than her outside option, and would have no incentive to participate in the first place. We further assume that when an agent is indifferent between accepting the current offer or waiting for future offers, she will choose to accept the current offer. The sequence of events in the bargaining game is as follows:

1 With equal probability, either the supplier or the buyer makes an offer that yields a certain split of the system surplus π

2 The other agent either

- accepts the offer (the negotiation ends).
- rejects the offer and waits for the next round offer.

3 With a certain probability, $(1 - \psi)$, the negotiation breaks down and the agents take their outside options, W_s and W_b.

4 If the negotiation continues, the game restarts from step 1.

The above bargaining game is similar to Rubinstein's alternating- offer bargaining model with three additional elements: (1) both players are equally likely to make the next offer, (2) the negotiation breaks down with a certain probability, and (3) each player has an outside option. The first treatment allows us to view each iteration of the bargaining processes independently regardless of who makes the previous offer. The breakdown probability characterizes the stability of the bargaining situations, which could be influenced by either player's anticipation of a more attractive future deal, non-perfectly rational players, and other intangibles that can not be measured by monetary gains (e.g., trust and goodwill, or there lack of). The breakdown probability is defined exogenously here but could perceivably be modelled endogenously with some added complexity. The outside option is important as a player's bargaining power is a combination of her ability to influence the breakdown probability and her outside options. The player with higher valuation on her outside option is more likely to receive a larger share of the surplus.

4.3 The Subgame Perfect Equilibrium

The bargaining game outlined above iterates until one of the agents accepts the offer (Step 2), or when the negotiation breaks down (Step 3). The subgame perfect equilibrium (SPE) strategies are the ones that constitute the Nash equilibrium in every iteration of the game (the subgame). In a perfect equilibrium, an agent would accept a proposal if it offered at least as much as what she expected to gain in the future, given the strategy set of the other agent. In this bargaining game, each subgame starts with the same structure: either it is initiated by the supplier or the buyer. Thus, the perfect equilibrium strategies of the agents are symmetrical in each subgame. We will analyze the game in a time line of offers to find the subgame perfect equilibrium, similar to the approach taken in Shaked and Sutton (1984) and Sutton (1986). We introduce the following additional notations:

$M_b(M_s)$: The maximum share the buyer (the supplier) could receive in a subgame perfect equilibrium for any subgame initiated with the buyer's (the supplier's) offer.

$m_b(m_s)$: The minimum share the buyer (the supplier) could receive in a subgame perfect equilibrium for any subgame initiated with the buyer's (the supplier's) offer.

ψ : The probability that negotiations will continue to the next round.

The subgame equilibrium analysis proceeds as follows: we first assume that in subgame perfect equilibrium there is an infinite number of solutions leading to gains ranging from m_b to M_b for the buyer, and m_s to M_s for the supplier. We then show that the player's share under each of the four extreme cases m_b, M_b, m_s and M_s can be derived from an event-tree structure shown in Figure 3.2. Given the derived shares, we can then determine if there is a unique SPE solution for the players where $m_b = M_b$ and $m_s = M_s$.

We now derive the best-case scenario for the buyer where she initiates the subgame and receives the maximum possible share M_b in SPE. This best-case scenario is illustrated in Figure 3.1. The root node represents that the buyer makes the initial offer, with probability $(1 - \psi)$ the bargaining breaks down. With probability ψ the bargaining continues to the next round, where the buyer and the supplier have equal probability ($\psi/2$) to make the next offer. If the buyer makes the next offer, the subtree repeats same structure. If the supplier makes the next offer, again, with probability $(1 - \psi)$ the bargaining breaks down. With probability ψ the bargaining continues to the next round, where

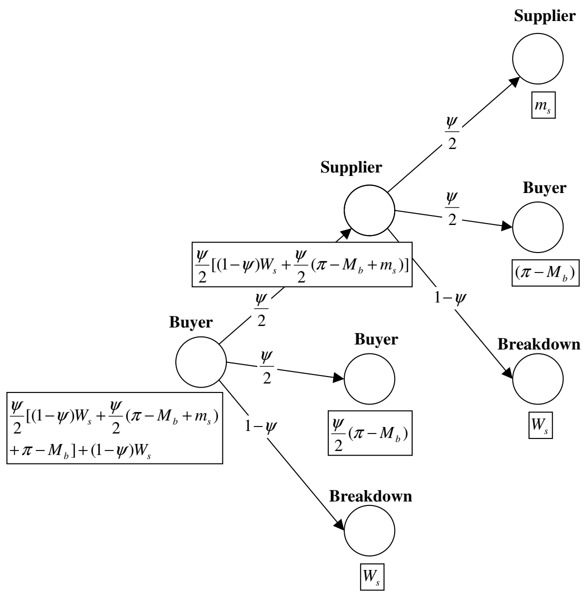

Figure 3.2. A tree defining the largest share the buyer could obtain in a subgame perfect equilibrium

the buyer and the supplier have equal probability ($\psi/2$) to make the next offer. The subtree from this point on repeats the same structure. For convenience, the nodal label in Figure 3.2 represents the share the *supplier* would receive in perfect equilibrium. Thus, the buyer's maximum gain would be labelled in terms of the supplier's share $\pi - M_b$, while the supplier's minimum gain is labelled m_s.

To derive the SPE condition we evaluate the event tree backward from the leaf nodes. Since the event tree in the figure represents the case where the buyer gets the largest possible perfect equilibrium share, when the supplier makes the offer, she settles for the minimum perfect equilibrium share m_s. When the buyer makes the offer, she receives the maximum gain possible and leaves $\pi - M_b$ to the supplier. In case the bargaining breaks down, the supplier receives her outside option W_s. The offers at the next tier follows the same logic. When the buyer makes the offer, she leaves $\pi - M_b$ to supplier as before. If the supplier makes the offer, she settles for the least amount she expects to gain in the future, which is equal to

$$(1-\psi)W_s + \frac{\psi}{2}(\pi - M_b + m_s) \tag{3.5}$$

Going back one offer to the root node, we can see that the supplier would expect to gain, in the perfect equilibrium, a minimum share of

$$\frac{\psi}{2}\Big[(1-\psi)W_s + \frac{\psi}{2}(\pi - M_b + m_s) + \pi - M_b\Big] + (1-\psi)W_s \qquad (3.6)$$

Therefore, the maximum share the buyer could gain in a SPE is as follows:

$$M_b = \pi - \left[\frac{\psi}{2}\Big[(1-\psi)W_s + \frac{\psi}{2}(\pi - M_b + m_s) + \pi - M_b\Big] + (1-\psi)W_s\right] \qquad (3.7)$$

With slight modification, we can also find the minimum SPE share that the buyer would receive in a subgame starting with the buyer's offer. In specific, we only need to replace M_b with m_b, and m_s with M_s in equation (3.7). Thus, the minimum share the buyer would receive in the subgame is as follows:

$$m_b = \pi - \left[\frac{\psi}{2}\Big[(1-\psi)W_s + \frac{\psi}{2}(\pi - m_b + M_s) + \pi - m_b\Big] + (1-\psi)W_s\right] \qquad (3.8)$$

Since the roles of the supplier and buyer are completely symmetrical in the game, we can write the expressions for M_s and m_s by simply changing the indices, and we end up with four linear equations with four unknowns. The following proposition summarizes the subgame perfect equilibrium description.

PROPOSITION 1 *The following system of equations defines the subgame perfect equilibrium for the bilateral bargaining between the supplier and the buyer.*

$$\begin{aligned}
M_b &= \pi - \left[\frac{\psi}{2}\Big[(1-\psi)W_s + \frac{\psi}{2}(\pi - M_b + m_s) + \pi - M_b\Big] + (1-\psi)W_s\right] \\
m_b &= \pi - \left[\frac{\psi}{2}\Big[(1-\psi)W_s + \frac{\psi}{2}(\pi - m_b + M_s) + \pi - m_b\Big] + (1-\psi)W_s\right] \\
M_s &= \pi - \left[\frac{\psi}{2}\Big[(1-\psi)W_b + \frac{\psi}{2}(\pi - M_s + m_b) + \pi - M_s\Big] + (1-\psi)W_b\right] \\
m_s &= \pi - \left[\frac{\psi}{2}\Big[(1-\psi)W_b + \frac{\psi}{2}(\pi - m_s + M_b) + \pi - m_s\Big] + (1-\psi)W_b\right]
\end{aligned}$$

We may solve the linear equations in Proposition 1 and find the exact expressions for M_b, m_b, M_s and m_s. We can now specify the subgame perfect equilibrium strategies of the players as follows.

PROPOSITION 2 *The unique subgame perfect equilibrium strategy for the players is as follows: if the buyer (supplier) initiates the offer, she should ask* *for X_b (X_s) share of the system surplus π, where*

$$X_b = (\pi - W_s) - \frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s) \quad (3.9)$$

$$X_s = (\pi - W_b) - \frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s) \quad (3.10)$$

Proof: By solving the system of equations given in Proposition 1, we may conclude that $M_b = m_b = X_b$ and $M_s = m_s = X_s$. $\diamond$

Since the maximum and the minimum SPE shares are equal for a given player, the SPE strategy is unique. We may interpret from expressions (3.9) and (3.10) that when a buyer (supplier) makes an offer, she ask for the difference between the system surplus π and the supplier's (buyer's) outside option W_s (W_b) minus a "risk premium" equals to $-\frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s)$. Note that the risk premium is a fraction of the "mutual gain" $(\pi - W_b - W_s)$, that the players could share if they reach an agreement. If they do not reach an agreement and continue with the bargaining, there is a risk that the process will break down and they receive only their respective outside options (thus the *mutual gain* would be lost). Proposition 2 says that in equilibrium the initiating party would offer a fraction of the *mutual gain* to the opponent that is sufficient to neutralize the opponent's desire to continue with the bargaining process.

