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Competition and Cooperative Bargaining Models in Supply Chains

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Abstract

In the last two decades or so, a significant emphasis of the research literature in operations management has been on the strategic interaction of firms in a supply chain. Individual firms in supply chains make decisions on multiple levers such as capacity, inventory and price, to name a few, that have consequences for the entire supply chain. In modeling strategic interactions, the operations literature has followed the large literature in industrial organization and economics. Competition between firms in a supply chain has largely been modeled using non-cooperative game theory and the associated concepts of equilibrium that predict the outcomes. There are a few key differences between the industrial organization literature and the research in operations management. First of all, the operations literature looks more at operational variables, such as capacity and inventory, as a response to various sources of process uncertainty that any firm faces. The preferences of individual customers, their valuations and the construction of the specific form of the uncertainty is less of a concern (although more

recent literature emphasize this). Second, the findings in the operations literature usually have the objective of improving individual firms' (and supply chains') profits and operational efficiencies rather than one of dictating economic policy. Third, although non-cooperative models are the norm, there is also an underlying emphasis in the operations literature on cooperation between firms in a supply chain to improve the overall profit of the supply chain. This is probably because, unlike the levers traditionally studied in economics, many operational variables in a supply chain are often jointly decided between firms. The goal of this review taps on this last sentiment. We provide an overview of some of the basic multi-firm models studied in supply chain management. We look at how the literature uses non-cooperative game theory to analyze these models. We then look at how some of these models can be analyzed using a cooperative bargaining framework. We compare the modeling tools and the insights one obtains by taking this twofold approach. This process also allows us to discuss a few topics of interest such as the relative channel power of a firm, the relative merits of using a non-cooperative game versus cooperative bargaining to model a supply chain setting, etc. Finally, we conclude this review by exploring some issues that remain unresolved and are topics for future research.

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Modeling and Analyzing Competition

1.1 Introduction

Supply chains often consist of several tiers or echelons, each with one or more firms. In a decentralized multi-tier supply chain, materials (components, products) flow through the system across multiple independent firms until they reach the end-customer. In this process, firms invest in effort (innovation, product development, quality, etc.), build manufacturing capacity, assemble components, store products, and set prices, all of which require managerial decisions which are generally based on each firm's self-serving interest. The structure of supply chains can vary substantially. Some industries are characterized by multiple suppliers producing components that are assembled by a relatively small number of final assemblers, while in others the opposite occurs. Likewise, there is a relatively small number of manufacturers producing consumer goods, but a large number of retailers selling those products to the market. Some of these retailers compete directly in the downstream market, while others are local monopolists. Papers analyzing competition in supply chains restrict attention to a certain portion of the system (e.g., one manufacturer and one retailer, one manufacturer and multiple retailers, multiple suppliers and one buyer or assembler, etc.). Competition in supply chains arises across firms in the same tier (horizontal competition), across firms in different tiers (vertical competition), or both.

In settings with horizontal competition, firms typically make their decisions simultaneously. Their equilibrium decisions are determined by the Nash equilibrium concept [80]. In the OM literature, horizontal competition generally involves competition through inventory availability, innovation or sales effort, quality, products' prices, warranties, or other dimensions of customer service, across firms in the same tier. For example, if a firm lowers its price (or increases inventory availability, sales effort, or its service level), the demand experienced by its competitors is likely to decrease. Vertical interactions are generally governed by one or more leading firms that move first by offering a contract — a natural strategy of interaction between parties — to other firms in the supply chain network. The contract may be as simple as a wholesale price contract. Other commonly studied contracts involve buy-back policies, revenue sharing agreements, quantity discounts, two-part tariffs, vertical price restraints, etc. (We will discuss many of these contracts later in the review.) The sequential timing of decisions leads to a Stackelberg game [59]. The leader makes its decision in anticipation of the decisions made by the followers. The contract sequence is one of the factors that may determine the relative power of firms in the supply chain. We discuss this issue later in this section. Some models in the supply-chain management literature consider a combination of vertical and horizontal competition. For example, a set of competing firms buys a product from a common upstream supplier (manufacturer) or sells complementary products to an assembler. This section reviews a representative set of papers in operations management addressing models of vertical and/or horizontal competition, particularly focused on capacity, inventory, and price competition. The scope of the review is limited to those models of competition as we have counterpart work examining the role of negotiation and cooperative bargaining in such models.

In decentralized supply chains, firms make decisions to optimize their own cost or profit, ignoring the implications of their actions on other firms in the system. That is, firms do not internalize the cost or benefit implied by their decisions. A challenge encountered in these systems consists of structuring the costs and rewards of all the firms to align their objectives with the aggregate supply-chain wide profit — namely, achieve supply-chain coordination. Supply-chain coordination requires modification of firms' incentives. This can be accomplished with contractual arrangements between the parties in the supply chain that allow individual firms to internalize the externalities imposed by their actions on other firms. A vast literature in operations management explores the design and practical applicability of coordinating contracts. This manuscript does not intend to provide a comprehensive review of the literature on supply-chain coordination. We refer the reader to Anupindi and Bassok [4, 5], Lariviere [62], Corbett and Tang [38], Cachon [20], and Li and Wang [66] for reviews on this subject.

We begin this section with a description of what we call the atomic model — one with a single manufacturer or supplier selling to a single retailer. We then consider settings with multiple firms in either the downstream or upstream tier of the supply chain — a distribution and an assembly system, respectively. This is followed by a review of models of competition in more complex supply chain networks and by a discussion of the role of Stackelberg leadership in modeling the firms' relative power in a supply chain.

1.2 The Atomic Model

Let us first look at a setting with vertical competition between a manufacturer selling to a single retailer, as illustrated in Figure 1.1.

A significant set of papers in operations management look at models with exogenous prices to isolate the effects of uncertainty and related inventory decisions. In practice, this applies to a class of products where a retailer has little wiggle room on retail prices, perhaps due to competition. In such settings, the manufacturer sets the terms of the contract (e.g., a wholesale price), based on which the retailer determines a stocking level. Demand is uncertain, so the retailer's purchasing decision involves the solution of a newsvendor problem.

