Channel Dynamics Under Price and Service Competition

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This paper studies a distribution system in which a manufacturer supplies a common product to two independent retailers, who in turn use service as well as retail price to directly compete for end customers. We examine the drivers of each firm's strategy, and the consequences for total sales, market share, and profitability. We show that the relative intensity of competition with respect to each competitive dimension plays a key role, as does the degree of cooperation between the retailers. We discover a number of insights concerning the preferences of each party regarding competition. For instance, there will be circumstances under which both retailers would prefer an increase in competitive intensity. Our analysis generalizes existing knowledge about manufacturer wholesale pricing strategies, and rationalizes behaviors that would not be evident without both price and service competition. Finally, we characterize the structure of wholesale pricing mechanisms that can coordinate the system, and show that the most commonly used formats (those that are linear in the order quantity) can achieve coordination only under very limiting conditions.
(*Channels of Distribution; Supply Chain Management; Coordination; Competition; Pricing; Service Levels; Manufacturing/Marketing Interface*)

1. Introduction

The management of supply chains consisting of independent parties with disparate agendas is of growing interest in the business community, to both academics and practitioners alike. A great deal of basic theory has been developed in the economics, marketing, and operations management literatures, providing insights into behavior and performance under various incentive designs and control regimes. Understandably, most formal results have been obtained at the expense of assuming very simple physical structures and a parsimonious set of decision variables and environmental parameters (see Tsay et al. 1999 for a recent review). Perhaps the most popular such framework is a manufacturer-retailer channel in isolation, in which the primary activities are pricing and/or quantity setting for a single product in a single period. Our objective is to generalize this existing knowledge by examining the interaction of a number of more realistic structural features: market demand that is sensitive to dimensions beyond the selling price, direct competition in the marketplace, and multi-echelon interaction.

We consider the case of two competing retailers who obtain a product from a common manufacturer, and in turn sell to an external market. The end consumers' perception of value and, therefore, their purchase decisions, are influenced not exclusively by the item's selling price, but also the amount of "service" that accompanies it. Here, service is taken to broadly represent all forms of demand-enhancing effort, which includes customer service before and after the sale, in-store promotions and product placement, advertising, and the overall quality of the shopping experience. These elements, which represent much of both the operations and marketing strategies of a firm, are aggregated into a single decision variable for each retailer. Hence, the product can be thought of as a bundle

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of two attributes: price and service. The nature of market demand is such that, ceteris parabis, a retailer that reduces price or increases service will enjoy sales growth. And, the nature of the competition is such that either tactic will diminish the sales of the rival. While each retailer chooses its own price and service, the manufacturer controls the product's wholesale pricing terms.

The purpose of this research is to provide understanding about the behavioral signatures of decentralized distribution channels, and the challenges of utilizing such channels efficiently. We examine the drivers of each retailer's marketing/operations strategy (price and service), the manufacturer's pricing strategy, and the consequences for total sales, market share, and profitability. We show that the intensity of competition with respect to each competitive dimension plays a key role, as does the degree of cooperation between the retailers. Finally, we characterize the structure of wholesale pricing mechanisms that can coordinate the system, and show that the most commonly used formats (those that are linear in the order quantity) can achieve coordination only under very limiting conditions.

The rest of the paper is organized as follows. Section 2 briefly reviews the relevant literature, and §3 details our key assumptions. We then formulate and analyze the behaviors of all decision makers, and the impact on end customers. In §4 we focus on the horizontal competition at the retail level to illuminate the dynamics of a market sensitive to both price and service, and then examine multi-echelon effects by including the manufacturer's pricing decision in §5. Section 6 considers in detail the issue of system efficiency, and explores the feasibility of coordinating the independently managed system by proper design of the wholesale price mechanism. Concluding remarks are presented in §7. All proofs are deferred to the appendix for clarity of exposition. The appendix also contains a table summarizing our mathematical notation (Figure 5).

2. Literature Review

We first discuss the issue of competition, in single and then multiple echelon settings. We will then focus on efforts to incorporate the notion of service.

While some researchers use the term "competition" broadly as an antonym for "cooperation" (cf. Cachon 1999), here we use it to mean that actions undertaken by one party to increase its own sales may *directly decrease the demand faced by another.* Horizontal competition (between two or more sellers pursuing the same pool of customers) is well studied in the economics literature and elsewhere. This dates at least as far back as the classic models of oligopoly, and notions of Cournot, Bertrand, and Stackelberg competition. Variants of this are too numerous to review here, so we direct the reader to Shapiro (1989) for extensive discussion.

In the inventory literature, competition has been treated primarily in a single-echelon environment, with product quantity as the sole dimension of competition. Parlar (1988) characterizes a duopoly of two "newsvendor" firms who become competitors because their products are partially substitutable (i.e., when either of the firms' stock is out, a fixed fraction of the excess demand transfers to the other). Lippman and McCardle (1997) generalize this by considering a variety of possibilities for how the realized aggregate demand is initially split between the firms as a function of their inventory levels, and more general substitution patterns. Each paper examines existence and uniqueness properties of Nash solutions, but explicit computation of the equilibria turns out to be nontrivial in both settings.

The inventory literature also includes numerous multi-echelon models that depict multiple entities at the retail level. However, this structure by itself does not necessarily entail demand competition as the retailers are often assumed to exist in completely distinct markets (e.g., due to spatial separation) (cf. Chen et al. 1998, Cachon 1999b, and references within). If such retailers interact at all, it is on their supply side, perhaps due to their common interest in a scarce input (e.g., Cachon and Lariviere 1999a, 1999b). Such models are known to be difficult to analyze even if the parties are not allowed to behave independently, as noted by Cachon (1999). This issue and the resulting ambiguity or complexity of the demand perceived upstream explain why simpler, and typically deterministic, formulations are found in most existing multi-echelon analyses incorporating competition, including ours. Such models are much more common in the economics (cf. Tirole 1988 and Katz 1989 for reviews) and marketing literatures (e.g., McGuire and Staelin 1983, McGuire and Staelin 1986, Moorthy 1987, Coughlan and Wernerfelt 1989, Ingene and Parry 1995, Choi 1996, Padmanabhan and Png 1997, Ingene and Parry 1998, Trivedi 1998). In the majority of these works, the basis of competition is a single product dimension, usually price or quantity.