4.4 Analysis of the Bargaining Game

Under complete information, we may conclude from Proposition 2 that the bargaining process will end in one iteration when either the supplier or the buyer initiates the negotiation with the SPE offer, and the opponent would accept the offer. This is true since the SPE offer makes the opponent indifferent between accepting the current offer and waiting for future offers. One important issue remains is whether there exists a first-mover advantage in the game. We attend to this issue in the following proposition.

PROPOSITION 3 *The first-mover advantage exists in the alternating offer bargaining game. The advantage diminishes as the probability of breakdown decreases, and goes to zero if the probability of breakdown is zero.*

Proof: If we take the difference between the SPE shares of the two players we get the following:

$$X_b - (\pi - X_s) = X_s - (\pi - X_b) = \frac{(\pi - W_b - W_s)(2 - \psi^2 - \psi)}{2 - \psi} \quad (3.11)$$

Since $2 \geq \psi^2 + \psi$ and $(\pi - W_b - W_s) \geq 0$, the above expression always yields a value greater than or equal to zero. It is zero when $\psi = 1$, or equivalently when the breakdown probability $(1 - \psi)$ is zero. In the following, we show that the players' *individual rationally* conditions are satisfied under SPE. $\diamond$

PROPOSITION 4 *The player who initiates, and the player who accepts the SPE offer both gain no less than their respective outside options.*

Proof: For the player who initiates the offer, the difference between her SPE share and her outside option is as follows:

$$X_b - W_b = X_s - W_s = \frac{1}{2}\frac{(\pi - W_b - W_s)(4 - \psi^2 - 2\psi)}{2-\psi} \tag{3.12}$$

The expression above is always positive. Hence the player who initiates the SPE offer will gain no less than her outside option. For the player who accepts the SPE offer, the difference between her SPE share and her outside option is as follows:

$$(\pi - X_s) - W_b = (\pi - X_b) - W_s = \frac{1}{2}\frac{(\pi - W_b - W_s)\psi^2}{2-\psi} \tag{3.13}$$

This expression is always positive as well. Therefore, in SPE both players gain no less than their outside options, regardless of who initiate the offer. $\diamond$

In the following, we further specify the relationship between the breakdown probability $(1-\psi)$ and the SPE share of the initiating player.

PROPOSITION 5 *The SPE share of the initiating player is linearly increasing (for $\psi > 0$) in her outside option, and linearly decreasing in her opponent's outside option.*

Proof: Taking the first and second derivatives of the buyer's SPE offer with respect to the outside options W_b and W_s, we see that

$$\begin{aligned}
\frac{\partial X_b}{\partial W_b} &= \frac{\psi^2}{2(2-\psi)} \geq 0, \\
\frac{\partial^2 X_b}{\partial W_b^2} &= 0, \\
\frac{\partial X_b}{\partial W_s} &= \frac{-(4-\psi^2-2\psi)}{2(2-\psi)} < 0, \\
\frac{\partial^2 X_b}{\partial W_s^2} &= 0.
\end{aligned}$$

It should be clear that the case when the supplier initiates the SPE offer would lead to similar results. $\diamond$

Another interesting aspect of the bargaining game is that, the offering party obtains the maximum share when the breakdown probability approaches 1 as described in the following proposition.

PROPOSITION 6 *The SPE share of the initiating player is maximized when the breakdown probability approaches 1 ($(1-\psi) \to 1$), where the share equals to the system surplus π less the opponent's outside option.*

Proof: Suppose the buyer is the offering player; taking the first derivative of the buyer's SPE offer with respect to ψ gives:

$$\frac{\partial X_b}{\partial \psi} = \frac{1}{2}\frac{\psi[(\psi-4)(\pi - W_b - W_s)]}{(2-\psi)^2} \tag{3.14}$$

Since $\frac{\partial X_b}{\partial \psi} \leq 0$ for $0 \leq \psi \leq 1$, and we have assumed that $\pi - W_b - W_s \geq 0$, we may conclude that X_b is maximized at $\psi = 0$.

It should be clear that the case when the supplier initiates the SPE offer would lead to similar results. $\diamond$

Proposition 6 is intuitive in that if both players know that the negotiation is likely to breakdown ($(1-\psi) \to 1$), the player initiating the bargaining would know that her opponent (in anticipation of the breakdown) is willing to accept an offer equivalent to the outside option. Thus, there is no reason for the offering player to offer more than the opponent's outside option.

4.5 Intermediary's Role in Price Setting, Searching, and Matching

Given the bilateral supply chain bargaining model and the supply chain intermediary theory described above, we will now examine the role of supply chain intermediary in setting prices, and in matching suppliers with buyers. Using the categorization in Section 2, these are transactional intermediation aiming to "reducing uncertainty by setting and stabilizing prices." and "reducing the costs associated with searching and matching."

We first establish the pricing criteria for a supply chain intermediary. Recall that a supply chain intermediary is economically viable if she can carry out transactions at a lower cost than (1) direct exchange between the suppliers and buyers, and (2) other competing intermediaries. If we use the result of bilateral bargaining to represent the expected gain the supplier and the buyer would expected from direct exchange, we may establish the role of any supply chain intermediary between the buyer and the supplier as follows.

THEOREM 1 *A supply chain intermediary is viable if she can operate with a transaction cost no more than*

$$(v-s) - W_b - W_s - \frac{\psi^2}{(2-\psi)}(\pi - W_b - W_s) \tag{3.15}$$

Proof: From Proposition 2 we know that the supplier and the buyer would expect from direct bargaining a payoff no less than $(\pi - X_b)$and $\pi - X_s$, respectively. To attract the supplier and the buyer from direct bargaining, a supply chain intermediary must offer an asked price $\acute{p}$ and a bid price $\acute{w}$ that satisfy the following conditions:

$$\begin{aligned} v - \acute{p} &\geq \pi - X_s \\ \acute{w} - s &\geq \pi - X_b \end{aligned} \tag{3.16}$$

Thus, we have

$$\begin{aligned} \acute{p} &\leq v - \pi + X_s \\ &= v - \pi + (\pi - W_b) - \frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s) \\ &= v - W_b - \frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s) \end{aligned}$$

$$\begin{aligned} \acute{w} &\geq \pi - X_b + s \\ &= \pi - [(\pi - W_s) - \frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s)] + s \\ &= W_s + s + \frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s) \end{aligned}$$

Therefore, the intermediary's bid-ask spread has an upper bound as follows:

$$\begin{aligned} \acute{p} - \acute{w} &\leq [v - W_b - \frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s)] \\ &- [W_s + s + \frac{\psi^2}{2(2-\psi)}(\pi - W_b - W_s)] \\ &= (v - s) - W_b - W_s - \frac{\psi^2}{(2-\psi)}(\pi - W_b - W_s) \end{aligned}$$

Moreover, under Bertrand price competition, the market price will equal to marginal cost and the intermediary will earn zero profit. Thus, she must offer a bid-ask spread no more than

$$Min\{K, (v - s) - W_b - W_s - \frac{\psi^2}{(2-\psi)}(\pi - W_b - W_s)\}$$

In order to stay viable (non-negative profit), the intermediary must be able to operate with a transaction cost K no more than the upper bound of the bid-ask spread (the second term). $\diamond$

From the above theorem, and more specifically from (3.15), note that the intermediary needs to be concerned about the supplier and the buyer's bargaining power. As the players' *outside options* increase, it will become increasing difficult for the intermediary to stay viable, and disintermediation will eventually occur. Moreover, the breakdown probability $(1-\psi)$ plays a role. In general, the *higher* the breakdown probability the *easier* it is for the intermediary to stay viable. Specifically, when the breakdown probability is zero ($\psi = 1$), the intermediary must offer a transaction cost no more than $(v - s - \pi)$. When the breakdown probability is 1 ($\psi = 0$), she may offer a transaction cost up to $(v - s - W_b - W_s)$.

The above analysis provides the following insights concerning supply chain intermediation:

> When both the supplier and the buyer are in weak bargaining positions (limited outside options), or when direct trade is expected to be volatile (as characterized by the breakdown probability), intermediated trade will be desirable. Conversely, when either the supplier or the buyer is in a strong bargaining position, or when direct trade is expected to be stable, disintermediation is likely to occur.

Note that the above insights are derived entirely from marginal cost analysis under complete information, and no consideration are given concerning information asymmetry. This is the subject of discussion in the remainder of the chapter.