The paper by Lariviere and Porteus [64] focuses on the interaction between a manufacturer and a newsvendor-type retailer in a market with stochastic demand and exogenous retail price. Using

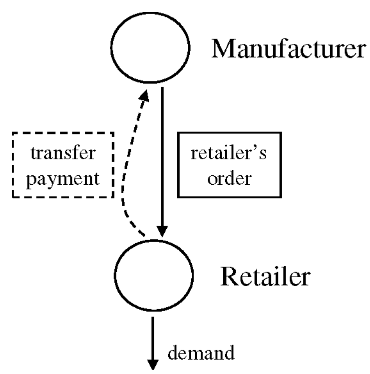

Fig. 1.1 Atomic model.

the Stackelberg framework, the paper examines the efficiency of the decentralized supply chain (as measured by the performance of the decentralized system relative to the centralized optimal profit) and the division of supply chain profit. Demand is assumed to follow a continuous distribution Φ with density ϕ. The manufacturer's marginal production cost is c and the fixed selling price is $r > c$. In the integrated system, the joint profit of the manufacturer and the retailer, as a function of the stocking level y, is given by $\Pi^I(y) = -cy + r\int_0^y \xi\phi(\xi)d\xi + ry(1 - \Phi(y))$. This function is concave in y, with maximizer $y^I = \Phi^{-1}[(r - c)/r]$. Under decentralized control, the retailer faces a similar problem as in the integrated system, but with the wholesale price $w > c$ replacing the production cost c. The retailer's optimal order quantity is $y(w) = \Phi^{-1}[(r - w)/r] < y^I$ — this strictly lower-than-system-optimal order quantity indicates a loss of efficiency due to decentralization. As the Stackelberg leader, the manufacturer chooses the wholesale price to maximize $\Pi^M(w) = (w - c)y(w)$. Since there is a one-to-one correspondence between wholesale price and stocking quantity, the manufacturer equivalently chooses a stocking quantity y to maximize $\Pi^M(y) = w(y)y - cy$, where $w(y) = r(1 - \Phi(y))$. To solve the Stackelberg game, the paper identifies a condition on the stochastic demand function that guarantees the unimodality of the manufacturer's profit. Specifically, the requirement is that the demand distribution belong to the class of distributions with an increasing generalized failure rate, that is, that the generalized failure rate of the distribution Φ, defined as $g(\xi) = \xi\phi(\xi)/(1 - \Phi(\xi))$, be an increasing function of ξ (refer to Lariviere [63] for more details). This finding implies that the optimal retailer stocking quantity in the decentralized system (that itself determines the optimal wholesale price charged by the manufacturer) is the solution to the manufacturer's first-order condition $(1 - \Phi(y))(1 - g(y)) = c/r$. The function $\nu(y) = 1/g(y)$ measures the elasticity of the retailer's order at the stocking level y, that is, the change in the retailer's order from a percent increase (or decrease) in the wholesale price. At the optimal manufacturer wholesale price w^*, both the manufacturer and the retailer earn positive margins $w^* - c$ and $r - w^*$, respectively. This is the "double marginalization" effect [103] that leads to system inefficiency — that is, the total profit in the decentralized system is less than that in the centralized system. A wholesale price higher than marginal cost leads to a lower retailer stocking quantity as compared to the optimal stocking quantity in the centralized system. In this atomic model, even though there are essentially two players differentiated only by their role, we see competition between these two players as they both compete on the margins they make from sales.

A buy-back contract (or returns policy) coordinates the supply chain composed of a single manufacturer selling to a newsvendor, provided that the retail price is exogenous. Under a returns policy, the manufacturer buys all unsold inventory back from the retailer at a given buy-back rate. That is, the wholesale price w is supplemented with a buy-back rate $b < w$ paid by the manufacturer to the retailer at the end of the selling season for all units unsold. Under a returns policy, the retailer's expected profit is given by $\Pi^R(y) = -wy + r\int_0^y \xi\phi(\xi)d\xi + ry(1 - \Phi(y)) + b(y - \int_0^y \xi\phi(\xi)d\xi)$, where the last term represents manufacturer payments for unsold products. The optimal stocking quantity for the retailer is $y(w,b) = \Phi^{-1}[(r - w)/(r - b)]$. As shown in Pasternack [89], an appropriately designed buy-back contract coordinates the supply chain. Moreover, this contract allows for an arbitrary division of the supply-chain profit. A returns policy offers the retailer an incentive to order more by essentially transferring some of the risk associated with demand uncertainty to the manufacturer. See Kandel [56] and Emmons and Gilbert [42] for additional discussion on returns policies.

In the spirit of a returns policy, supply chain coordination in the atomic model can be achieved through a quantity flexibility contract. Under this contract, the newsvendor retailer places an order y with the manufacturer, who commits to providing $y(1+u)$ units to the retailer, with $u \leq 0$. Once demand is realized, the retailer commits to ordering at least $y(1-d)$ units from the manufacturer, with $0 \leq d < 1$. That is, instead of returning unsold units at the end of the selling season, the retailer can cancel a portion of its initial order if demand is low. Taylor [105] shows that, in a supply chain consisting of a manufacturer selling to a single newsvendor retailer, channel coordination can also be achieved with a rebate contract. This contract specifies a payment to the retailer (rebate) for each unit sold beyond a pre-determined target.

When prices are endogenous, the newsvendor retailer selects both a stocking quantity y and a retail price p. Demand is a function of the retail price and is assumed to be of the multiplicative form, i.e., $D(p,\epsilon) = d(p)\epsilon$, or of the additive form, i.e., $D(p,\epsilon) = d(p) + \epsilon$, where $d(p)$ is a deterministic downward sloping function of price and ϵ is a random term, independent of p. (Petruzzi and Dada [91] provide a comprehensive review of results regarding the optimal decisions of a price-setting newsvendor.) Bernstein and Federgruen [14] show that no buy-back contract is capable of coordinating a decentralized system with a price-setting newsvendor, except for a trivial contract in which the wholesale price equals marginal cost and the buy-back rate is set to zero (if the retailer has a positive salvage value, then the buy-back rate must equal the retailer's salvage value). Song et al. [102] examine structural properties of buy-back contracts in a decentralized system with a manufacturer selling to a price-setting newsvendor. The paper considers a Stacklberg setting, with the manufacturer as the leader. Under the assumption of an increasing generalized failure rate, as in Larivere and Porteus [64], and under an assumption on the curvature of $d(p)$, the paper shows that the retailer's stocking and pricing problem has a unique solution. The assumption on $d(p)$ requires that the elasticity $\eta(p) = -p(d'(p)/d(p))$ be increasing in p, $p/\eta(p)$ be monotone and convex, and $p(1 - 1/\eta(p))$ be strictly increasing in p. The assumptions on $d(p)$ guarantee that the retailer's profit is unimodal in p and, together with the increasing generalized failure rate assumption on the distribution of the random term, imply that the retailer's pricing and stocking problem under a given buy-back contract has a unique solution. This enables the authors to derive properties of the manufacturer's profit function and, in turn, characterize the optimal contract parameters. Moreover, the paper identifies conditions on $d(p)$ under which the optimal manufacturer buy-back contract is independent of the demand distribution. Refer to Granot and Yin [49] and Liu et al. [68] for related studies of decentralized supply chains with endogenous price-dependent demand — the former under buy-back contracts and the latter under an ex-ante retailer commitment to a fixed retail price markup.