Recognizing that this approach may oversimplify buyer preferences, some researchers have developed models containing an additional attribute that is desirable to end customers but costly to provide. This is typically encoded in a deterministic demand curve that is downward-sloping in price and shifts upward with the amount of that attribute, in conjunction with a cost function that increases with both the production volume and the attribute. Because of the generality of this structure, labels such as "service," "quality," or "advertising" have been virtually interchangeably applied to the attribute. Early examples of this approach from the economics literature include Spence (1975) in a single-firm analysis, and Dixit (1979) for horizontal competition. See Tirole (1988, §2.2.1) for a synopsis. Similar efforts appeared later in the marketing literature, one example being the treatment of nonprice variables by Jeuland and Shugan (1983) in their seminal analysis of a bilateral monopoly channel. Desiraju and Moorthy (1997) also visit this single-manufacturer/single-retailer case, except with the manufacturer as Stackelberg leader and asymmetric information about a market demand parameter. In a multi-retailer setting, Mathewson and Winter (1984) include advertising as a decision, although it is not directly a dimension of competition. Perry and Porter (1990) focus on a type of service that unlike ours, has a positive externality effect across the retailers. Banker et al. (1998) use this general approach to model the possibility that two firms might pool their product development efforts even though they will compete (on price) in the market for the resulting product. Karmarkar and Pitbladdo (1997) allow a multi-dimensional representation of quality, which includes both a "class" attribute (of which more is better) and a "conformance" attribute (for which proximity to a specified target is the goal), and comment on the implications for the single-echelon equilibrium under conditions of monopoly, perfect competition, and oligopoly with the possibility of firm entry and exit.

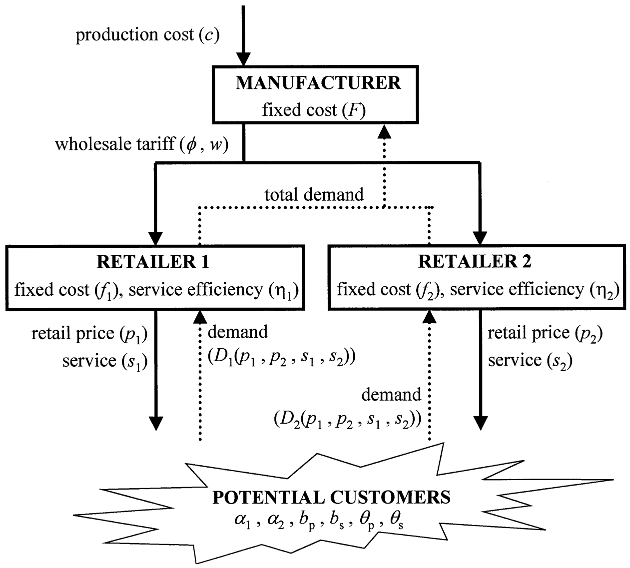
Among existing models, the most salient are by Winter (1993) and Iyer (1998), who both study systems structurally comparable to ours in the presence of nonprice product attributes. However, both focus primarily on the question of multi-echelon coordination via vertical price restraints, and formulate demand models and decision structures that are fundamentally dissimilar to ours. In particular, both provide detailed representation of individual consumer behavior in terms of the value of service and disutility of travel, and from this infer properties of each retailer's demand curve. In contrast, we begin with an explicit demand function that contains direct metrics for the intensity of competition along each dimension (price and service), for which there are no obvious analogs in their models. Although these are certainly related to individual consumer preferences, we do not pursue this linkage in detail. This level of abstraction allows us to definitively characterize how changes in the competitive climate affect behavior and performance under complete decentralization as well as central control, which is the main contribution of our work.

3. The Model

We consider a market in which all activity occurs within a single period. There are two retailers, indexed by $i \in \{1, 2\}$ and $j = 3 - i$, who sell the same product. Retailer i chooses its own retail price and service level (p_i and s_i, respectively), and then realizes Demand $D_i(p_i, p_j, s_i, s_j)$, which reflects the decisions of both firms in the following key ways[1]: (i) each retailer's demand is decreasing in its own price and increasing in its own service, and (ii) one retailer's price increase can only

[1]The retailers' interdependence reflects the existence of underlying preferences of consumers for one retailer over the other, which we do not model explicitly. These can be due, for example, to geographic proximity, familiarity with a particular store, or the appeal of the retail "brand." However, such loyalties are not absolute, and can be overcome by sufficiently compelling price or service differentials. The key ramification is that the retailers are engaged in direct competition along both these dimensions.

Figure 1 The Supply Chain



increase the its rival's demand, and likewise one retailer's service increase can only decrease its rival's demand.[2] (A specific functional form which implements these properties will be detailed and discussed below, after we outline the decision structures to be analyzed.)

Retailer i's cost of providing service level s_i is $\eta_i\, s_i^2/2$ where the quadratic form suggests diminishing returns[3] on such expenditures and η_i and η_j (strictly positive terms we refer to as "service cost factors") differentiate the retailers vis-a-vis their relative cost-effectiveness in operational deployment of service. Similar approaches to modeling service effort have been used in a number of other papers (e.g., Desiraju and Moorthy 1997, Iyer 1998, and references within). Retailer i also incurs a fixed operating cost of f_i. Each retailer orders exactly enough from the single manufacturer to fill its own market demand.

The manufacturer has the production capacity to create unlimited supply at unit production cost of c, and charges a two-part tariff $W(Q) \equiv \phi + wQ$ to deliver quantity Q, so that w is the incremental wholesale price per unit. (More general wholesale pricing schemes will be considered in §6.) The manufacturer's fixed cost of operation is F. We assume that the manufacturer will serve both retailers. Figure 1 illustrates the system under consideration.

In this paper we will examine behavior and performance with independent decision making by all members. First, to fully understand the competitive implications of demand that is sensitive to both price and nonprice attributes, we will focus attention on the horizontal interaction between the retailers. We will derive the Nash equilibrium in prices and service levels for a given wholesale tariff and compare it to a setting in which the retailers can fully cooperate/collude in selling to the market (§4). This will control for any effects due to the manufacturer's manipulation of W(). We will then expand the analysis to include multi-echelon issues by including the manufacturer, who takes Stackelberg leadership in setting W( ) (§5 and §6). Here the primary benchmark for the fully decentralized system will be the case of full cooperation both *between retailers* and *across echelons*.

Demand Model

The customer demand faced by Retailer i is

$$D_i(p_i, p_j, s_i, s_j) = \alpha_i - b_p p_i + \theta_p (p_j - p_i) + b_s s_i - \theta_s (s_j - s_i), \qquad (1)$$

[2]Some researchers have suggested that certain forms of a retailer's service can have a positive externality effect on a rival's demand. For example, if a retailer excels at providing product information over the telephone or the Internet, or invests in out-of-store advertising which endorses a product's quality and utility, more consumers may indeed buy the product, just not necessarily from that retailer. This is the dynamic modeled in Perry and Porter (1990), and seems to be more appropriate for informational types of service, which can be consumed without making a purchase. In contrast, customers cannot derive the benefit of a specific retailer's well-stocked shelves, courteous and efficient cashiers, clean stores, free delivery and installation, and generous warranties if the actual purchase is made elsewhere. The analysis in our model emphasizes this concept of service, so that the net externality is negative. Hence, service acts strictly as a competitive weapon.