5. Bilateral Bargaining with Incomplete Information

The supply chain intermediary theory takes the viewpoint that supplier-buyer interaction could be either direct or intermediated. If the interaction is direct, it can be modelled explicitly as a bargaining process. If it is intermediated, the intermediary must convince the players that they are not worse off than they would be with direct bargaining. Thus, the bargaining theoretic analysis does not suggest that every supplier-buyer negotiation is actually taking place as a bilateral bargaining game. Rather, the bargaining-theoretic outcomes provide the rationale for the third-party intermediary to perform her intermediation functions. Specifically, the intermediary is to carry out the expected bargaining outcome via an efficient mechanism, while eliminating the needs for bilateral bargaining to actually take place. In Sections 3 and 4 we combine the theoretic foundation established by Spulber (1999) and Rubinstein (1982) to define a posted-price model of the supply chain intermediary theory. In this model, the intermediary posts the bid-ask spread, and the trade takes place if and only if the buyer and the supplier agree to the ask and bid prices, respectively. To establish the bid-ask spread, the intermediary must offer prices such that the players are no worse off than bargaining directly with one another. The Rubinstein (1982) model allows us to consider a richer set of bargaining parameters such as bargaining power, breakdown probability, etc. This analysis is based entirely on marginal costs, which is sufficient if we assume the players and the intermediary have complete information. We demonstrate that the bargaining power of supply chain participants determines the nature of their interactions. We show that players' relative bargaining power could be used to characterize when an intermediated trade is viable and when disintermediation is likely.

In this section, we consider the case when players are subject to asymmetric information, i.e., each player may hold private information on her valuation of the object, her outside options, or her quality level/expectation, which directly influence the bargaining process. Specifically, we are interested in the case where the supplier holds private information on her opportunity cost s, and the buyer holds private information on her willingness to pay level v. Acting on this information, the supply chain intermediary establishes intermediated trade via a mechanism. We introduce the analytic framework established by Myerson (1982), and Myerson and Satterthwaite (1983) that lays out the foundation for intermediated trades under incomplete information. We then introduce potential research topics using this perspective.

There is a significant and growing literature on bargaining with incomplete information. For the alternating-offer bargaining game described above, the offer and counter offers not only express a player's willingness to settle on the deal, they also serve as signals by which the players communicate their private information. Such signals may not be truthful as both parties may have incentive to distort the signal if doing so could increase their gains. Earlier literature in this area uses the notion of a sequential equilibrium due to Kreps and Wilson (1982) by reducing the bargaining situation to Harsanyi's (1967) game with imperfect information. To further refine the notion of sequential equilibrium in bargaining, Rubinstein (1985a,b)Rubinstein, 1985a; Rubinstein, 1985b introduces the alternating-offer model with incomplete information. He shows that many sequential equilibria may exist, and he defines unique equilibrium outcomes by adding conjectures on the way players rationalize their opponents' bargaining power.

5.1 The Basic Setting

We consider a one-buyer, one-supplier basic model where the players could either trade through an intermediary, or via a direct matching market (their outside option). The players hold private information on their costs, established based on their respective outside options. The *supplier* holds private information on her opportunity cost $\tilde{s}$, which takes values on the interval $[s_1,s_2]$ with a prior probability density function $f(s)$, and cumulative distribution function $F(s)$. Similarly, the *buyer* holds private information on her willingness to pay level $\tilde{v}$, taking on the interval $[v_1,v_2]$, with cumulative distribution G, and density g. Each player knows her own valuation at the time of trade, but considers the other's valuation a random variable, distributed as above.

In competition with the players' outside options, the intermediary must offer an intermediated trade that is "more attractive" to the buyer and the supplier. The intermediary is subject to the same information asymmetry in the market as the market participants, however, the intermediary has two main advantages: (1) she has access to aggregate information gained by dealing with multiple buyers and suppliers over time, and (2) she has the freedom to design an intermediated trading mechanism that taxes, subsidizes, or calls off individual transactions. The latter is important due to the *impossibility theory* by Vickrey (1961), which states that it is impossible to design a mechanism that satisfies incentive compatibility, budget balanceness, and ex post Pareto efficiency at the same time. Since the intermediary does not need to balance the budget in every single transaction as is required in a direct matching market, Myerson and Satterthwaite (1983) show that it is possible to design an incentive compatible mechanism that is ex post efficient. For instance, a profit maximizing intermediary could tax the market by setting a bid-ask spread, rejecting an unprofitable trade, or subsidizing the trade while achieving budget balance (and profit) over the long run.

By the *revelation principle* (Section 3.2), it is sufficient to consider an incentive compatible direct mechanism. In other words, regardless of the mechanism constructed by the intermediary, given the equilibrium of the mechanism, we can construct an equivalent incentive compatible direct mechanism, where the buyer and the supplier report their respective valuations to the intermediary, and the intermediary determines if the trade is to take place. If so, she determines the buyer's payment and the suppliers' revenue. Otherwise, the players take their outside options in a direct matching market. Let $\Gamma(\beta, p, w)$ represents the direct revelation mechanism, where $\beta(s, v)$ is the probability that the trade will take place, $p(s, v)$ is the expected payment to be made by the buyer to the intermediary (the asked price), and $w(s, v)$ is the expected payment from the intermediary to the supplier (the bid price), where s and v are the valuations given by the supplier and buyer, respectively. As mentioned above, the intermediary is aware of the buyer and the supplier's outside options as random variables characterized by distributions G and F, respectively. Based on this information the intermediary establishes the buyer's virtual willingness to pay $\Psi_b(v)$ as follows:

$$\Psi_b(v) = v - \frac{1 - G(v)}{g(v)} \tag{3.17}$$

Similarly, the intermediary establishes the supplier's virtual opportunity cost $\Psi_s(s)$ as follows:

$$\Psi_s(s) = s + \frac{F(s)}{f(s)} \tag{3.18}$$

Given a direct mechanism $\Gamma(\beta, p, w)$, we define the following quantities. The expected payment from the buyer to the intermediary (given that her willingness-to-pay level $\tilde{v} = v$) is as follows:

$$\tilde{p}(v) = \int_{s_1}^{s_2} p(\tau_s, v) f(\tau_s) d\tau_s \tag{3.19}$$

The probability for the buyer to complete the trade given that her opportunity cost $\tilde{v} = v$ is

$$\tilde{\beta}_b(v) = \int_{s_1}^{s_2} \beta(\tau_s, v) f(\tau_s) d\tau_s \tag{3.20}$$

Similarly, the supplier's expected payment from the intermediary given that her opportunity cost $\tilde{s} = s$ is as follows:

$$\tilde{w}(s) = \int_{v_1}^{v_2} w(s, \tau_b) g(\tau_b) d\tau_b \tag{3.21}$$

The probability for the supplier to complete the trade given that her opportunity cost $\tilde{s} = s$ is:

$$\tilde{\beta}_s(s) = \int_{v_1}^{v_2} \beta(s, \tau_b) g(\tau_b) d\tau_b \tag{3.22}$$

Thus, from (3.19) to (3.22), the buyer's and the supplier's expected gain from the intermediated trade can be defined as follows:

$$\pi_b(v) = v\tilde{\beta}_b(v) - \tilde{p}(v) \tag{3.23}$$
$$\pi_s(s) = \tilde{w}(s) - s\tilde{\beta}_s(s) \tag{3.24}$$

The direct mechanism Γ is said to be *incentive compatible* if reporting the truthful valuation is the preferred strategy for the players:

$$\pi_b(v) \geq v\tilde{\beta}_b(\acute{v}) - \tilde{p}(\acute{v}), \ \forall v, \acute{v} \in [v_1, v_2] \tag{3.25}$$
$$\pi_s(s) \geq \tilde{w}(\acute{s}) - s\tilde{\beta}_s(\acute{s}), \ \forall s, \acute{s} \in [s_1, s_2] \tag{3.26}$$

In other words, there is no incentive for the players to report $\acute{v}$ and $\acute{s}$ when their true valuations are v and s, respectively. The mechanism is said to be *individually rational* if it offers each player an expected gain that is non-zero.

$$\pi_b(v) \geq 0, \ \forall v, \acute{v} \in [v_1, v_2] \tag{3.27}$$
$$\pi_s(s) \geq 0, \ \forall s, \acute{s} \in [s_1, s_2] \tag{3.28}$$

5.2 The Direct Revelation Mechanism

In the general framework of supply chain intermediation (Section 3.2), an intermediary can be characterized in a mechanism design framework using the *revelation principle*, requiring the specification of a direct revelation mechanism that is *individually rational, incentive compatible,* and *ex post efficient.* We know that any Bayesian-Nash equilibrium of any trading game with intermediary can be simulated by an equivalent incentive compatible direct mechanism. Following the supply chain intermediary framework we may specify intermediation under bilateral bargaining with incomplete information as follows:

Step 1. To the intermediary, the buyer reveals her valuation, her outside options, and her quality requirements, characterized by v. The supplier reveals her valuation, her outside options, and her quality type, characterized by s.

Step 2. The intermediary is subject to the same information asymmetry as the players. Based on the players' reports, and the probability distributions G and F characterizing the asymmetric information, the intermediary constructs a virtual willingness to pay $\psi_b(v)$ for the buyer a virtual opportunity cost $\psi_s(s)$ for the supplier, in reference to the trade at hand.

Step 3. The intermediary specifies a mechanism $\Gamma(\beta, p, w)$ as follows:

1 The intermediary determines $\beta(s, v)$ which specifies if the current trade is to take place:

$$\begin{aligned} \beta(s,v) \quad &= 1, \quad \text{if } \Theta(\Psi_b(v), \Psi_s(s)) \text{ is satisfied} \\ &= 0, \quad \text{Otherwise.} \end{aligned}$$

where $\Theta(x, y)$ specifies the relationship between x and y.