Revenue-sharing contracts supplement a unit wholesale price with transfer payments that comprise a percentage of the revenues $0 \leq \alpha \leq 1$ generated in the supply chain. These contracts are common, for example, in the video-rental industry. Similar pay-on-production contracts are prevalent in the automobile industry. Cachon and Lariviere [23] study revenue-sharing contracts in supply chains with a supplier selling to one or multiple competing retailers (or any link between two levels in the supply chain). Retailer revenues are determined by its purchase quantities and selling price. The model is quite general, allowing for deterministic or stochastic demand. In a setting with a single retailer, a revenue-sharing contract coordinates the supply chain and the system profit can be arbitrarily divided among firms. In fact, in that setting, a revenue-sharing contract is equivalent to a buy-back contract. A revenue-sharing contract also coordinates a supply chain consisting of competing retailers with exogenously determined prices. Consider a system with n retailers. Let $R_i(q)$ denote the expected revenue of retailer i associated with a vector of stocking levels $q = (q_1, \ldots, q_n)$. $R_i(q)$ is assumed to be decreasing in q_i and $\partial^2 R_i / \partial q_i \partial q_j \leq 0$, that is, inventory at different retailers are substitutes. Letting c_i denote the system's cost associated with producing and selling products to retailer i, the total supply chain profit is $\sum_{i=1}^{n} (R_i(q) - c_i q_i)$. The revenue-sharing contract consists of a wholesale-price w_i, revenue-share α_i pair for each retailer i. The coordinating revenue-sharing contract includes a term that reflects the externalities each retailer imposes on its competitors. In the atomic model, the parameter α in a revenue-sharing contract serves the purpose of allocating the profits between the supplier and the retailer. Cachon and Lariviere [23] state that, "The particular profit split chosen probably depends on the firms' relative bargaining power. As the retailer's bargaining position becomes stronger, one would anticipate [α] increases. As a proxy for bargaining power, each firm may have an outside opportunity profit ... that the firm requires to engage in the relationship."

As indicated, many of the contracts discussed earlier allow for an arbitrary division of the supply chain profit between the manufacturer and the retailer (through the appropriate choice of the contract parameters). In some cases, the terms of the contract are specified a priori by the manufacturer and remain unmovable. In others, the contract adopted in the supply chain is the result of a negotiation process between the parties. This aspect of the contract negotiation is generally ignored in much of the literature that analyzes competition using a non-cooperative game approach. In the next section, we present a cooperative bargaining framework to explore the process of contract negotiation.

A number of papers explore vertical competition in infinite horizon, decentralized supply-chain settings. Cachon and Zipkin [26] study a two-stage decentralized series system. Both firms in the serial system share a portion of the penalties incurred for consumer backorders and independently select the base-stock levels to minimize their own costs. The paper analyzes two games that differ in how firms track their inventory levels — the echelon game, in which firms follow echelon policies (a firm's echelon inventory is its local inventory plus all inventory downstream in the supply chain), and the local game, in which they use local policies — and compares the resulting equilibria. Cachon [21] considers a two-echelon supply chain with one supplier and multiple retailers in which all firms operate under a continuous review inventory policy. All retailers are identical. The supplier's policy parameters impact the retailers' cost functions (e.g., a late retailer shipment may lead to retail backorders), and vice versa. The game between the supplier and the retailers is supermodular, that is, the action set of each firm is a compact lattice and the marginal change in a firm's cost due to an increase in one of its action variables is increasing in any other of its competitors' action variables. The paper shows that, in some settings, the optimal policy in the centralized system arises as a Nash equilibrium. Unlike the papers described earlier, the above models assume away any leadership position induced by the role of the Stackelberg leader and analyze simultaneous competition between the upstream and downstream firms. (Cachon and Zipkin show that endowing one player with Stackelberg leadership in general changes the equilibrium base-stock levels relative to a setting with simultaneous competition.)

In most existing infinite-horizon models of competition in the operations management literature, decisions are made at the beginning of the season once and for all, reducing the complexity involved in modeling the firms' interactions over time. In multi-period settings, decisions made in each period use information from the history of transactions up to that point and anticipate the other firms' reactions to this period's decisions in future periods. These so-called closed-loop games are significantly more complex as the firms' equilibrium decisions need to contemplate the future repercussions of their current actions. Very little work has been done in this area so far, so this remains a research topic of relevance that is worth pursuing. Nevertheless, there has recently been greater interest in multi-period games that explicitly model operational interactions. Parker and Kapuscinski [87] consider a decentralized two-stage serial supply chain with capacity limits. By appropriately setting the salvage value functions, the paper inductively shows that the cost function in each period is separable in a certain domain, in a way that helps ensure the existence of a closed-loop, subgame perfect equilibrium. The equilibrium policy is a modified echelon base-stock policy. The paper also examines the performance of the decentralized system relative to the first-best solution and discusses the need for a coordinating contract.