[3]Diminishing returns is certainly natural if this notion of service has a significant store-level inventory component. Under the assumptions of standard inventory models, moving from, say, 97% to 99% fill rate typically requires a greater incremental investment than does moving from 95% to 97%. For other concepts of service, we presume that a rational manager will always target the "lowest-hanging fruit," so that subsequent improvements are progressively more difficult.

where α_i, $b_p > 0$, and b_s, θ_p, $\theta_s \geq 0$ (our model generalizes the existing literature as long as θ_p or θ_s is nonzero).[4] α_i, which we refer to as a "market base," parametrizes the scale of Retailer i's market. The relative values of α_i and α_j can be used loosely to describe comparative advantage in terms of access to customers (e.g., due to location or brand), controlling for price or service effects. Mathematically, α_i is the demand faced by Retailer i when both retailers price at 0 but offer no accompanying service. b_p and b_s measure the responsiveness of each retailer's market demand to its own price and service, respectively. θ_p and θ_s are measures of the intensity of competition between the two retailers with regards to pricing and service behavior, respectively.[5] More precisely, all else being equal, every unit by which Retailer i cuts price will attract $(b_p + \theta_p)$ customers: b_p of these customers would not have purchased at all otherwise, and the remaining θ_p customers are diverted from Retailer j (note that $dD_i/dp_i = -(b_p + \theta_p)$, and $dD_j/dp_i = \theta_p$). A higher value of θ_p magnifies such price effects and, therefore, elevates the importance of pricing competitively. θ_s has a similar connotation for the service competition.[6]

To focus attention on incentives and the effects of competition, we make the common assumption that all model parameters are deterministic and common knowledge (e.g., Jeuland and Shugan 1983, McGuire and Staelin 1983, Winter 1993, Ingene and Parry 1995, 1998, Choi 1996, Iyer 1998). A number of additional conditions on the parameters are necessary to ensure a reasonable model (nonnegativity of all decisions and boundedness of all objective functions). These are described in the appendix.

As noted in §2, this approach to modeling demand is more amenable to analysis of competition than those seen in traditional inventory models (e.g., newsvendor-style models). Such models predominantly represent the entire market size, e.g., as a single, random variable with known distribution that is independent of price. They then explicitly compute how much of this total demand a provider of goods can capture as a result of the stocking level, which is often described as "service."[7] Although holding more stock obviously means capturing more demand on average, the exact relationship and, therefore, the profit function are stochastic. Embedding this feature in a duopoly setting has been found to dramatically complicate the analysis (cf. Parlar 1988, Lippman and McCardle 1997). In contrast, our approach leaves the theoretical total market undefined, but captures the dependence of sales volume on both service and price in the more tractable form of deterministic linear expressions. The diminishing returns of service that commonly occur in stochastic models as the supporting stock level approaches the upper tail of the demand distribution can be enforced through the functional representation of service-related costs, such as the quadratic form we use.

4. Dynamics of the Retail Competition

To control for any effects of the manufacturer's pricing, we begin by isolating the horizontal interaction between retailers for a fixed wholesale tariff parametrized as (w, ϕ). This will be worthwhile not only as a

[4]Service that exhibits positive externalities (examples of which were discussed earlier) can be modeled with $\theta_s < 0$. All expressions reporting equilibrium outcomes remain valid. While some results describing relative magnitudes of certain expressions and comparative statics are affected, the appropriate modifications may be obtained in a straightforward fashion. To simplify the exposition of the main insights from our analysis, we will focus on the case where $\theta_s \geq 0$.

[5]We will be careful in our terminology to avoid confusion. The term "competition" describes a property of market dynamics induced by consumer preferences that exists whenever θ_p or θ_s is strictly positive. Taking this into consideration, the retailers can either "cooperate" or not. As we will see, certain effects of competition can persist even though the retailers cooperate.

[6]Our functional representation of demand has the desirable property that, *for a fixed set of retailer actions*, the total market size is invariant to changes in θ_p or θ_s. This is best appreciated on comparison to an obvious alternative of the form $D_i = \alpha_i - b_p p_i + \theta_p p_j + b_s s_i - \theta_s s_j$. Here, increasing θ_p (θ_s) spontaneously increases (decreases) $D_1 + D_2$, which is difficult to rationalize economically and to reconcile with the aspiration of using these parameters to represent competitive intensity. Choi (1996) propounds a similar argument.

[7]The term "service" has a very specific tradition in the inventory and operations management literatures, denoting the availability of product to satisfy a stochastic demand. This is commonly formalized as a fill rate or probability of stockout (cf. Nahmias 1997) and has been incorporated as the primary metric of customer satisfaction in numerous models of both single and multiple stage production systems.

Figure 2 Horizontal Analysis for a Given w and ϕ

	Noncooperating Retailers	Cooperating Retailers
Retailer i Retail Price	$M_i + w$	$N_i + w$
Retailer i Service	$((b_s + \theta_s)/\eta_i)M_i$	$[b_sN_i + \theta_s(N_i - N_j)]/\eta_i$
Retailer i Demand	$(b_p + \theta_p)M_i$	$b_pN_i + \theta_p(N_i - N_j)$
Retailer i Profit	$U_iM_i^2/2 - f_i - \phi$	$N_i(b_pN_i + \theta_p(N_i - N_j)) - (b_sN_i + \theta_s(N_i - N_j))^2/(2\eta_i) - f_i - \phi$

preliminary to the multi-echelon analysis in §5, but also because this subproblem by itself has apparently not been fully explored in the literature.[8]

For a given w and ϕ, Retailer i solves $max_{p_i,s_i}\pi_i\ (p_i, s_i; w, \phi, p_j, s_j)$, where

$$\pi_i(p_i, s_i; w, \phi, p_j, s_j) = (p_i - w)\cdot D_i(p_i, p_j, s_i, s_j) - \eta_i s_i^2/2 - f_i - \phi$$

is the retailer's profit function conditional on the wholesale terms and the rival's actions, and $D_i(p_i, p_j, s_i, s_j)$ is as specified in (1). Figure 2 presents the resulting Nash equilibrium, as well as the cooperative benchmark (in which p_i, p_j, s_i, and s_j are set jointly to maximize $\pi_i + \pi_j$). These price and service outcomes represent the retailers' reaction functions to the manufacturer's wholesale pricing. Details of all calculations appear in the appendix, as do mathematical definitions of the terms M_i and N_i, which represent Retailer i's margins in the respective systems. We remind the reader that even though the decisions are made jointly by the retailers in the cooperative case, price and service competition still exist in the dynamics of the market.

The outcomes in Figure 2 serve as the basis for understanding the effect of the various elements of the business environment. At this stage any costs that are fixed to the retailer (f_i and ϕ) do not affect decision making, so retailer behavior must be driven by the unit wholesale price and asymmetry in the market bases and service cost factors. Because of the complexity of the completely general model, we obtain insight about the effect of each parameter in turn by imposing simplifying conditions on the remaining parameters, as detailed in Proposition 1.

PROPOSITION 1. *The equilibrium for the horizontal interaction between retailers displays the following characteristics:*

(a) Effect of market base: Whether the retailers cooperate or not, when they are symmetrical in service cost factors ($\eta_i = \eta_j$), the retailer with the larger market base has the higher service, retail price, demand, and profit (ignoring fixed costs), and increasing the larger market base further increases the differential in each variable.