2 If the trade is to take place ($\beta(s, v) = 1$), the intermediary specifies a bid-ask spread (p, w) to maximize her own expected profit

$$\pi_I(s,v) = \int_{v_1}^{v_2} \int_{s_1}^{s_2} (p(\tau_s, \tau_b) - w(\tau_s, \tau_b)) f(\tau_s) g(\tau_b) d\tau_s d\tau_b \tag{3.29}$$

subject to *incentive compatibility*, and *individually rationality* constraints.

3 If the trade is not to take place ($\beta(s, v) = 0$), the players take their outside options.

4 The intermediary must ensure that mechanism $\Gamma(\beta, p, w)$ is ex post efficient.

We further illustrate the construct of this framework in the remainder of this section. The expected gain of trade from the buyer's (supplier's) perspectives is π_b (π_s) as defined in (3.23) ((3.24)). Thus, the total expected gains from trade for the buyer and the supplier are as follows:

$$\int_{v_1}^{v_2} \pi_b(\tau_b) g(\tau_b) d\tau_b + \int_{s_1}^{s_2} \pi_s(\tau_s) f(\tau_s) d\tau_s \tag{3.30}$$

By definition, the total expected gain from trade is as follows:

$$\pi_T = \int_{v_1}^{v_2} \int_{s_1}^{s_2} (\tau_b - \tau_s) \beta(\tau_s, \tau_b) f(\tau_s) g(\tau_b) d\tau_s d\tau_b \tag{3.31}$$

Since the expected gains for the buyer and supplier must equal to the expected gains from trade minus the expected net profit to the intermediary, we have the following relationship.

$$\pi_T - \pi_I = \int_{v_1}^{v_2} \pi_b(\tau_b) g(\tau_b) d\tau_b + \int_{s_1}^{s_2} \pi_s(\tau_s) f(\tau_s) d\tau_s \tag{3.32}$$

Furthermore, Myerson and Satterthwaite (1983) presents the following important theorem:

THEOREM 2 *For any incentive-compatible mechanism with an intermediary, $\tilde{\beta}_s(s)$ is nonincreasing, $\tilde{\beta}_b(v)$ is nondecreasing, and*

$$\begin{aligned} \pi_I + \pi_b(v_1) + \pi_s(s_2) &= \pi_I + \min_{v \in [v_1, v_2]} \pi_b(v) + \min_{s \in [s_1, s_2]} \pi_s(s) \\ &= \int_{v_1}^{v_2} \int_{s_1}^{s_2} (\Psi_b(\tau_b) - \Psi_s(\tau_s)) \beta(\tau_s, \tau_b)) f(\tau_s) g(\tau_b) d\tau_s d\tau_b \end{aligned}$$

To streamline the discussion we will only outline the main component of the proof as follows. First of all, by incentive compatibility (3.25) and (3.26), it is straightforward to show that $\tilde{\beta}_s(s)$ is nonincreasing, $\tilde{\beta}_b(v)$ is nondecreasing. Furthermore, from relationship (3.32), we have

$$\begin{aligned} & \int_{v_1}^{v_2} \int_{s_1}^{s_2} (\tau_b - \tau_s) \beta(\tau_s, \tau_b) f(\tau_s) g(\tau_b) d\tau_s d\tau_b \\ = \; & \pi_I + \int_{v_1}^{v_2} \pi_b(\tau_b) g(\tau_b) d\tau_b + \int_{s_1}^{s_2} \pi_s(\tau_s) f(\tau_s) d\tau_s \\ = \; & \pi_I + \pi_b(v_1) + \int_{v_1}^{v_2} \int_{v_1}^{\tau_2} \tilde{\beta}_b(\tau_b) d\tau_b f(\tau_2) d\tau_2 \\ & + \pi_s(s_2) + \int_{s_1}^{s_2} \int_{\tau_1}^{s_2} \tilde{\beta}_s(\tau_s) d\tau_s f(\tau_1) d\tau_1 \\ = \; & \pi_I + \pi_b(v_1) + \pi_s(s_2) + \int_{s_1}^{s_2} F(\tau_s) \tilde{\beta}_s(\tau_s) d\tau_s + \int_{v_1}^{v_2} G(\tau_b) \tilde{\beta}_b(\tau_b) d\tau_b \\ = \; & \pi_I + \pi_b(v_1) + \pi_s(s_2) \\ & + \int_{v_1}^{v_2} \int_{s_1}^{s_2} (F(\tau_s) g(\tau_b) + (1 - G(\tau_b) f(\tau_s)) \beta(\tau_s, \tau_b) d\tau_s d\tau_b \end{aligned} \tag{3.33}$$

Thus, we have the following relationship:

$$\begin{aligned} & \pi_I + \pi_b(v_1) + \pi_s(s_2) \\ = & \int_{v_1}^{v_2} \int_{s_1}^{s_2} (\tau_b - \tau_s)\beta(\tau_s, \tau_b) f(\tau_s) g(\tau_b) d\tau_s d\tau_b \\ & - \int_{v_1}^{v_2} \int_{s_1}^{s_2} (F(\tau_s) g(\tau_b) + (1 - G(\tau_b)) f(\tau_s)) \beta(\tau_s, \tau_b) d\tau_s d\tau_b \end{aligned}$$

Rewriting the above relationship using the definition of $\Psi_b(.)$ and $\Psi_s(.)$ in (3.17) and (3.18) gives us the equation stated in the theorem.

A mechanism is ex post efficient iff the buyer gets the object whenever her valuation v is higher than the supplier's cost s, otherwise the trade is not taking place. Using Theorem 2, Myerson and Satterthwaite (1983) shows that it is possible to construct an ex post efficient mechanism so long as the trade is subsidized by an intermediary as needed. Specifically,

$$\pi_I + \pi_b(v_1) + \pi_s(s_2) = - \int_{v_1}^{s_2} (1 - G(\tau)) F(\tau) d\tau \tag{3.34}$$

Thus, $\int_{v_1}^{s_2} (1 - G(\tau)) F(\tau) d\tau$ is the minimum subsidy required from the intermediary. However, a profit-minded intermediary may want to optimize her profit over a longer time horizon, or design a trading mechanism that would maximize her profit in each individual trade. The former requires enhanced knowledge of the market which presents an interesting research topic to be discussed further. The latter could be done by a mechanism which only allow *profitable* (while individually rational) trades to take place. We describe the construct of such a mechanism in the following.

With Theorem 2, we may rewrite the intermediary's profit function as follows:

$$\pi_I = \int_{v_1}^{v_2} \int_{s_1}^{s_2} (\Psi_b(\tau_b) - \Psi_s(\tau_s)) \beta(\tau_s, \tau_b)) f(\tau_s) g(\tau_b) d\tau_s d\tau_b - \pi_b(v_1) - \pi_s(s_2) \tag{3.35}$$

Based on the supply chain intermediation framework outlined above, the intermediary devises a direct mechanism $\Gamma(\beta, p, w)$ to maximize her profit (3.35), subject to incentive compatibility and individual rationality. First, the intermediary must determine $\beta(s, v)$ which specifies whether the trade is to take place given the reported s, v and her knowledge of their virtual opportunity costs and virtual willingness to pay. Given the simple form of the profit function (3.35) it is straightforward to find a profit maximizing β subject to individual rationality as follows:

$$\begin{aligned} \beta(s, v) &= 1, \quad \text{if } \Psi_b(v) \geq \Psi_s(s) \\ &= 0, \quad \text{Otherwise.} \end{aligned} \tag{3.36}$$

and $\pi_b(v_1) = \pi_s(s_2) = 0$. In other words, we simply define the condition $\Theta(\Psi_b(v), \Psi_s(s)) \equiv \Psi_b(v) \geq \Psi_s(s)$. Moreover, while the intermediary satisfies the individual rationality constraint she offers no additional surplus to the players. Under this mechanism the intermediary's profit is determined by the difference between the buyer's virtual willingness to pay and the supplier's virtual opportunity cost. If the trade is to take place (i.e., $\Psi_b(v) \geq \Psi_s(s)$), the intermediary must specify an asked price $p(s,v)$ and a bid price $w(s,v)$ that satisfy the incentive compatibility constraints (3.25) and (3.26). From Theorem 2, it can be shown that if $\Psi_b(.)$ and $\Psi_s(.)$ are monotone functions, one possible solution is to set $p(s,v) = v_1$ and $w(s,v) = s_2$. In other words, to attract the players from their outside options to the intermediated trade, the intermediary asks the lowest willingness to pay level the buyer could have quoted, while paying the supplier the highest possible opportunity cost. Of course, in order for the trade to occur in the first place, it must be the case that $\Psi_b(v_1) \geq \Psi_s(s_2)$. We now state the following theorem (Myerson and Satterthwaite (1983)).

THEOREM 3 *Suppose* $\Psi_b(.)$ *and* $\Psi_s(.)$ *are monotone increasing functions in* $[v_1, v_2]$ *and* $[s_1, s_2]$, *respectively. Then among all individually rational mechanisms, the intermediary's expected profit is maximized by a mechanism in which the trade takes place iff* $\Psi_b(\tilde{v}) \geq \Psi_s(\tilde{s})$.