1.3 Two-Stage Systems with Retailer Competition

In a system with a single manufacturer and a single retailer, supply-chain coordination can also be achieved by using a two-part tariff that involves a wholesale price equal to the production cost and a side payment given by a fixed fee. The manufacturer can collect all profits

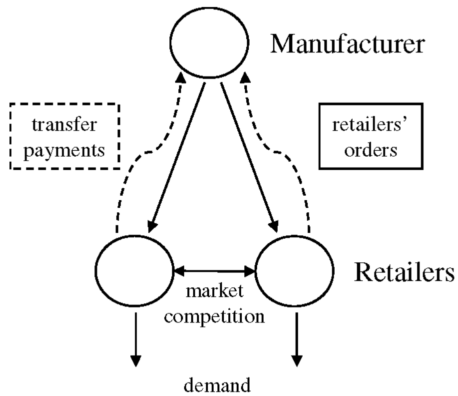

Fig. 1.2 Retailer competition.

through the fixed fee. Therefore, the incentive problem discussed above has a fairly simple remedy. In contrast, in a system with a manufacturer selling to two competing retailers, Krishnan and Winter [60] discuss the presence of two externalities that distort the firms' decisions. Figure 1.2 illustrates this setting.

The vertical externality arises because, as the retail price is increased, the manufacturer collects the wholesale mark-up on a lower quantity sold through the retailer. The horizontal externality arises through the cross-price elasticity of demand between the two retailers. The authors find that a two-part tariff alone cannot coordinate this system — it needs to be complemented with a vertical price floor that restricts the range of retail prices available to the retailers (i.e., a lower bound on the price the retailer can charge). The system can also be coordinated with a wholesale price combined with a buy-back contract and a fixed fee. The paper then considers a system with two competing retailers making pricing and inventory decisions, in which excess demand at one retailer spills over to the other retailer. The coordinating contract is significantly more complex in that setting, and may again require a price floor on the retail price.

Horizontal competition plays a central role in supply-chain settings in which retailers compete in the downstream market. Supermodular games naturally arise in many models of horizontal competition — in those models, the firms' decisions are strategic complements, that is, the increase in a firm's own decision (e.g., its price) leads to an increase in the marginal change of its competitors' payoffs with respect to their own decisions (in that example, their own prices). Bernstein and Federgruen [12] consider a distribution system in which one supplier sells products to multiple competing retailers. The supplier and each retailer i incur inventory-carrying costs h_0 and h_i, respectively, while all supplier orders and transfers to retailer i incur fixed costs K_0 and K_i, respectively, and variable costs c_0 and c_i, respectively. All firms make decisions regarding their selling prices and replenishment strategies. Market demand is deterministic and retailers engage in either price or quantity competition. Under price competition, demand at each retailer i is a function of all retailer prices, $d_i(p)$, which is decreasing in retailer i's own price and increasing in the competitors' prices. The paper analyzes the decentralized system, in which the supplier acts as the Stackelberg leader setting wholesale prices and the retailers follow by choosing their policy variables. Specifically, retailer i follows a power-of-two policy with replenishment interval T_i (under a power-of-two policy, the retailer gets replenished when its inventory level is down to zero and replenishments arrive after a constant interval, which is chosen as a power-of-two multiple of a base period) and sets a price p_i. Retailer i's profit function is given by $\pi_i(p_i, T_i | p_{-i}, w_i) = (p_i - c_i - w_i)d_i(p) - \frac{K_i}{T_i} - \frac{1}{2}d_i(p)h_iT_i$ and it is a function of the retailer's own decision variables, the wholesale price w_i, and the vector of prices of retailer i's competitors, p_{-i}. Existence and uniqueness of a Nash equilibrium requires a condition that relates each retailer's demand price elasticity with the ratio of its annual sales to its combined inventory and fixed setup costs: $\epsilon_{ii} \leq \frac{4\times\mathrm{REV}_i}{\mathrm{INV}_i}$, where $\epsilon_{ii} = -\frac{\partial d_i(p)}{\partial p_i}\frac{p_i}{d_i(p)}$ is retailer i's price elasticity, $\mathrm{REV}_i = p_i d_i(p)$ is retailer i's total gross revenue, and $\mathrm{INV}_i = \sqrt{2d_i(p)h_iK_i}$ is retailer i's optimal total inventory and setup cost. Under this condition, the paper shows that the retailer game is supermodular and has a unique Nash equilibrium. The paper provides empirical evidence to demonstrate that this condition is generally satisfied in practice. The paper concludes with a discussion of a coordinating contract that involves a quantity discount as well as a discount based on each retailer's order frequency. (Several papers examine the effectiveness of quantity discounts in distribution channels, see, e.g., Weng [112, 111], Munson and Rosenblatt [76], Corbett and de Groote [36], Chen et al. [31], Viswanathan and Wang [107], and Altintas et al. [3].)

With a focus on horizontal competition, Bernstein and Federgruen [13] study a model of multiple retailers facing stochastic demands and competing in terms of their retail prices and service levels. Retailers operate following a periodic review, infinite-horizon inventory policy. The paper considers three settings that differ in the sequence in which retailers make decisions. In the first setting, firms engage in price competition while their service levels are exogenously set. In the second setting, firms simultaneously choose a service level and a combined price and inventory strategy. In the last setting, firms make their decisions sequentially, first selecting a service level and subsequently choosing a combined pricing and inventory strategy with full knowledge of the service levels selected by all competitors. The conclusion is that, in general, the equilibrium service level in the two-stage game may differ significantly from the one arising in the simultaneous game. However, under certain demand specifications, each firm adopts the same equilibrium service level in both settings. This further illustrates how the order of play may impact the firms' equilibrium decisions and the resulting division of supply-chain profit. Bernstein and Federgruen [14] study the equilibrium behavior of a set of competing retailers in a newsvendor setting. Prices are endogenous, but unsatisfied demand at a store is lost. Retailers make simultaneous ordering and pricing decisions. The paper provides conditions that ensure that the retailer game has a unique Nash equilibrium. Supply-chain coordination in this setting requires a non-linear price-discount sharing scheme, under which the supplier subsidizes a portion of the retailers' retail price discounts. Bernstein and Federgruen [15] and Krishnan and Winter [61] explore retailer competition and supply-chain coordination in multi-period settings. In a supply chain consisting of a manufacturer selling to two competing retailers, Kostamis and Ziya [58] examine the role of retailer cost asymmetry and competition intensity on the manufacturer's optimal contract.