(b) Effect of service cost factor: Whether the retailers cooperate or not, when they are symmetrical in market base ($\alpha_i = \alpha_j$), the retailer with the smaller service cost factor has the higher service, retail price, demand, and profit (ignoring fixed costs).

(c) Effect of wholesale price: Whether the retailers cooperate or not, when they are symmetrical in market base and service cost factors ($\alpha_i = \alpha_j$ and $\eta_i = \eta_j$), increasing w reduces all retail margins ($p_i - w$), services, demands, and profits (ignoring fixed costs); the retail prices respond to increases in w in the following way:

(i) in the noncooperative case, the retail prices increase if and only if $(b_p + \theta_p) > b_s\ (b_s + \theta_s)/\eta_i$;

(ii) in the cooperative case, the retail prices increase if and only if $b_p > (b_s)^2/\eta_i$.

Results (a) and (b) of Proposition 1 reinforce the interpretation of the market base and service cost factors

[8]Karmarkar and Pitbladdo (1997) use a very different representation of the oligopoly competition. Specifically, their oligopoly equilibrium is defined by an entry and exit condition that drives individual firm profits close to zero, whereas we assume a fixed number of competitors and study the resulting behavior and performance in detail. Banker et al. (1998) consider a setting more similar to ours, but with different decision and cost structures. Moreover, they operationalize competitive intensity purely in terms of relative market size rather than cross-effects in price and service. Iyer (1998) does not explicitly discuss the retail-level equilibrium.

as measures of comparative advantage and serve primarily as a check on the validity of the model. In general, the differences between the outcomes for the two retailers will reflect the tension between the two countervailing forces. For instance, a retailer with smaller market base may somewhat offset this disadvantage with superior efficiency in providing service.

Result (c) describes the adverse effect of a procurement cost increase, and elaborates on the impact for end customers. While it seems reasonable that an increase in w should be partially absorbed by retailers via a reduction in margin, Result (c.i) suggests a richer set of strategies than would be apparent in a model of pricing alone. In the noncooperative case, each retailer may choose to cut its margin by even more than the increase in w (so that the end retail price actually decreases). This occurs whenever $b_s\,(b_s + \theta_s)/\eta_i > (b_p + \theta_p)$, which suggests that service is a more strategic dimension for competition than price. In such a case, cutting service seems to hurt profits less than would raising prices, due to the steepness of the quadratic service cost function. However, because of the presence of a competing retailer, service reductions must be accompanied by price reductions. Cooperating retailers also compensate for an increase in w through a reduction in service when $(b_s)^2/\eta_i > b_p$. This has a similar interpretation as the condition for competing retailers, except that θ_s and θ_p no longer play a role because these affect only the *allocation* of demand between retailers and not the *total*. Thus, (c) shows the importance of explicitly allowing the retailers nonprice degrees of freedom, because a richer set of empirically verifiable behaviors and competitive strategies can be revealed and studied.

Asymmetry between retailers greatly confounds any comparison of the price and service levels across the control regimes, or the influence of the parameters of competitive intensity. However, insights into the competitive dynamics can be obtained if we neutralize such effects by considering symmetric retailers, as reported in Proposition 2.

PROPOSITION 2. *When the retailers are symmetric in market base and service cost factor (i.e., $\alpha_i = \alpha_j$ and $\eta_i = \eta_j$), the intensity of competition affects the retail equilibrium in the following ways:*

(a) Comparative statics: Noncooperative price and service both decrease with θ_p and increase with θ_s.

(b) Comparison of noncooperative vs. cooperative price and service:

(i) The emphasis placed on price and service by noncooperating retailers, relative to that of cooperating retailers, is shown in the following table:

Region	Price and Service Choices of Noncooperating Retailers (vs. Those Chosen Under Full Retail Cooperation)	
	Price	Service
I: $\theta_p > (2b_p/b_s)\theta_s$	*lower*	*lower*
II: $(b_s/\eta_i)\theta_s < \theta_p < (2b_p/b_s)\theta_s$	*lower*	*higher*
III: $\theta_p < (b_s/\eta_i)\theta_s$	*higher*	*higher*

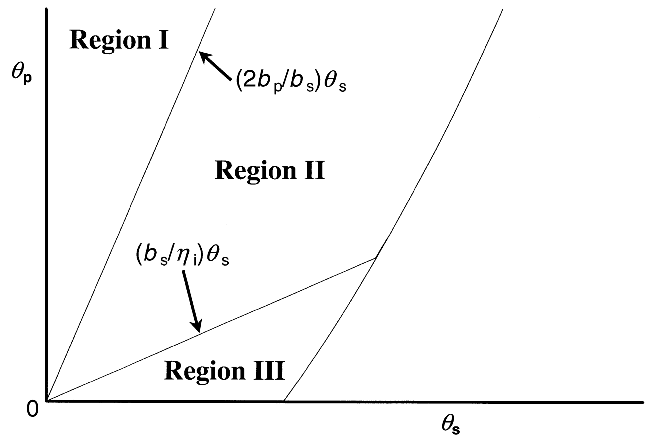
(ii) As long as service competition exists ($\theta_s > 0$), noncooperating retailers must provide strictly more service per unit of profit margin than do cooperating retailers.

(c) The ideal amount of competition: Each retailer prefers no competition along both dimensions ($\theta_p = \theta_s = 0$); however, given that competition exists along one dimension, some competition along the other dimension is always desirable.

With the cooperative decisions as the point of reference in labeling the noncooperative decisions as "high" or "low," results (a) and (b) of Proposition 2 illuminate how the impact of competition reflects the relative intensity of the different types of competition. In general, the results are intuitively appealing in that the relative aggressiveness of noncooperating retailers along each dimension of competition goes hand-in-hand with the intensity of that competition. In particular, Part (b.i) uses the cooperative benchmark to show the direction in which independence in decision making affects retail price and service strategies. The outcomes can be classified into three distinct regions in the (θ_p, θ_s) plane, as described below and illustrated in Figure 3:

- Region I: The condition that defines this region, $\theta_p > (2b_p/b_s)\theta_s$, suggests that price competition is the dominant concern. And indeed, this type of competition drives the independent retailers to emphasize low price, with less concern for service. As θ_s rises, the

Figure 3 Regions of Strategic Emphasis[9] (Illustrated for $b_p = 2$, $b_s = 1.5$, $\eta_i = 3$)



[9]The unlabeled region represents disallowed combinations of θ_p and θ_s.

heightening intensity of service competition compels the retailers to increase their service offerings (and raise price to help offset the costs).

• Region II: In this region, defined by $(b_s/\eta_i)\theta_s < \theta_p < (2b_p/b_s)\theta_s$, both dimensions of competition are of comparable priority, resulting in both lower prices and higher service relative to the cooperative benchmark. Note that assumption (13) implies $b_s/\eta_i < 2b_p/b_s$ (see appendix), so that a region II always exists as long as $\theta_s > 0$.