In essence, to maximize her own profit the intermediary must restrict the trade to "profitable" situations, as indicated by the difference between the buyer's virtual willingness to pay and the supplier's virtual opportunity cost. For instance, suppose $\tilde{s}$ and $\tilde{v}$ are both uniformly distributed on the unit interval. Then, based on the above mechanism the trade takes place if and only if $\Psi_b(\tilde{v}) = 2\tilde{v} - 1 \geq 2\tilde{s} = \Psi_s(\tilde{s})$. Or equivalently, $\tilde{v} - \tilde{s} \geq \frac{1}{2}$, i.e., the trade takes place iff the buyer's valuation exceeds the supplier's valuation by $\frac{1}{2}$.

The insights provided by the above analysis is important in that it illustrates another important role played by the supply chain intermediary. In theory, the intermediary must subsidize trade as needed, but it is possible for the intermediary to regulate trades based on the players' virtual valuations such that only trades expected to be profitable are actually taking place. Note that under the criteria specified in (3.36) the intermediary's profit (based on (3.35)) is always non-negative. In other words, one way for the intermediary to manage is by regulating when the trade is to take place, while never sponsoring any trade that she is expected to subsidize. However, this results in a fairly conservative policy for intermediated trade, e.g., in the above example, the buyer's valuation must exceed the supplier's by $\frac{1}{2}$. An important extension for this line of research is to model the situation where the intermediary subsidizes a certain unprofitable trades with the goal of maximizing gains over a longer horizon.

6. Multilateral Trade with Incomplete Information

Our analysis has so far focused on the role of intermediary in bilateral bargaining situations. We now turn our attention to multilateral trades. In the supply chain, multilateral trade could occur in at least two different settings. First, in a **vertically integrated** setting, a pre-established supply chain structure dictates the set of suppliers a wholesaler deals with, or the set of retailers a supplier sells to. What is left to be determined is the particular term of trade (e.g., price, quality, delivery date). At any one time, a supplier may face a particular set of buyers. In this setting, the intermediary creates value by devising efficient mechanisms that help the supplier to elicit willingness to pay information from the buyers and to identify the most lucrative trade. Similarly, in a buyer-centric environment, the intermediary may devise mechanisms that help the buyer to elicit cost information from a preestablished set of suppliers, identifying the most desirable supplier for the trade. In Section 6.1, we characterize multilateral trade with vertical integration using the basic framework of Myerson (1981) and Bulow and Roberts (1989). We will show that from the perspective of supply chain intermediation, this multilateral trading environment is directly linked to the bilateral bargaining framework established before.

The second setting is in a **matching markets**. In this setting, there is no preestablished supply structure, the buyers and suppliers come to a central exchange (e.g., an eCommerce site, a procurement auction) and the intermediary functions as a coordinator of the exchange. A matching market emerges since it may be costly for the buyers and the suppliers to seek out each other directly. However, there are costs involved in setting up a central place (e.g., infrastructure costs) and there are variable costs associate with the transactions (e.g., communication of price, quality, and product specifications). The intermediary creates value by continuously shaping the portfolio of suppliers (customers) that best match the needs (market potential) of the customers (suppliers). The intermediary makes a profit by creating a nonzero bid-ask spread which clears the market. In Section 6.2, we characterize the role of an intermediary in multilateral trade with markets using the framework by McAfee (1992). Similarly, from the viewpoint of supply chain intermediation, the model associated to matching markets is directly linked to the bilateral bargaining model.

6.1 Multilateral Trade with Vertical Integration

In this section, we characterize the role of intermediary in multilateral trades where one supplier faces multiple buyers or one buyer faces multiple suppliers. Without the lost of generality, we consider a supplier facing m buyers so that $M = (1, ..., m)$. The trade under consideration consists of one particular bundle of goods and services that can be considered a single object. The intermediary faces a mechanism design problem with the goal of eliciting buyers' willingness to pay for the object. The supplier's opportunity cost s is common knowledge. Each buyer i holds private information about her valuation $v_i \in [a_i, b_i]$ that is known to the others in the form of distribution function $G_i(v_i)$ and density $g_i(v_i)$. Each buyer i holds a vector of value estimates $v_{-i} = (v_1, ...v_{i-1}, v_{i+1}, ..., v_m)$ for other buyers. All players are influenced by other buyers' valuations, which result in a quasi-linear valuation $u_i(v)$ for each buyer i. This problem has been examined extensively in the context of optimal auctions (c.f., Myerson 1981; Maskin and Riley 1984; Milgrom and Weber 1982). Riley and Samuleson (1981) shows that for a broad family of auction rules, expected seller (supplier) revenue is maximized if the seller announces a certain reserve price (the minimum bid she would accept). They show that this reserve price is independent of the number of buyers and it is strictly greater than the supplier's opportunity cost s. Myerson (1981) proposes the optimal auction design problem: the supplier chooses, among all possible mechanisms, one that would maximize her expected net revenue. This perspective is useful in that it helps us to define the role of the intermediary in the one-supplier, multiple-buyer setting. As before, it is sufficient to consider an incentive compatible direct mechanism that will carry out the trade. To the intermediary, the supplier reports her opportunity cost s, and each buyer i reports her valuation v_i. Thus, the intermediary holds a vector of value estimates $v = (v_1, ..., v_m)$. The intermediary establishes the buyer's virtual willingness to pay $\Psi_i(v_i)$ as follows:

$$\Psi_i(v_i) = v_i - \frac{1 - G_i(v_i)}{g_i(v_i)} \tag{3.37}$$

Since the supplier's opportunity cost s is known, the intermediary establishes the supplier's opportunity cost $\Psi_s(s) = s$. However, the intermediary may announce a reserve price $u_s(v)$ based on her knowledge of the vector v and that $u_s(v) \geq \Psi_s(s) = s$. It may be convenient to think that the intermediary determines a reserve price for the object at $u_s(v)$, and she submits a bid of $u_s(v)$ such that if none of the bids received from the buyers are above $u_s(v)$, the intermediary keeps the object (the trade fails to take place).

Let $\Gamma(\beta, p, w)$ represents the direct revelation mechanism, where $\beta_i(v)$ is the probability that buyer i will get the object, $p_i(v)$ is the expected payment from buyer i to the intermediary, and $w(v)$ is the expected payment from the intermediary to the supplier. Given mechanism $\Gamma(\beta, p, w)$, knowledge of her own valuation v_i, and other bidders $j \neq i$ valuations in terms of $g_j(v_j)$ buyer i's expected gain from the trade is as follows:

$$\pi_i(\beta, p, v_i) = \int_{T_{-i}} (u_i(v)\beta_i(v) - p_i(v))g_{-i}(\tau_{-i})d\tau_{-i} \tag{3.38}$$

where $d\tau_{-i} = d\tau_1, .., d\tau_{i-1}, d\tau_{i+1}, ..., d\tau_m$ and $T_{-i} = [a_1, b_1] \times ...[a_{i-1}, b_{i-1}] \times [a_{i+1}, b_{i+1}] \times ...[a_m, b_m]$. Similarly, the intermediary's expected gain for the trade as follows:

$$\pi_I(\beta, p, w) = \int_T [u_s(\tau)(1 - \sum_{j=1}^{m} \beta_j(\tau)) + \sum_{j=1}^{m} (p_j(\tau))] g(\tau) d\tau \qquad (3.39)$$

where $d\tau = d\tau_1, ..., d\tau_m$ and $T = [a_1, b_1] \times ... \times [a_m, b_m]$. The intermediary is to maximize (3.39) subject to the following constraints:
individual rationality:

$$\pi_i(\beta, p, v_i) \geq 0 \;\; \forall i \in M \qquad (3.40)$$

incentive compatibility:

$$\pi_i(\beta, p, v_i) \geq \pi_i(\beta, p, \acute{v_i}) \;\; \forall v_i, \acute{v_i} \in [a_i, b_i] \qquad (3.41)$$

(where $\acute{v_i}$ is the valuation reported by buyer i) and the probability conditions:

$$\beta_i(v) \geq 0 \;\text{ and} \sum_{j=1}^{m} \beta_i(v) \leq 1, \;\; \forall i \in M \;\; \forall v \in T \qquad (3.42)$$

Using similar techniques as described in the bilateral bargaining analysis (Section 5), we may rewrite the intermediary's maximization function similar to that of (3.35) as follows:

$$\pi_I(\beta, p) = \int_T (\sum_{i \in M} (\Psi_i(v_i) - \Psi_s) \beta_i(\tau)) g(\tau) d\tau - \sum_{i \in M} \pi_i(\beta, p, v_i) \qquad (3.43)$$

Similar to the bilateral case, the intermediary could satisfy the individual rationality constraint by offering no additional surplus to the players, i.e.,

$$\sum_{i \in M} \pi_i(\beta, p, v_i) = 0, \psi_s = w = s. \qquad (3.44)$$

Thus, the intermediary's profit is determined by the difference between the buyers' virtual willingness to pay and the supplier's opportunity cost. If the trade is to take place, there must be at least one buyer i such that $\Psi_i(v_i) \geq \Psi_s = s$). The intermediary could ensure that this is the case by stating a reserve price $u_s(v) \geq s$. It can be shown that if $\Psi_i(v_i)$ is a monotone strictly increasing function of v_i, for every $i \in M$, one possible solution to the above auction maximization problem is as follows:

$$\begin{aligned} \beta_i(v) \;\; &= 1, \;\; \text{if } \; \Psi_i(v_i) = \max_{j \in M} \Psi_j(v_j) \geq u_s(v) \\ &= 0, \;\; \text{Otherwise.} \end{aligned} \qquad (3.45)$$

In other words, the intermediary offers the object to the buyer with the highest virtual valuation $\Psi_i(v_i)$ so long as it is above the reserve price. While the above model was developed in the context of auction optimization, it provides a general framework of analysis for multilateral trade with vertical integration. Similar to the bilateral bargaining case, the intermediary plays the important role of regulating the trade such that it is profitable. Moreover, the intermediary may screen out buyers by setting the reserve price, i.e., buyers whose willingness to pay $v_i < u_s(v)$ has no incentive to participate in the trade. Since the intermediary only need to pay the supplier her opportunity cost s, she could generate profit from the difference $(u_s(v) - s)$, where $u_s(v)$ represents her knowledge of the market.