Several papers explore models of inventory-based competition. One of the earliest papers on this subject is Parlar [88]. Anupindi and Bassok [4, 5] considers a manufacturer selling a product to two retailers that compete in the downstream market. Specifically, a fraction of customers that find the product out of stock in one location, visit the second retailer to look for the product there. The retailers can maintain the stocks in their own locations, or pool inventory at a central location. The paper shows that centralization may not benefit the manufacturer. Rather, retailer competition may lead to higher aggregate sales than centralization, resulting in greater benefit to the manufacturer. Mahajan and Van Ryzin [70] analyze inventory competition between multiple retailers in a newsvendor setting. Customers choose where to buy a product based on the retailers' product availability. Demand at each retail store is stochastically decreasing in the other retailers' stocking levels. Based on this property, the paper proves the existence of a Nash equilibrium. Moreover, the paper shows that, under competition, retailers tend to overstock relative to the centralized solution. Existence of an equilibrium is based on a result in Lippman and McCardle [67]. The latter studies a model of inventory competition between newsvendor retailers. Initial demand D is split among firms according to an exogenous splitting rule and excess demand is reallocated among the firms that have leftover inventory. For the case of two firms, $D = D_1 + D_2$, where D_i is the initial demand for firm i, $i = 1,2$, and a fraction a_i of demand exceeding firm j's stocking level y_j is reallocated to firm i. Effective demand for firm i is $D_i + a_i(D_j - y_j)^+$. Firm i's profit function depends not only on its own stocking level, but also on the stock of the competing firm through the effective demand experienced by firm i. The paper shows that this two-firm newsvendor game is submodular and an equilibrium exists. It also extends the proof of existence of an equilibrium to the case of multiple firms.

Netessine and Rudi [84] and Boyaci [19] examine similar settings of competitive inventory management in which firms compete on product availability. That is, if a seller is out of stock, then a fraction of customer demand spills over a competing firm. The papers show that firms tend to overstock in this environment. In a multi-period setting, an out-of-stock situation may lead to either a lost sale, a backorder, or a customer switching to another seller. Netessine et al. [85] examine the impact of customers' response to stockouts on the equilibrium stocking quantities and profits. Li and Ha [65] and Caro and Martinez-de-Albeniz [27] study models of inventory-based competition in the context of accurate response and quick response strategies, respectively. Netessine and Zhang [86] consider a supply chain in which an upstream wholesaler sells to multiple competing newsvendor retailers. The upstream firm selects the wholesale price and the retailers choose their stocking quantities. In addition to vertical competition arising from the wholesaler's pricing decision, the paper considers two settings of horizontal competition — one in which retailers' products are substitutes and another in which they are complements. In the first setting, competition is modeled through stock-out based substitution. Instead, when products are complements, an increase in a retailer's stocking quantity stochastically increases demand for other retailers. The paper examines the horizontal externalities originated from retailer competition and concludes that in settings with complementary products, competition exacerbates the understocking that arises from double marginalization. In contrast, when products are substitutes, retailers tend to overstock, thereby compensating for the inefficiency brought by double marginalization. Cachon and Lariviere [22] study a setting in which retailer competition arises from the need to earn an adequate allocation of a supplier's limited capacity. The supplier operates under a turn-and-earn allocation scheme that bases a retailer's capacity allocation on past sales.

Another form of inventory competition arises when firms have the ability to transship excess inventory to satisfy demand in an out-of-stock location. In those settings, the firms' stocking decisions are interrelated. In the case of a stock-out, a firm may have access to additional inventory transshipped from another firm with excess inventory. Dong and Rudi [40] consider a manufacturer selling to multiple newsvendor retailers that are centrally managed. The manufacturer determines the wholesale price and the retailers jointly select their stocking quantities and can transship excess inventory. Competition with the manufacturer leads to the kind of vertical externalities discussed in Section 1.2. Rudi et al. [99] study a horizontally decentralized setting with two locations that can transship excess inventory at extra cost if the other location is out of stock.

The papers discussed in this section illustrate two of the most common sources of horizontal competition — through prices (without stock-out-based substitution) or through inventory availability (with fixed retail prices). The papers by Zhao and Atkins [115] and Xu and Hopp [113] explore newsvendor settings in which firms compete both through prices and inventory availability. Price competition arises naturally in the retail market as firms continuously gauge their competitors' prices to try to match them or to offer even more attractive prices. Inventory competition, on the other hand, presumes that firms can monitor their competitors' prevailing inventory levels. However, it turns out that, in many settings, the effect of inventory competition is relatively modest, especially when price is also a decision variable. Huh et al. [54] show that when the retailers' fill rates are in the 95%–99% range, stock-out based competition has a small effect on firms' decisions. That is, retailers can just stock their base-stock levels ignoring whatever their competitors do and still get close to what they would achieve by being strategic. This effect may be particularly noteworthy as in one can question the realism of information assumptions required by players to pursue equilibrium strategies.

1.4 Models with Risk Preferences

There are papers in the supply chain and related literature that look at risk averse players and the effect on order quantities and contract parameters. We provide a brief discussion here. Agrawal and Seshadri [2] study a supply chain with one supplier and multiple independent non-competing retailers where every agent maximizes the expectation of a concave utility function. They show that performance of the supply chain is improved if there exists a risk-neutral intermediate agent taking all the risks. Spulber [104] studies a similar model with a single supplier selling to multiple non-competing retailers. They show that in the setting with a risk-neutral agent, the risk-neutral agent takes all the risks to achieve supply-chain coordination. However, if no risk-neutral agent exists in the system, all agents share the risks. Gan et al. [46] study a supply chain with a single supplier and a single retailer, and model risk aversion by the expected exponential utility objective and the mean–variance objective. They show that the agents share risks under coordinating contracts in both cases. All these studies show that coordination is achieved when the agents share the risks unless a risk-neutral agent exists in the system. In contrast, Chen et al. [30] find that when the agents consider CVaR (Conditional Value at Risk), coordination can be achieved only when the least risk-averse agent takes all the risks. The general message is somewhat clear: When risk-averse agents exist in a supply chain, the nature of the contracts starts to matter a whole lot more than in systems with risk neutral players. The simple reason is that some contracts are more effective at allocating risks appropriately among the different players. The technique used to model risk aversion also matters, that is, CVaR produces different results than a general concave utility function. Choi et al. [35] consider risk aversion in a single-supplier, single-newsvendor-retailer setting, both under decentralized and centralized control. In the context of inventory competition, Shi et al. [101] examine the existence of Nash equilibria when the newsvendor retailers are risk averse.