• Region III: Once $(b_s/\eta_i)\theta_s > \theta_p$, the service competition becomes the overwhelming concern, and here the noncooperative arrangement has higher service (and price).

The absolute size of these regions is an artifact of the scaling of variables and is less significant than the existence of the general structure (three regions defined by two partitioning lines that radiate from the origin in the (θ_p, θ_s) plane, with a clockwise progression of competitive emphases as described).

While we have chosen not to model the value proposition of individual end consumers, we will catalog insights that would apply under fairly general utility assumptions. These will be meaningful to supply chain managers as customer welfare may impact long-term profits for the firms. Along this vein, one implication of (b.i) is that blocking retail cooperation (as some antitrust arguments might advocate) can in fact *raise prices* or *lower service*. However, consumers are not conclusively harmed because the two outcomes cannot happen simultaneously. Indeed, a price increase may be palatable if accompanied by a sufficient service increase and, likewise, a cut in service can be made tolerable by a price reduction. Naturally, focusing on either dimension in isolation would miss this point. Result (b.ii) provides further insight as to how prohibiting retail cooperation might specifically benefit end customers.

Result (c) contains two ideas, the former of which is intuitive and the latter much less so. The retailer preference for $\theta_p = \theta_s = 0$ is intuitive because this allows each firm to independently maximize profits on an exclusive territory. The latter idea concerns the behavioral response to competitive interaction. When only one dimension of competition exists, there is a tendency to go overboard on that dimension, which benefits neither party. This has the flavor of a "Prisoner's Dilemma," because each firm wishes to take a more moderate stance, but neither can do so unilaterally. Adding competition along the other dimension effectively allows the parties to correlate their actions away from the battle of attrition, delivering mutual benefit in a self-enforcing manner. For instance, when service competition is the only interdependence, adding some price competition enables the competitors to simultaneously reduce service. While they must also lower their prices, the marginal savings on service costs dominate because the cost function is convex. Likewise, when price competition is the only interdependence, the retailers are locked in a price war. Adding a small amount of service competition enables the retailers to simultaneously increase prices. They must increase service to compensate, but this is relatively inexpensive on the "no-frills" end of the service cost curve. One can show that the greater the competition along one dimension, the greater the ideal amount of competition along the other.[10]

While this insight illuminates the dynamics of the competition, our current model is silent on how either

[10]In a model of oligopoly interaction in price only, and with a different demand representation, Demange and Ponssard (1985) identified asymmetry in input cost as a reason why a (low cost) firm could potentially prefer an intensification of the effect of price competition.

firm could exploit this because the parameters of competitive intensity are exogenous. A possible extension would be to consider ways by which the firms might be able to influence (θ_s, θ_p). For instance, certain advertising efforts could conceivably elevate the relative priority which end customers place on service, i.e., increase θ_s. This could be beneficial if the current retail equilibrium reflects an overemphasis on price. The potential benefits must, of course, be weighed against the costs of achieving such influence.

5. The Multi-Echelon System

Now that we have characterized the competitive interaction between retailers, we can gain further insight to supply chain performance by incorporating the role of the manufacturer. We consider two distinct control structures that differ in the coordination between the manufacturer and retail echelons:

NC ("No Cooperation"): complete decentralization, with all parties behaving independently to maximize individual profits, and
TC ("Total Cooperation"): complete coordination to maximize total system profit.

In the NC case, the manufacturer takes Stackelberg leadership in dictating the wholesale pricing terms. This is a fairly standard assumption in models of manufacturer-retailer channels (e.g., McGuire and Staelin 1983, 1986, Ingene and Parry 1995, 1998, Chen et al. 1998). We assume in this section that the manufacturer charges a two-part tariff with a fixed fee of ϕ and a linear per-unit price of w, the same for both retailers so as to not violate the Robinson-Patman Act. We will consider the implications of more general price structures in §6.

The Manufacturer's Pricing Decision in the NC Case

In designing the wholesale tariff the manufacturer solves the following optimization problem, which maximizes the manufacturer's profit π^M (w, ϕ) while guaranteeing that neither retailer will be unprofitable:

$$max_{w,\phi}\pi^M(w, \phi) \equiv (w - c)(D_i(w) + D_j(w)) + 2\phi - F$$

subject to

$$\pi_i^R(w, \phi) \equiv U_i[M_i(w)]^2/2 - f_i - \phi \geq 0 \quad \text{for } i \in \{1, 2\}.$$

Here, $D_i(w)$ and $D_j(w)$ denote the respective retailer's demands absent cooperation for a given w, $\pi_i^R(w, \phi)$ is the profit for Retailer $i \in \{1, 2\}$ as defined in Figure 2, and $M_i(w)$ is as defined in Figure 5. The solution to this problem is described in Proposition 3.

Proposition 3 can be considered a generalization of Ingene and Parry (1998) to include non-price dimensions,[11] and corroborates their key results. Specifically, the manufacturer's optimal two-part tariff depends on the retailer fixed costs and, in particular, can be segmented into three "zones" in the $(f_j - f_i)$ space. In Zone 1 (3) the manufacturer extracts all profits from Retailer i (j) via the tariff's fixed fee and Retailer j (i) is profitable, while in Zone 2 both retailers just break even. This structure arises because the manufacturer's ability to extract profits from the retail level is constrained by the less profitable retailer. The identification of this retailer and, hence, the segmentation into zones, depends on a Function $Z(\,)$ that calculates the gap between the retailers' profits (ignoring fixed costs and the fixed part of the tariff) for a given wholesale price, and how this relates to the differential in retailer fixed costs. While supporting the robustness of the general structural results of Ingene and Parry (1998), we have discovered that some attributes of their optimal wholesale price are apparently valid only when retailers compete exclusively on price. For instance, their analog of $w(ij)$ is a simple weighted average of $w(i)$ and $w(j)$, with weights that are a linear function of $(f_j - f_i)$. This continues to be true in our model only when the retailers are symmetric in their cost structures for providing service (note that in (6) the term $(f_j - f_i)$ appears under a square root when $\eta_i \neq \eta_j$). Also, Ingene and

[11]Our model can exactly replicate the results of Ingene and Parry (1998) by assuming that their $c_1 = c_2 = 0$, indicating that the retailers do not incur any additional costs for handling each unit of product (although our model could easily incorporate this). Then let $b_p = b - \theta$, and $\theta_p = \theta$ to match their price dynamics, and $\theta_s = b_s = 0$ to eliminate service effects from the model. The latter can alternatively be accomplished by letting $\eta_i, \eta_j \rightarrow \infty$, which will make service prohibitively expensive to provide for any θ_s and b_s.