An important insight from the above analysis is that the intermediary matches the supplier with the buyer with the highest virtual willingness to pay, which may not be the buyer with the highest willingness to pay. This is because Myserson's model assumes asymmetric buyers (i.e., v_i's are draw from independent, but not necessarily identical distributions). Bulow and Roberts (1989) offers an insightful interpretation of *virtual willingness to pay* as follows.

Define the X axis as the probability that the buyer's value exceeds a certain value, $1-G_i(v_i) = q$, and the Y axis as value v. For each buyer i, graph the inverse of her cumulative distribution function G_i (where $G_i(a_i) = 0, G_i(b_i) = 1$) (see Figure 3.3). This represents the buyer's demand curve. The buyer's revenue is qv_i, where $v_i = G_i^{-1}(1-q)$. From the demand curve for each buyer, we may compute the buyer's marginal revenue as follows, i.e.,

$$\begin{aligned}
\frac{dq \cdot v_i}{dq} &= \frac{dqG_i^{-1}(1-q)}{dq} \\
&= G_i^{-1}(1-q) + \frac{dG_i^{-1}(1-q)}{dq} \\
&= G_i^{-1}(1-q) - \frac{q}{g_i(G_i^{-1}(1-q))} \\
&= v_i - \frac{1-G_i(v_i)}{g_i(v_i)}
\end{aligned}$$

Clearly, the buyer's marginal revenue is identical to her virtual valuation Ψ_i (3.37). In setting up the reserve price, the intermediary may be thought of as a buyer with a value and marginal revenue of zero. Thus, the intermediary offers the object to the buyer with the highest marginal revenue so long as it is positive (above her own).

Using the above interpretation, Bulow and Roberts (1989) show that Myerson's optimal auction problem can be described as the third-degree monopoly price discrimination problem where instead of m independent bidders, there are m independent markets. The monopolist allocates the object(s) to the

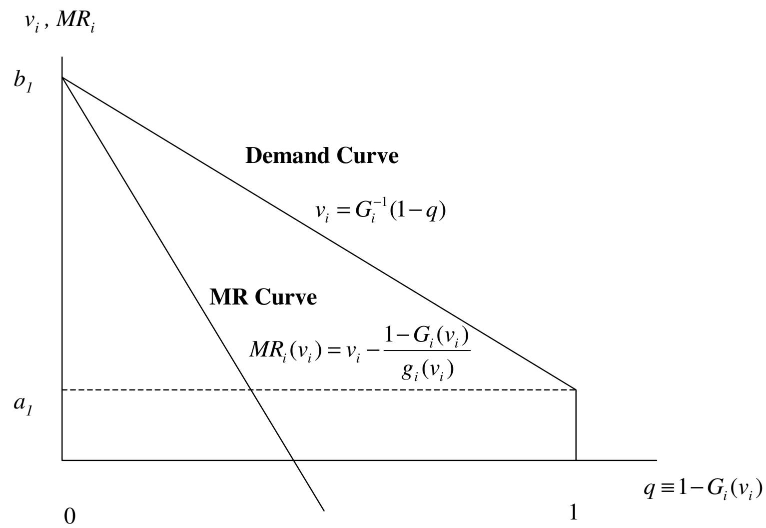

Figure 3.3. Interpretation of the Bidder i's Virtual Willingness to Pay (Bulow and Roberts (1989)

buyer(s) with the highest marginal revenue. The only crucial assumption being made here is that marginal revenue is downward sloping in quantity within each market. Moreover, in the context of bilateral bargaining with incomplete information (5), Bulow and Roberts (1989) offer a similar interpretation for the buyer's *virtual willingness to pay* Ψ_b (3.17) and the supplier's *virtual opportunity cost* Ψ_s (3.18), showing that Ψ_b and Ψ_s are equivalent to the buyer's *marginal revenue* and the supplier's *marginal cost*, respectively. Thus, the intermediary's function is to make sure the trade only takes place when the (buyer's) *marginal revenue* is greater than the (supplier's) *marginal cost*.

From the above discussion, it is interesting to note that the theoretical underpinning of multilateral trade is directly linked to the bilateral bargaining situation, and both can be interpreted in the context of pricing problem in microeconomics theory.

6.2 Multilateral Trade with Markets

In this section, we further extend the insights derived from bilateral bargaining in a multilateral setting. We introduce a multilateral trading model that captures the basic essence of intermediation in an exchange setting. There are m buyers and n suppliers, each buyer i has a private valuation v_i for a single unit of good, and each supplier j has a privately known cost s_j for the good she sells. It is the common believe of all traders that each buyer's value is distributed according to $G(v)$, and each supplier's cost is distributed according to $F(s)$. A well known form of trading in this environment is a *call market*, which describe the basic operation of the New York Stock Exchange (NYSE). In a call market, the intermediary collects bids from the buyers and offers (asks) from the suppliers, constructs supply and demand curves, determines a market-clearing price, and executes the trade. Several mechanisms have being proposed to model the call market. Wilson (1985) initiated the study of double auction as a means to model multilateral trading with incomplete information. Extending the results from Myerson (1981), Myerson and Satterthwaite (1983), and Gresik and Stterthwaite (1989) he shows that a sealed-tender double action is incentive efficient if the number of traders are sufficiently large. In such a double auction, all trades are made at a single market clearing price. Rustichini et al. (1994) models the call market as a *k-double auction*, where the buyers' bids and the suppliers' offers are aggregated to form (discrete) supply and demand curves. The crossing of their graphs determines an interval $[a, b]$ from which a market clearing price p_0 is defined as $p_0 = (1-k)a + kb$. The choice of $k \in [0, 1]$ defines a specific mechanism. Trades occur among buyers who bid at least p_0 and sellers who offer no more than p_0. Hagerty and Rogerson (1985) discusses a fixed-price mechanism where trades occur among buyer and sellers who indicate their willingness to trade at a fixed-price p_0^*, with traders on the long side of the market randomly given the right to trade.

McAfee (1992) proposes a double auction model that explicitly considers the role of an intermediary who intervenes in the trade and keeps track of supply and demand at asked and bid prices. Like the market specialist in NYSE, the intermediary makes a profit by regulating the trade using a certain mechanism. In the following, we describe this double auction as a direct revelation mechanism.

Step 1. The buyers report their willingness-to-pay to the intermediary, who ranks them as $v_{(1)} \geq v_{(2)} \geq ... \geq v_{(m))}$. Similarly, the suppliers report their opportunity costs and are ranked as $s_{(1)} \leq s_{(2)} ... \leq s_{(n)}$. Where index (i) represents the ith highest valuation buyer or the ith lowest cost supplier. Further, we define $v_{(m+1)} = sup\{v : G(v) = 0\}$ (the lowest possible value) and $s_{(n+1)} = inf\{s : F(s) = 1\}$ (the highest possible cost).

Step 2. The intermediary finds the efficient *trading quantity* $k \leq \min m, n$ satisfying $v_k \geq s_k$ and $v_k + 1 < s_k + 1$.

Step 3. The intermediary determines the *market clearing price* p_0 as follows:

$$p_0 = \frac{1}{2}(v_{(k+1)} + s_{(k+1)}) \tag{3.46}$$

Step 4. To execute the market with budget balanceness, if $p_0 \in [s_{(k)}, v_{(k)}]$, all buyers and suppliers (1) through (k) trade at the market clearing price $p = w = p_0$. The intermediary makes zero profit $(p - w = 0)$. Otherwise, the $k - 1$ highest value buyers and trade with the $k - 1$ lowest cost suppliers, where buyers pay $p = v_{(k)}$ and suppliers receive $w = s_{(k)}$, and the intermediary keeps the total bid-ask spread $(k - 1)(p - w)$.

The final step is key for the intermediary to maintain budget balanceness while making a profit (sometimes) by: (1) charging the buyers a higher price then the sellers receive, i.e., buying at the asked price $w = s_{(k)}$ and selling at the bid price $p = v_{(k)}$, thus creating a profit $(k-1)(p-w) = (k-1)(v_{(k)} - s_{(k)}$, and (2) preventing the least profitable trade (the trade between the lowest value buyer and highest cost seller) from taking place. McAfee (1992) shows that for the direct mechanism described above, it is a dominant strategy for the traders to truthful reporting their valuations. This is important as it eliminates the needs to consider strategic behavior of the traders, which is the a complication found in the double auction analysis.