1.5 Assembly Systems

Vertical and horizontal interactions are also prevalent in assembly systems. There is an abundant literature in operations management exploring pricing and capacity decisions in decentralized assembly systems. In these systems, the upstream tier consists of multiple independent firms, producing and delivering components that are subsequently assembled by a downstream firm. The assembler establishes a contract with the suppliers that indirectly determines the suppliers' capacity decisions. In turn, suppliers produce components, all of which are required to make the final product. Therefore, the total quantity assembled and sold to the market depends on the suppliers' collective production capacity decisions. In single-product assembly systems, complementarity of the suppliers' components facilitates the use of supermodular game techniques to compute and compare equilibria. Figure 1.3 below illustrates this setting.

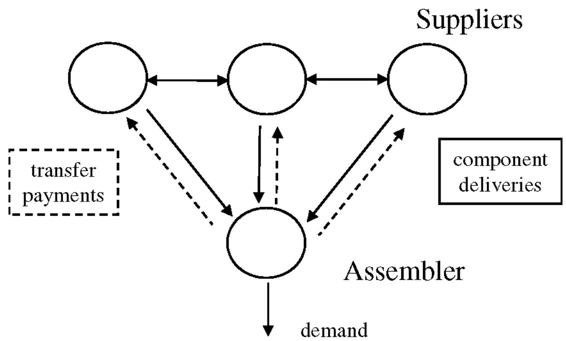

Fig. 1.3 Assembly system.

The assembly models described above typically assume that there is a single supplier for each component — i.e., no competition at the component level. Another stream of papers explores issues of supplier management in which multiple suppliers (or servers) of the same component compete for an allocation of the buyer's business. We provide a brief review of work on these issues. Ha et al. [52] study a buyer acquiring components from two suppliers in a deterministic setting. Suppliers compete either in terms of delivery frequency, with the buyer setting the prices, or in terms of the prices of their components, with the buyer setting the delivery frequency. The buyer allocates demand based on the suppliers' service delivery or price choices. Cachon and Zhang [25] study performance-based competition. Suppliers compete for the delivery of the same product or service, and the buyer allocates demand to suppliers according to their delivery speeds. In the remainder of this section, we focus on papers examining competition in multi-component assembly systems as depicted in Figure 1.3.

Wang and Gerchak [110] examine the impact of decentralization in an assembly system. All the suppliers and the assembler make capacity decisions. Due to the complementarity of their actions, the firm with the lowest capacity dictates the available capacity in the system. This is the essential property that drives the equilibrium results. While the firms' individual optimal capacities are nondecreasing in their component prices, in equilibrium, all firms choose the same capacity level equal to the lowest capacity in the system. The authors consider two contracting sequences that result in different equilibrium capacity decisions and profits. In the first setting, representative of industries with large manufacturers, the assembler acts as the Stackelberg leader, deciding the component prices to pay to the suppliers. In the second setting, the suppliers move first by setting their individual component prices. The effects of production and assembly costs and of the number of suppliers differ substantially in the two decentralized settings. This finding again illustrates how the order of play (arising possibly, in this case, as a result of the power structure in the supply chain) may impact the firms' equilibrium decisions and profits. The paper identifies a capacity-subsidy contract that can coordinate the assembly system under certain conditions. Tomlin [106] studies linear and piecewise linear price schedules in a similar assembly setting. Other papers exploring decentralized assembly systems include Gerchak and Wang [47], Gurnani and Gerchak [50] who consider the effect of random yield in the suppliers' production quantities, Fang et al. [44], and Bernstein and DeCroix [9], who explore issues of system design in a modular assembly setting. Bernstein et al. [11] study the impact of decentralized decision making on the behavior of multi-product assembly systems. Specifically, they consider a system where three components (two product-specific and one common) are used to produce two end-products to satisfy stochastic customer demands. The paper studies the system under both centralized and decentralized decision making, and focuses on the impact of decentralization on the use of commonality and hedging strategies.

In an infinite horizon setting, Bernstein and DeCroix [10] explore the impact of lead times and availability of inventory information on the performance of the firms in an assembly system. As in Cachon and Zipkin [26], the paper studies two games that differ in the way the firms track inventory. In the local game, all firms track their local (on-hand) inventory. In the echelon game, all firms are committed to tracking echelon inventory. The paper analyzes and compares the equilibria that arise in these games. It also describes a payment scheme between the assembler and the suppliers that allows the decentralized system to achieve the centralized solution. Bernstein and Kök [16] consider a decentralized assembly system in which a buyer purchases components from several first-tier suppliers over a finite horizon. Demand is deterministic. The paper examines the suppliers' investments in cost reduction initiatives under a contract that dynamically stipulates the components' purchase prices in every period. The paper models the suppliers' investment decisions under this contract as a dynamic game in closed-loop strategies. It is shown that there always exists an equilibrium in which the suppliers' investments are synchronized, that is, in each period either all suppliers invest in process improvement or no supplier does. Bernstein et al. [17] investigate the benefits of establishing a knowledge sharing network in a decentralized assembly system. Suppliers first non-cooperatively determine their investment in process improvement activities to reduce fixed operating costs. Subsequently, the assembler establishes a knowledge sharing network that facilitates the exchange of best practices among suppliers. This is modeled as a cooperative game in which, as a result of cooperation, all suppliers achieve reductions in their fixed costs from the knowledge sharing activities.

The above papers focus on the incentive distortion issues arising in assembly systems. It is not difficult to observe that the assembler in the role of a principal can dictate an appropriate contract that can end the distortion caused by competing suppliers. However, due to complementarity of the components and the unique role of the different players, the division of profits that a specific contract arrives at depends on the relative bargaining power of the players. Further, as is often seen in such systems, players can resort to strategies outside of the contract, such as strategic collusion, to increase their stake in the supply chain's profits. In Section 2 we explore this issue in greater detail.

1.6 Larger Networks

A number of papers have looked at vertical and horizontal interaction between firms in larger supply-chain networks. Corbett and Karmarkar [37] consider a multi-tier supply chain with multiple competing firms in each tier. Market demand is deterministic and linear in quantity, that is, the linear inverse demand function is $p = a - bQ$, where Q is the total quantity sold and a and b are constant parameters.