PROPOSITION 3. *The manufacturer's optimal two-part tariff* (w^*, ϕ^*) is:

$$w^* \equiv \begin{cases} w(i) & \text{if } f_j - f_i \leq Z(w(i)), \text{ so that } \pi_i^R(w^*, \phi^*) = 0 \quad \text{(Zone 1)} \\ w(ij) & \text{if } Z(w(i)) < f_j - f_i < Z(w(j)), \text{ so that } \pi_i^R(w^*, \phi^*) = \pi_j^R(w^*, \phi^*) = 0 \quad \text{(Zone 2)} \\ w(j) & \text{if } Z(w(j)) \leq f_j - f_i, \text{ so that } \pi_j^R(w^*, \phi^*) = 0 \quad \text{(Zone 3)} \end{cases} \tag{2}$$

$$\textit{and } \phi^* \equiv \min_{i\in\{1,2\}} \{U_i[M_i(w^*)]^2/2 - f_i\}, \tag{3}$$

where

$$Z(w) \equiv \frac{U_j}{2}[M_j(w)]^2 - \frac{U_i}{2}[M_i(w)]^2, \tag{4}$$

$$w(i) \equiv c + \frac{\begin{bmatrix} (\alpha_i/b_p - c)[(b_p+\theta_p)(U_j+V_i) - 2b_pU_iU_j(U_j+V_j)/(U_iU_j - V_iV_j)] \\ + (\alpha_j/b_p - c)[(b_p+\theta_p)(U_i+V_j) - 2b_pU_iV_j(U_j+V_j)/(U_iU_j - V_iV_j)] \end{bmatrix}}{2[(b_p+\theta_p)(U_i+U_j+V_i+V_j) - b_pU_i(U_j+V_j)^2/(U_iU_j - V_iV_j)]} \quad \text{for } i \in \{1, 2\} \textit{ and } j = 3 - i \tag{5}$$

$$w(ij) \equiv \begin{cases} c + [(\alpha_i/b_p - c)\Gamma + (\alpha_j/b_p - c)(1-\Gamma)] \\ \cdot \left[1 + \sqrt{1 - \dfrac{U_i[(\alpha_i - cb_p)U_j + (\alpha_j - cb_p)V_j]^2 - U_j[(\alpha_i - cb_p)V_i + (\alpha_j - cb_p)U_i]^2 + 2(f_j - f_i)(U_iU_j - V_iV_j)^2}{(U_i(U_j+V_j)^2 - U_j(U_i+V_i)^2)[(\alpha_i - cb_p)\Gamma + (\alpha_j - cb_p)(1-\Gamma)]^2}}\right] & \text{if } \eta_i \neq \eta_j \\ c + \left[\left(\dfrac{\alpha_i}{b_p} - c\right) + \left(\dfrac{\alpha_j}{b_p} - c\right)\right]\Big/ 2 - \left(\dfrac{f_j - f_i}{\alpha_j - \alpha_i}\right)(U^2 - V^2)/(b_pU) & \text{if } \eta_i = \eta_j \end{cases} \tag{6}$$

$$\textit{and } \Gamma \equiv \frac{U_j[U_i(U_j + V_j) - V_i(U_i + V_i)]}{U_i(U_j + V_j)^2 - U_j(U_i + V_i)^2}.$$

Parry noted that w^* is monotonically decreasing in $(f_j - f_i)$ within Zone 2, which is not guaranteed here.

Numerous studies have shown that in a bilateral monopoly channel the manufacturer can maximize profits by setting the wholesale price equal to the production cost so as to eliminate the distortion of *double marginalization*[12] and then completely extracting the retailer's profits through the fixed fee. Existing literature indicates that this is no longer necessarily appropriate when the manufacturer deals with multiple retailers that compete or are asymmetric. For instance, the analysis of Ingene and Parry (1995) shows that even when the retailers control exclusive territories, the wholesale price that maximizes the manufacturer's profit may exceed c. This is due to a dependency between channels induced by the manufacturer's need to treat the disparate retailers equally per the Robinson-Patman Act. But, even if the retailers are completely symmetrical, the presence of price competition exerts downward

[12]Double marginalization is a well known cause of supply chain inefficiency that results from the existence of two separate entities within the distribution channel. In the classic setting of a manufacturer-retailer dyad facing a deterministic downward-sloping demand curve (Spengler 1950), the retailer's choice of selling price p represents a trade-off between the unit profit margin (which favors higher p) and the volume of sales (which favors lower p). If the retailer pays the manufacturer a unit price w that is strictly greater than the production cost c (hence creating the two distinct profit margins referred to by the name of this phenomenon), the retailer's choice of p will be consistent with a profit margin of $(p - w)$ rather than the $(p - c)$ that the system as a whole perceives. The end result of this distortion is a retail price that is higher than would be globally optimal.

pressure on retail prices, so that the manufacturer charges a wholesale price higher than c to deter the price war.

Our findings are consistent with these conclusions. To focus attention on the implications of competition along multiple dimensions we assume from this point forward that $f_i = f_j$. Without loss of generality, we refer to the more profitable retailer as Retailer j, so that the Zone 1 formula applies (Zone 2 is immaterial because it requires that the rank ordering of fixed costs *strictly* oppose the ordering of the retailer profits ignoring fixed costs.) Consider the following progression through special cases:

• When $\theta_p = \theta_s = 0$ (exclusive territories), (2) reduces to:

$$w^* = c + \frac{1}{2}\left(\frac{\alpha_i}{b_p} - c\right)\left[\frac{\alpha_j - \alpha_i}{\alpha_i - cb_p} + \frac{(b_s)^2}{U_i}\left(\frac{1}{\eta_j} - \frac{1}{\eta_i}\right)\right]$$

If $\alpha_j > \alpha_i$ and $\eta_i > \eta_j$, guaranteeing that Retailer i would be less profitable at any wholesale price, clearly $w^* > c$. This occurs because while the retailers are asymmetric, the manufacturer must offer them the same contract so as not to violate the Robinson-Patman Act.

• If we instead assume that the retailers are symmetrical in market base ($\alpha_j = \alpha_i$) but compete in price and service (θ_p, $\theta_s > 0$), then

$$w^* = c + \left(\frac{\alpha_i}{b_p} - c\right)\frac{\theta_p U_i - (b_p + \theta_p)V_i}{2(b_p + \theta_p)(U_i - V_i) - b_p U_i}.$$

From this and the previous point it is apparent that in general $w^* \neq c$.

• When $b_s = \theta_s = 0$ and $\theta_p > 0$, corresponding to the price-only competitive setting of Ingene and Parry (1995, 1998), $w^* = c + (\alpha_i/b_p - c)\theta_p/[2(b_p + \theta_p)] > c$.

• To this we add that if $\theta_p = 0$ but $\theta_s > 0$, so that competition is along only the service dimension, $w^* = c + (\alpha_i/b_p - c)\theta_s(b_s + \theta_s)/(U_i\eta_i + 2\theta_s(b_s + \theta_s)) > c$. By Proposition 1, such a competitive environment would tend towards high service offerings and retail prices, and the manufacturer, therefore, elevates the wholesale price to reduce the service war.