The simple model above describes the main role of the intermediary in multilateral trading. In addition to coordinating the multilateral exchange, the intermediary designs (bidding) mechanisms for customers and suppliers that reveals their willingness to pay levels and opportunity costs. The intermediary sets bid and asked prices to maximize profit and balances the purchases and the sales. As mentioned above, the intermediary sets up a central place for the suppliers and buyers to trade, while continuously selecting the portfolio of suppliers (buyers) that best match the needs (market potential) of the buyers (suppliers). This selection process occurs naturally in the above mechanism as only (up to) k most efficient trades take place between the most compatible pairs of suppliers and buyers. All buyers with a below threshold willingness-to-pay level and all suppliers with an above threshold opportunity cost will be excluded from the exchange. The above selection function can be further illustrated by the oral double auction described in McAfee (1992).

Milgrom and Weber (1982) describes a variant of the English Auction where the price is posted electronically. All bidders are active at price zero. The price is raised continuously, and a bidder who wishes to remain active at the current price must depress a button. When she releases the button, she is dropped out of the auction. No bidders who has dropped out can become active again. After any bidder withdraws, all remaining bidders know the price at which she drops out. When there is only one bidder left in the room, the auction ends. McAfee (1992) proposes an oral double auction work in a similar fashion, but with multiple buyers and sellers. In the following, we use the oral double auction model to characterize the basic functions of exchange coordination carried out by a market intermediary (see Figure 3.4).

Step 0. Buyers and suppliers enter a central trading space operated by an intermediary. The intermediary keeps track of the state of the system $(m(t), n(t), p(t), w(t))$ in continuous time t; where $m(t)$ and $n(t)$ are the number of active buyers and suppliers, $p(t)$ and $w(t)$ are the bid and asked prices, respectively. At $t = 0$, $m(0) = m$, $n(0) = n$, and the bid and asked prices are set at the most favorable levels, i.e.,

$$\begin{aligned} p(0) &= inf\{v : G(v) > 0\} \\ w(0) &= sup\{s : F(s) < 1\}. \end{aligned} \tag{3.47}$$

The buyers and suppliers may choose to leave the trading space anytime during the process, thus become inactive. An inactive trader can not be active again during the trading process.

Step 1. At any time t during the trading process, the intermediary updates the bid and asked prices based on the number of active buyer and suppliers. Specifically, she raises the bid price at a unit rate if there are more buyers than suppliers; she reduces the asked price at a unit rate if there are more suppliers than buyers, i.e.,

$$\begin{aligned} p^{'}(t) &= 1, \quad \text{if } m(t) \geq n(t) \\ &= 0, \quad \text{if } m(t) < n(t) \\ w^{'}(t) &= 1, \quad \text{if } n(t) \geq m(t) \\ &= 0, \quad \text{if } n(t) < m(t) \end{aligned} \tag{3.48}$$

Step 2. The trading process completes at the first time T when the number of buyers equals the number of suppliers, and the bid price is no less than the asked price, i.e.,

$$\begin{aligned} m(T) &= n(T) \\ p(T) &\geq w(T) \end{aligned}$$

Step 3. The trades take place. The intermediary collects the bid price $p(T)$ from the buyers and pay the asked price $w(T)$ to the suppliers. The intermediary keeps the difference $m(T)(p(T) - w(T))$.

The decision for the buyers and the suppliers are quite simple. They only need to decide whether to stay active in the trade or not. It is a dominant strategy for a buyer with willingness-to-pay of v to remain active in the intermediated trade as long as $v > p(t)$, and for a supplier with opportunity cost s to stay active as long as $s < w(t)$. The above procedure is a stylized implementation of the direct mechanism described earlier. Suppose there are more suppliers than buyers initially entering the intermediated trade ($m \leq n$). The

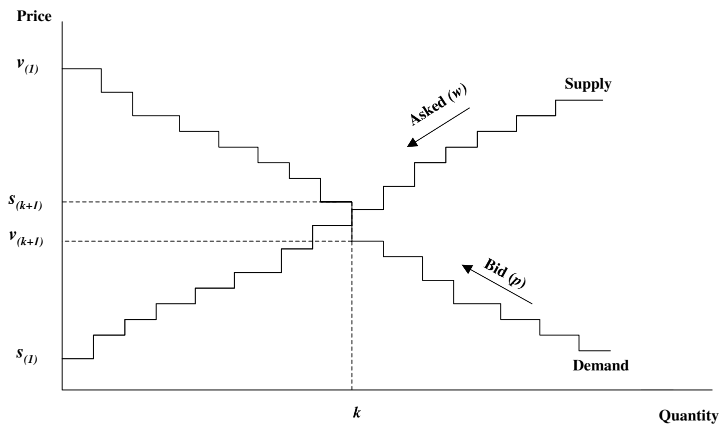

Figure 3.4. Oral Double Auction Proposed by McAfee (1992)

asked price decreases until $n - m$ (highest cost) suppliers drop out. The trading process now continues with the equal number of buyer and suppliers, but $p(t) < w(t)$. If a supplier leaves, asked prices freeze and bid prices rise until a buyer leave. Similarly, if a buyer leaves, bid prices freeze and asked prices decline until a supplier leaves. In this way, the gap between ask and bid prices decrease until $p(t) \geq w(t)$.

The general settings of the double auction assume that any supplier can be matched with any buyer. In the context of industrial procurement, Kalagnanam et al. (2000) propose a double auction mechanism allowing additional "assignment constraints" that specify which bids can be matched with which asks. It is possible that a buyer's demand can be met by the a subset of suppliers, and vice versa. They propose efficient network flow algorithms to find the market clearing allocation which satisfies the assignment constraints. They further examine the case where demand is indivisible. In this case, finding the market clearing allocation requires the solution of a combinatorial optimization problem. For an overview of various aspects of combinatorial auction such as this, please refer to Chapter 7.

7. Related Work in the Supply Chain Literature and Research Opportunities

In this chapter, we explore a modelling paradigm for supply chain coordination using the notion of supply chain intermediary. Our goal is to complement the view offered by the supply chain contracting literature that uses long-term coordination contracts as a primary mechanism to achieve channel efficiency. We propose to look at the problem of supply chain coordination somewhat differently: for any subset of players in the supply chain who desire to establish supplier-buyer relationships, they may choose to do so directly or through some form of intermediation. A transactional intermediary improves operational efficiencies by serving as an intermediate supply chain player or as a third party service provider. An informational intermediary alleviates the effects of information asymmetry by serving as a broker, an arbitrator, or a mediator. An intermediary utilizes a variety of mechanisms such as bilateral contracts, alliances, coalitions, and auctions to facilitate her coordination/arbitration functions. To streamline the thinking, we consider the intermediary a profit-seeking entity. This provides an unambiguous way to divide the system surplus generated from coordination, i.e., after providing the players proper incentives to participate and to truthfully reveal their private information, the intermediary keeps the remainder of the system surplus (if non-negative). Thus, the intermediary's profit is the net surplus from trade minus the transaction costs she has incurred. One may consider an intermediary's "profits" as the performance measure of an intermediated trade. When an intermediated trade is unprofitable, one may infer that either an alternative form of intermediation is needed, or disintermediation may be unavoidable. Since we allow the intermediary to call off the trade, trades where the surplus is insufficient to cover the incentive costs and/or the transaction cost may not take place at all.

We establish the analysis of supply chain intermediation using a bargaining-theoretic framework. We introduce four basic settings: bilateral bargaining with complete information, bilateral bargaining with incomplete information, multilateral trade with vertically integration, and multilateral trade with markets. Each setting captures a different aspect of transactional/informational intermediation. As we have demonstrated in the chapter, the direct-mechanism framework introduced in the context of bilateral bargaining with incomplete information forms the basis for multilateral analysis. This theoretical connection establishes a convenient analytical framework for the study of supply chain intermediaries, thus the study of supply chain coordination.