Firms in the same tier engage in quantity or Cournot competition. Each firm i selects a selling quantity q_i to maximize its profit, given that tier's resulting selling price $p = a - b(q_i + Q_{-i})$, where $Q_{-i} = \sum_{j \neq i} q_j$ is the aggregate quantity sold by firm i's competitors, and given the upstream input price. That is, firms in the same tier interact through their quantity decisions. The resulting aggregate equilibrium quantity is a function of the input price and affects the input price of the firms in the next downstream tier. Vertical interaction occurs as a result of the derived demand curve for the input. As demonstrated in Corbett and Karmarkar, the solution procedure entails solving for prices and quantities backwards from the most downstream to the most upstream tiers in the supply chain. For a given input price, firms in the same tier select their quantities according to a Nash equilibrium. The upstream input firms act as Stackelberg leaders, setting their price in anticipation of the aggregate equilibrium purchase of the downstream firms. Because downstream demand is linear, the derived equilibrium inverse demand function at each stage is also linear. The paper establishes the existence of a price/quantity equilibrium. Based on these results, the paper further explores the impact of fixed entry costs on the structure of the supply chain (equilibrium number of firms in each tier). Cho [32] builds on the model of Corbett and Karmarkar [37] to study the effects of a horizontal merger of two firms located in the same tier on the outputs and profits of the merging firms and of all other firms in the same or upstream/downstream tiers of the decentralized supply chain. A merging of two firms reduces the competitive intensity at the tier where the merging occurs and, at the same time, leads to a reduction of the marginal cost of the merged firm.

Also within the scope of vertical and horizontal competition, Carr and Karmarkar [28] examine a broader supply chain in which multiple sectors of firms within a tier produce different component that are subsequently assembled by other downstream firms. Each firm in a sector selects a production quantity to maximize its profit, given the input price, the quantities produced by other firms in the sector, and the decisions made by firms in other (complementary) sectors within the same tier. The paper develops an equilibrium concept defined as *coordinated successive Cournot* to derive the equilibrium prices and quantities of all firms. In a setting similar to those of Corbett and Karmarkar [37] and Carr and Karmarkar [28], and using a similar solution procedure, Majumder and Srinivasan [71] consider the effect of contract leadership on the efficiency of supply chains. The location of the Stackelberg leader within the supply network determines the contract sequence and, therefore, the resulting equilibrium prices and quantities. The paper finds that a leading firm earns a higher profit than its followers. The optimal location of the Stackelberg leader (in terms of supply-chain efficiency) depends on the demand and cost parameters. Adida and DeMiguel [1] study competition in a supply-chain setting with multiple manufacturers that supply products to a set of risk-averse retailers. In a model of Stackelberg competition, manufacturers determine the supply quantities in anticipation of the retailers' order quantities and the resulting market clearing wholesale prices. The paper analyzes the firms' equilibrium strategies and explores the extent of supply chain efficiency — i.e., the ratio of profit in the decentralized system to the optimal profit in the centralized system. There is, in fact, a stream of research quantifying the efficiency of decentralized supply chains — the so-called price of anarchy — in several models of vertical and horizontal competition (see Perakis and Roels [90] and the references therein).

1.7 Modeling Negotiation Power

Power in a supply-chain manifests itself in several ways. In many supply-chain models which use a Stackelberg game framework, the Stackelberg leader enjoys a certain amount of power simply by virtue of being the first mover who dictates the terms of the contract as, for example, in Majumder and Srinivasan. The advantage bestowed by being a leader is subtle and difficult to fully characterize. We illustrate this by using a few examples. Consider a simple supplier–retailer game where the retailer sets the final price p and faces a linear demand $a - bp$. Assume the supplier sells to the retailer at a wholesale price w per unit and we normalize the production cost to zero. In a pure Stackelberg game where the supplier acts as a leader and sets a wholesale price anticipating the retailer's reaction, it can be easily verified that, in equilibrium, the supplier earns two-thirds of the channel's profit and the retailer earns one-third. If we allow a larger contract space, say a wholesale price and a transfer payment T, then the supplier can simply extract as much of the channel's profit as possible, the retailer's reservation level being the only constraint. If the demand at the retailer has a different form, say, a simple downward sloping demand curve with constant price elasticity ap^{-b}, then using a wholesale price, the supplier gets 50% of the channel's profit. This simple example shows that the advantage of being a leader hinges on many factors such as the demand elasticity and the contracting space. (Related observations are found in Wang and Gerchak [110] and in Bernstein and Federgruen [13].)

Now consider a different example, where two suppliers sell (partially) differentiated products through a common retailer who sets retail prices for both products and faces market demand. Assume that a wholesale price contract is used. Here, a Stackelberg–Nash game is employed to study the interactions. Choi [34] shows a variety of surprising results. The ones relevant to this discussion are those that show that a Stackelberg leader in this setting may actually be worse off than the follower and this depends on the demand shape. In summary, although Stackelberg games may be a chosen mode of modeling channel interactions and power structures, one needs to be very careful on how this is done. Further, if one looks at interactions between a single supplier and single retailer, since there are no outside options endogeneous to the model, one can argue that a Stackelberg setting which endows the leader the power to set contract terms unilaterally may be somewhat inappropriate.

Within the framework of non-cooperative games in two-stage supply chains, an approach to modeling bargaining power is to assume that the retailers have an exogenous reservation profit level below which they will not participate in the supply chain. These reservation profit levels are usually assumed to represent the profit that the retailers could achieve by pursuing another opportunity outside the supply chain. Furthermore, they are often assumed to be exogenous, that is, independent of the negotiation process and of the retailers' opportunities within the supply chain. Ertogral and Wu [43] consider a setting with one supplier and one buyer, and model the process of contract negotiation with the presence of outside opportunities for both firms. Caruana and Einav [29] show that in a model with switching costs, players may have commitment power, that is, the ability to stake a position of power, even without having a first-mover advantage.