• A possibility not highlighted in the existing literature ignoring nonprice competition is that under certain conditions $w^* < c$. For instance, suppose $\theta_s = 0$ but b_s, $\theta_p > 0$ (meaning that a retailer's service increase tends to bring completely new customers rather than attracting the customers of the rival retailer, although customers do switch in response to price). Here Equation (2) yields $w^* = c + (\alpha_i/b_p - c)\theta_p((b_p + \theta_p) - (b_s)^2/\eta_i)/(2(b_p + \theta_p)(U_i - V_i) - b_pU_i)$. This can be less than c when $(b_p + \theta_p) < (b_s)^2/\eta_i$, meaning that the price effects in market demand are sufficiently low relative to the service effects. The manufacturer prices so low to encourage the provision of service, which in turn buttresses the retail prices (cf. Proposition 2). In this way the manufacturer guides the retailers toward behavior that tends to expand the total market rather than cause switching of existing customers. As noted earlier, each retailer would like to pursue this course of action but neither could do so unilaterally. The intervention of the manufacturer enables this, creating additional profits at the retail level that can then be extracted via the fixed fee.

• Finally, for completeness note that when $\theta_s = \theta_p = 0$, and the retailers are identical, all sources of divergence from the bilateral monopoly case are eliminated. And indeed, Equation (2) predicts that $w^* = c$ for this case.

System Equilibrium

The specification of (w^*, ϕ^*) in (2) and (3) completely determines the system equilibrium for the NC case. This is displayed in Figure 4 along with the TC benchmark, using constructs M_i and L_i as defined in Figure 5. The NC column combines the retail-level equilibrium (cf. Figure 2) with the manufacturer's optimal tariff as described in Proposition 3. The results for TC follow from Figure 2 as well, based on the observation that TC is equivalent to the case of cooperating retailers with w set to c.

In general, these expressions are sufficiently complex that meaningful comparative statics results cannot be obtained algebraically. Nevertheless, our derivation of closed form expressions for these equilibria enables the execution of any desired sensitivity analysis numerically. One might also be interested in questions such as how much the manufacturer sacrifices by using a two-part tariff as opposed to some more general pricing scheme of greater complexity. To answer this would require repeating Proposition 3's line of analysis with the manufacturer pricing scheme of interest, computing the corresponding equilibrium profit

Figure 4 Comparison of Control Structures for the Multi-Echelon System

	NC ("No Cooperation")	TC ("Total Cooperation")
Retailer *i* Retail Price	$M_i(w^*) + w^*$	$L_i + c$
Retailer *i* Service	$((b_s + \theta_s)/\eta_i)M_i(w^*)$	$[b_sL_i + \theta_s(L_i - L_j)]/\eta_i$
Retailer *i* Demand	$(b_p + \theta_p)M_i(w^*)$	$b_pL_i + \theta_p(L_i - L_j)$
Retailer *i* Profit	$U_i[M_i(w^*)]^2/2 - f_i - \phi^*$	
Manufacturer Profit	$(w^* - c)(b_p + \theta_p)(M_i(w^*) + M_j(w^*)) + 2\phi^* - F$	
System Profit	$(w^* - c)(b_p + \theta_p)(M_i(w^*) + M_j(w^*)) + U_i[M_i(w^*)]^2/2 + U_j[M_j(w^*)]^2/2 - f_i - f_j - F$	$b_p[(L_i)^2 + (L_j)^2] + \theta_p(L_i - L_j)^2 - (b_sL_i + \theta_s(L_i - L_j))^2/(2\eta_i) - (b_sL_j + \theta_s(L_j - L_i))^2/(2\eta_j) - f_i - f_j - F$

for the manufacturer, and then comparing to the manufacturer profit in the NC column of Figure 4. Our experience suggests that this would be a nontrivial task.

In the next section we will consider the question of whether there exist pricing terms for the wholesale transaction capable of leading the system of individually managed parties to act as if centrally managed, so as to attain the efficiency of TC.

6. On System Coordination

A number of studies have addressed the possibility of restoring cooperative efficiencies by proper design of the manufacturer-retailer relationship, specifically the wholesale pricing terms. These include Jeuland and Shugan (1983), Moorthy (1987), Ingene and Parry (1995, 1998), and Desiraju and Moorthy (1997). While such works have shown that schemes with quantity discount or two-part tariff structure enable coordination in a variety of settings, which may include retail competition or service variables, they provide no guidance when both factors are simultaneously present. In fact, Winter (1993) shows that a linear price contract will be insufficient, and Iyer (1998) argues that the same is true of quantity discounts. Our framework can illuminate the exact role of competition in causing this breakdown.

We begin by considering the theoretically most general wholesale pricing scheme, denoted as $W(Q, s)$ to indicate that a retailer's payment depends on both the quantity received (Q) and the service (s) provided by that retailer. While such a scheme may be impractical for a variety of reasons (e.g., the retailer's service level may be difficult to monitor), it provides a number of insights and a basis for subsequent discussion of more workable schemes. Specifically, we will turn our attention to payments of the form $W(Q)$, a commonly observed type of pricing. (A special instance of this was assumed by the analysis of the preceding sections, as well as most other extant research.) In all cases, we assume that the same price schedule must be offered to both retailers, per the Robinson-Patman Act. Also, we disallow any side deals between retailers, such as pooling of purchases to exploit volume discounts.

In contrast to the previous section in which the manufacturer maximized individual profit, here we pose the question of whether the first-best profit for the entire system can be achieved through proper design of the wholesale price mechanism used under the NC decision structure. It remains to be established whether such an outcome is desirable to the individual parties.

Proposition 4 describes conditions a general $W(Q, s)$ must meet if it is to coordinate the fully independent system, then comments on the implications of pursuing a more easily implementable linear form. We show in the Appendix that coordination can be achieved for fully asymmetrical retailers that compete in both price and service, but the complexity of the coordinating wholesale pricing scheme (documented in Equations (19) and (20)) precludes any detailed analysis. To enable deeper study of the channel dynamics, we focus here on the special case in which the two retailers are identical in their cost structures for providing service (i.e., $\eta_i = \eta_j$). We use asterisks to identify the retail prices, service offerings, and demand levels that a central planner would choose (i.e., p_i^*, s_i^*, and D_i^*, respectively, for $i \in \{1, 2\}$), whose explicit values are reported in the TC column of Figure 4. These depend on the market and production cost parameters, but not the wholesale payment (which is a transfer internal to the system). We also abbreviate $\partial W(Q, s)/\partial Q$ and $\partial W(Q, s)/\partial s$ as $W_Q'(Q, s)$ and $W_s'(Q, s)$, respectively.