A steam of research has appeared in the supply chain literature which also considers the use of bargaining theoretic models to expand the view of negotiation and coordination in the supply chain. Chod and Rudy (2003) consider a situation where two firms unilaterally decide on the investment levels on resources (capacity or inventory) based on imperfect market forecasts. As new information becomes available, the firms update their forecasts and they have the option to trade excess resources. Chod and Rudy (2003) formulate this problem as a non-cooperative stochastic investment game in which the payoffs depend on an embedded Nash bargaining game. Deng and Yano (2002) consider the situation where a buyer first orders from the supplier (at the contracted price) before market demand is observed, then places additional orders (at the spot price) after the demand is observed. They consider the setting of the spot price the result of a bargaining process. They show that the players' bargaining power regarding the spot prices depends upon the outcomes of demand. Taylor and Plambeck (2003) argue that writing binding contracts that specify the price (and possibly capacity) prior to the supplier's capacity investment may be difficult or impossible. Instead of formal, court-enforceable contracts, they study informal agreements that are sustained by repeated interaction. These relational contracts are analyzed in as a repeated bargaining game where the buyer's demand and the supplier's capacity are private information. Kohli and Park (1989) analyze quantity discounts as a cooperative bilateral bargaining problem. Instead of the typical setting where the seller dictates the quantity discount scheme, the order quantity and its corresponding price (discount) are determined through seller-buyer negotiation. They show that joint efficiency can be achieved through the bargaining process, and they study the effect of bargaining power on the bargaining outcome. Nagarajan and Bassok (2002) consider a cooperative, multilateral bargaining game in a supply chain, where n suppliers are selling complementary components to a buyer (an assembler). They propose a three-stage game: the suppliers form coalitions, the coalitions compete for a position in the bargaining sequence, then the coalitions negotiate with the assembler on the wholesale price and the supply quantity. They show that each player's payoff is a function of the player's negotiation power, the negotiation sequence, and the coalitional structure. Plambeck and Taylor (2001) consider the situation where two independent, price-setting OEM's are investing in demand-stimulating innovations. The OEMs may outsource their productions to an independent contract manufacturer (CM), and the negotiation of the outsourcing contract is modelled as a bargaining game. They show that the bargaining outcome induces the CM to invest in the system-optimal capacity level and to allocate capacity optimally among the OEMs. In a subsequent paper, Plambeck and Taylor (2002) consider the situation where two OEMs sign quantity flexible (QF) contracts with the CM *before* they invest in the innovation. In case the CM has excess capacity after the demands are observed, the three parties (two OEMs and the CM) bargain over the allocation of this capacity. They shown that this "renegotiation" could significantly increases system profit if it is anticipated in the supply contract. Van Mieghem (1999) considers two asymmetric firms, a subcontractor and a manufacturer, who invest non-cooperatively in capacity under demand uncertainty. After demand is realized, the manufacturer may purchase some of the excess capacity from the subcontractor. He models the problem as a multivariate, multidimensional, competitive newsvendor problem. He argues that ex ante contracts may be too expensive or impossible to enforce, while the supplier's investments (in quality, IT infrastructure, and technology innovation) may be non-contractible. Thus, he analyzes *incomplete contracts* Hart and Moore, 1988 where the players leave some contract parameters unspecified ex ante while agreeing to negotiate ex post. Modelled as a bilateral bargaining game, the incomplete contract allows the consideration of the player's bargaining power. Anupindi et al. (2001) consider a decentralized distribution system with n independent retailers. Facing stochastic demands, the retailers may hold stocks locally and/or at centralized locations. Each retailer chooses her own inventory level based on a certain stocking policy. After demand is realized, the retailers bargain cooperatively over the transshipment of excess inventories to meet additional demands. They propose a cooperative inventory allocation and transshipment mechanism that induces the retailers to choose the Nash equilibrium inventory levels that maximize the system profit.

As discussed throughout the chapter, the viewpoints offered by the supply chain intermediary theory and the bargaining theory could potentially broaden the scope for *supply chain coordination*. In the following, we outline a few research opportunities offered by the proposed paradigm.

Supply Chain Coordination and the Division of Surplus . Most supply chain contracts split the channel surplus arbitrarily, which invariably favor the channel-leader who designs the contract. Bargaining theory offers a generalized view of the negotiation process, taking into account the influence of bargaining power on the division of systems surplus. Both cooperative (c.f., Nagarajan and Bassok 2002) and non-cooperative (c.f., Ertogral and Wu 2001) bargaining games could be used to model the negotiation involved in splitting the channel surplus. In any case, a supply chain intermediary may devise a mechanism (e.g., post a bid and an asked prices) and eliminates the need for bilateral bargaining (contract negotiation) to actually taking place. The bargaining theory and the intermediary theory suggest that the mechanism offered by the intermediary reflects supply chain players' bargaining power. Suppose a supply chain has a retailer significantly more powerful than the manufacturers. One would expect that the power structure is reflected in the bid-ask spread set by the wholesales and distributors. In other words, a supply chain player's bargaining power ultimately determines the offers she receives from the intermediary, thus the share of the system surplus she receives. A variety of supply contracts in the literature (e.g., buy-back, QF, profit-sharing) could be examined based on the players' bargaining power, and new insights could be gained on the actual division of system surplus. While it is quite straightforward to incorporate outside options in the complete information setting (as shown in Section 4), it is significantly more challenging when the players' outside options (therefore bargaining power) are defined endogenously as private information. Moreover, it might be interesting to model the signaling game during the negotiation process where the players choose to reveal a certain portion of their outside options at a certain point in time during the negotiation. Computing Baysian-Nash equilibrium under these conditions are known to be very challenging.

Strategic Supply Chain Design . As suggested earlier in the chapter, we may take the viewpoint of a supply chain integrator who uses intermediaries as a strategic tool to improve overall supply chain design. Suppose a high-tech OEM has a traditional, third party distribution channel for her electronic products. The OEM is interested in developing an Internet channel incorporating the drop-shipping model, i.e., the manufacturer fills customer orders directly without going through intermediaries such as the retailers and distributors. In order to integrate the traditional and the Internet channels, the OEM may have to address issues such as the following: How to configure transactional intermediaries who could support the growth of both traditional and Internet channels? How to configure informational intermediaries who could overcome information asymmetry (e.g., demand, pricing) across and within the channels? How to reintermidate exiting intermediaries in the traditional channel for the integrated channel? What incentives are there to facilitate the transition from traditional to integrated channels? The above example represents opportunities to study strategic supply chain design focusing on placing new intermediaries, disengaging existing intermediaries, evaluating the interdependencies of intemediation/disintermeidation, and assessing the impact of different intermediation strategies to overall supply chain efficiency.

Intermediary to foster Information Sharing . The need for information intermediation arises when supply chain players recognize their limited abilities to share information. For instance, supply chain partnership agreements are typically built on the basis that the buyer desires favorite pricing and responsive supply, while the supplier wants improved demand visibility and stability. However, as discussed earlier in the chapter, the players may not want to share private information such as pricing, quality level, and sourcing strategies, thus a third party auditor is typically called in to monitor the partnership. In this context, the auditor is an informational intermediary who alleviates the inefficiency due to asymmetric information. In fact, the success of any supply chain partnership hinges on the intermediation mechanism used to handle information sharing. The design of such informational intermediation presents significant research opportunities. Suppose the supply chain partners are to develop a joint demand management process, but there is information asymmetry since only the buyer can observe the demand. The demand sharing process may be described as a simple signaling game as follows:

(1) Nature draws demand d_t for period t from a distribution D, (2) the buyer observes d_t and then choose a message $\hat{d}_t$ for the supplier, (3) The supplier observes $\hat{d}_t$ (but not d_t) and use it to determine the production level k_t, (4) The buyer and the supplier each receives a payoff as a function of $d_t, \hat{d}_t$, and k_t. The game repeats for each period t. This signaling game is a dynamic game with incomplete information, and it is known that the perfect Bayesian equilibrium outcome leads to inefficiency. Similar to the bilateral bargaining game with incomplete information, it is possible to develop a direct mechanism such that it is incentive compatible and individually rational for the players to align their demand signals thus avoiding adverse selection. Designing an informational intermediary in this context involves the selection of a payoff function, a demand signaling scheme, and a fundamental understanding of the players' behaviors under perfect Bayesian equilibrium.

Emerging Supply Chain Microstructure It is beneficial to broaden the view of multilateral trade from the discussion in Section 6 to consider the case where the intermediary competes with a direct matching market (c.f., Rubinstein and Wolinsky, 1987; Gehrig 1993), i.e., markets where the supplier and buyer meet directly without any form of intermediation. Thus, a buyer must choose from (1) entering the matching market, in which case she searches and meets the supplier directly and bargain over the price and (2) transacting through an intermediary who offers a bid-ask spread by aggregating price/capacity information from many buyers and suppliers. In the latter case, the buyer may get to choose from competing intermediaries who offer alternative price/performance trade-offs. When the buyer bargains directly with a supplier in the matching market, the bargaining may breakdown since the supplier's capacity may not be sufficient to accommodate the buyer's demands, or the buyer's demands may not be sufficient to justify the supplier's investment on capacity. When the buyer enters an intermediated trade, the intermediary may be able to increase the probability of a successful trade since she possesses aggregated information concerning the buyers and suppliers in the market, and she expects to transact with many buyers and suppliers over time. In general, the buyer chooses to transact with an intermediary when the expected cost of searching and bargaining in the matching market exceeds the intermediary's offer. Given the choice, the buyer transacts with the intermediary who offers the most attractive price/performacne trade-off. The general setting described here allows us to study the microstructure in emerging supply chain environments. For instance, contract manufacturers in the high-tech industry such as Solectron, Flextronics, and Celestica maybe considered emerging intermediaries between the the brand-carrying OEM such as HP, Dell, and Nokia and the upstream supply chain capacity. By consolidating demands from different OEMs, and by investing and developing highly flexible processes, these contract manufacturers are able to realize a much higher utilization on their equipment and, therefore, reduce the unit costs. On the other hand, by consolidating the component procurement for different customers, contract manufacturers are able to enjoy economies of scale from upstream suppliers. Thus, the contract manufactures are intermediaries who could offer the OEMs greater variety of products at a significantly lower cost, while offering the component suppliers greater stability in their demands. However, the contract manufacturers must compete with one another on different price/performance tradeoffs. The key for a contract manufacturer's competitiveness is in her ability to sustain highly flexible processes in a dynamically changing environment of technological innovations. As a result, the price/performance profile of a contract manufacturer changes over time as the technological life-cycle marches over time, leading to a challenging and dynamic research problem.

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