In a supply chain with one supplier selling to two competing retailers, Bernstein and Marx [18] investigate the effect of retailer bargaining power in the allocation of total supply-chain profit among all channel members, using a non-cooperative game approach. The paper models bargaining power by endowing retailers with the ability to set their reservation profit levels. A retailer's reservation profit level is the minimum amount of profit it requires to participate in the supply chain and carry the supplier's product. By making the reservation profit level an endogenous variable, this quantity not only reflects the retailer's opportunity outside the supply chain, but also its bargaining position within the supply chain relative to the competing retailer. The supplier and the retailers trade under a revenue sharing contract. A fully integrated firm (horizontally and vertically) would sell positive quantities at both retail outlets. When wholesale prices are w_1 and w_2 and both retailers are active (sell the supplier's product), let $\Pi(w_1,w_2)$ denote the joint payoff of all three firms. This joint payoff attains a maximum of $\Pi^* \equiv \Pi(w_1^*,w_2^*)$, where $w_i^* = \arg\max_{w_i \geq 0} \Pi(w_i,w_{3-i}^*)$. When only retailer i is active and the wholesale price is w_i, let $\Pi(w_i,\infty)$ be the overall joint payoff of the supplier and retailer i. The overall joint profit maximum in this case is $\Pi_i^m \equiv \Pi(w_i^m,\infty)$, where $w_i^m = \arg\max_{w_i \geq 0} \Pi(w_i,\infty)$. In contrast to the case in which both retailers are active, the joint-profit maximizing wholesale price with only one active retailer equals marginal cost.

Under revenue-sharing contracts, Cachon and Lariviere [23] show that any profit-sharing contract of the form $w_i^* = c_i - \xi_i^*$, with $\xi_i^* = \frac{\partial R_{3-i}}{\partial q_i}(q^*)$, and a revenue-sharing parameter $0 < \alpha \leq \frac{R_i(q^*) - c_i q_i^*}{R_i(q^*) - (c_i - \xi_i^*) q_i^*}$, coordinates the supply chain, where q^* is the integrated optimal stocking quantity vector. The vector (w_1^*,w_2^*) maximizes $\Pi(w_1,w_2)$ for any revenue-sharing parameters $\alpha_i,\ i = 1,2$. If each retailer's alternative to accepting the supplier's offer is to have profit given by an *exogenous* reservation profit level, then the supplier can extract all profit in the channel above the retailers' exogenous profits through the appropriate choice of the revenue-sharing parameters. With endogenous reservation profit levels, the retailers establish their reservation profit levels after learning the supplier's wholesale price offers. As in Muthoo [77], reputational concerns bind the retailers not to trade with the supplier if they cannot obtain a profit at least equal to their reservation profit. Thus, a retailer can credibly commit not to trade with the supplier if it does not receive a minimum level of profit from the transaction. In response to the reservation profit levels, the supplier sets the revenue-sharing parameters, essentially determining how system profits will be allocated. Finally, each retailer chooses the quantity to purchase from the supplier, which is zero if its reservation profit level constraint is not met. As one might expect, in this environment, the supplier's equilibrium profit is reduced relative to the setting with exogenous reservation profit levels and channel profit is not maximized. Allowing retailers to determine their reservation profit levels effectively increases their bargaining power, and so reduces the amount of surplus that the supplier is able to capture. When retailers determine their reservation profit levels, they can extract their incremental contribution to the channel. If only one retailer sells the supplier's product in equilibrium, then it is clear that channel profit is not maximized. If both retailers sell the supplier's product, then retailer 1's incremental contribution is $\Pi(w_1,w_2) - \Pi(\infty,w_2)$ and retailer 2's incremental contribution is $\Pi(w_1,w_2) - \Pi(w_1,\infty)$. If both retailers capture their incremental contributions, then the supplier's payoff is $\Pi(w_1,\infty) + \Pi(\infty,w_2) - \Pi(w_1,w_2)$, which has maximum at wholesale prices less than (w_1^*,w_2^*), and so channel profit is not maximized. The paper shows that the maximum supplier's profit is $\min\{\Pi_1^m,\Pi_2^m\}$. These observations indicate that a retailer's bargaining power may affect the portion of supply-chain profit that it claims for itself. Moreover, the results in Bernstein and Marx suggest that when retailers have bargaining power, a supplier's product may be sold through only one retailer, even when the maximization of channel profit requires that the supplier's product be sold through both retailers. Marx and Shaffer [72, 73] obtain similar results, but in their model reservation profit levels are exogenous and equal to zero and the retailers have all the bargaining power, including the ability to set the wholesale price.

Let us now consider a setting with two retailers that face random demand and purchase inventory from a common supplier. Competition between the retailers is modeled as in the competing newsvendor model of Lipman and McCardle [67]. Assume initial firm demands D_1 and D_2 are independent, and each is uniformly distributed on $[0,1]$. Denote aggregate demand by $D \equiv D_1 + D_2$. Since the retailers' products are substitutes, a proportion of the unsatisfied demand at each retailer may try to purchase the product from the other retailer. Thus, effective demand for retailer i is given by $D_i^e = D_i + s[D_j - y_j]^+$, where y_j denotes the inventory level of retailer j, and s, $0 < s \leq 1$, is the proportion of excess demand at one retailer that substitutes at the other retailer. That is, s measures the degree of substitutability between the retailers' products. (Lipman and McCardle [67], introduce this example for the case $s = 1$.) Assume that the unit selling price is $p = 2$ and the unit production cost is $c = 1$. The wholesale price charged to retailer i is given by $w_i \in [1,2]$. When only one retailer is active, it serves the entire market and $\Pi(w_i, \infty)$ is maximized when $w_i = 1$, with $\Pi_i^m = 1/2$. If both retailers are active, the equilibrium inventory levels increase with the substitution coefficient s. Applying the results in Bernstein and Marx, it is shown that both retailers are active in equilibrium, but the revenue sharing contract that arises in equilibrium does not coordinate the system. Furthermore, the supplier's equilibrium profit is always below $\Pi_1^m = \Pi_2^m = 1/2$. As the retailers become stronger substitutes (higher s), their equilibrium reservation profit levels increase, while the supplier's equilibrium profit decreases. At the same time, system efficiency (system profit under the equilibrium contract versus centralized profit) decreases with s. Stronger competition between the retailers increases their bargaining power by increasing aggregate downstream inventory.

To conclude, we discussed how Stackelberg leadership endows players with intrinsic power. In certain settings, manipulating reservation levels can also be a tool in modeling power. The preceding discussion gives way to the next question we address in this review. Namely, the role of the bargaining process and the firms' negotiation power on the terms of the contract that is eventually adopted in the supply chain which, in turn, affects the division of supply-chain profit. There are a number of ways one might try to formalize the bargaining process and the firms' negotiation power in a supply chain. We provide a discussion on these issues in the next section.

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