PROPOSITION 4. *Coordinating the NC system via wholesale pricing that depends on both the retailer's purchase quantity and service, when $\eta_i = \eta_j$:*

(a) A general $W(Q, s)$ coordinates the system only if it satisfies the following conditions for $i \in \{1, 2\}$ and $j = 3 - i$:

$$W_Q'\,(D_i^*, s_i^*) = c + \frac{\theta_p}{b_p + \theta_p}(p_j^* - c) \tag{7}$$

$$W_s'(D_i^*, s_i^*) = \frac{b_p\theta_s - b_s\theta_p}{b_p + \theta_p}(p_j^* - c) \tag{8}$$

(b) For schedules of the form $W(Q, s) = \phi + wQ + ks$ ("three-part tariff"), coordination will be achieved if and only if the following conditions are satisfied:

(i) retailers asymmetric in market base (i.e., $\alpha_i \neq \alpha_j$): $\theta_s = \theta_p = 0$, $w = c$, and $k = 0$

(ii) retailers symmetric in market base (i.e., $\alpha_i = \alpha_j$):

$$w = c + (\alpha_i - cb_p)\theta_p/[(b_p + \theta_p)(2b_p - b_s^2/\eta_i)] \text{ and}$$

$$k = (\alpha_i - cb_p)(b_p\theta_s - b_s\theta_p)/[(b_p + \theta_p)(2b_p - b_s^2/\eta_i)].$$

Assuming away for the moment any obstacles to contracting on retail service, this result suggests that a manufacturer interested in a fully efficient system should compute p_1^*, p_2^*, s_1^*, and s_2^* (and, therefore, D_1^* and D_2^*), and then construct a schedule $W(Q, s)$ such that the slopes at the two specific points (D_1^*, s_1^*) and (D_2^*, s_2^*) satisfy conditions (7) and (8) in part (a) of Proposition 4. Many such schedules may be possible.

Part (b) considers as a special case the class of schedules that are linear in both Q and s, an easily implementable form which we call a "three-part tariff." The conditions under which such structures are efficient offer insights into the system dynamics. We find that for retailers that are *asymmetric* in market base, coordination is impossible unless the two retailers do not interact at all, in which case the system behaves as two independent manufacturer-retailer channels. If this is the case, the service component of $W(Q, s)$ is unnecessary as a two-part tariff (based on quantity only) and is sufficient. Within each relationship, the cause of inefficiency is double-marginalization, and the only linear solution features a variable wholesale cost exactly equal to the unit production cost. This is reminiscent of the strategies proposed by Moorthy (1987) for the Jeuland and Shugan (1983) system, and Desiraju and Moorthy (1997) for a model more similar to ours.[13] However, if any cross-retailer interaction exists (θ_s or θ_p is nonzero), even the three-part tariff is insufficient. (This also confirms that at equilibrium system NC must be strictly inefficient when competition exists, because it assumes an extreme case of three-part tariff pricing.) On the other hand, if the retailers are symmetric in market base and service cost factors, a coordinating three-part tariff exists for general θ_s and θ_p.

Note that the coordinating w is nonnegative and increases with θ_p. So, an increase in unit wholesale price is required to counteract the downward pressure on retail prices associated with any intensification in price competition. Note that the coordinating k can be either negative or positive, meaning that the manufacturer may either reward or penalize the retailer for providing service. In particular, if $\theta_s > (b_s/b_p)\theta_p$, the coordinating schedule offers a discount for increasing service, but otherwise it imposes a penalty. While the latter measure may seem unorthodox, discouraging service is appropriate if the retailers are providing too much of it, which will be the case when service competition is sufficiently intense. Note also that any increase in θ_s (which further shifts the retailer emphasis towards service) must be even more aggressively discouraged with an increase in k (i.e., $\partial k/\partial\theta_s \geq 0$); by a similar logic, when θ_p increases, the coordinating k should be reduced (i.e., $\partial k/\partial\theta_p \leq 0$).

[13]Jeuland and Shugan (1983) and Moorthy (1987) both assume a bilateral monopoly channel with demand dependent on price and service, in which the manufacturer and retailer play a Nash, rather than Stackelberg, game. Desiraju and Moorthy (1997) treat the manufacturer as Stackelberg leader, and show this particular two-part tariff to be a coordinating mechanism when the retailer's market base is common knowledge. Their demand model is a special case of ours corresponding to $\theta_p = \theta_s = 0$, $b_p = 1$, $b_s = \gamma$, obtainable by replacing our s_i with $\sqrt{s_i}$. This also requires that we restrict both our service cost factors η_i and η_j to be identically 1.

As noted, in practice the provision of service may be difficult to monitor, so wholesale price schedules conditioned on service may be untenable. Therefore, we consider in Proposition 5 the effectiveness of more conventional pricing schemes (depending only on Q).

PROPOSITION 5. *Coordinating the NC system via wholesale pricing that depends only on the retailer's purchase quantity:*

(a) A schedule $W(Q)$ can coordinate the system only under the very restrictive condition that $b_s\theta_p = b_p\theta_s$. In this case, coordination requires:

$$W'(D_i^*) = c + \frac{\theta_p}{b_p + \theta_p}(p_j^* - c) \text{ for } i \in \{1, 2\} \text{ and } j = 3 - i. \tag{9}$$

(b) For schedules of the form $W(Q) = \phi + wQ$ ("two-part tariff"), coordination will be achieved if and only if the following conditions are satisfied:

(i) retailers asymmetric in market base (i.e., $\alpha_i \neq \alpha_j$): $\theta_p = \theta_s = 0$ and $w = c$

(ii) retailers symmetric in market base and service cost factor (i.e., $\alpha_i = \alpha_j$ and $\eta_i = \eta_j$): $b_s\theta_p = b_p\theta_s$ and $w = c + (\alpha_i - cb_p)\theta_p/[(b_p + \theta_p)(2b_p - b_s^2/\eta_i)]$.

Because in any real system it is almost surely true that $b_s\theta_p \neq b_p\theta_s$, the main implication of Proposition 5 is that in general no wholesale price schedule that depends only on the purchasing retailer's order quantity, no matter how complex, can achieve coordination when the retail interaction includes competition along multiple dimensions. The combination of double marginalization, price and service trade-offs at each retailer site, and retail competition, is too much for any one single-attribute pricing mechanism to overcome. Such mechanisms simply possess too few independent degrees of freedom to guide the retail prices and service levels simultaneously to the system-optimal choices.[14] Nevertheless, studying the coordinating schedules for the special cases in which they do exist (i.e., $b_s\theta_p = b_p\theta_s$) reveals some interesting structural insights. For instance, (9) is consistent with quantity discounting.[15] Also, in contrast to Jeuland and Shugan (1983) and Moorthy (1987), in general, the coordinating unit wholesale cost does not equal the marginal production cost. This is seen most readily for the case of completely symmetric retailers, when, (9) simplifies to $W'(D_i^*) = c + (\alpha_i - cb_p)\theta_p/[(b_p + \theta_p)(A_i - B)] > c$, and comes about because the strategic interplay between the retailers complicates the double-marginalization effect.

Result (b) discusses the efficacy of the two-part tariff, a form of $W(Q)$ that has achieved considerable attention in the literature due to its ease of implementation. The result for asymmetric retailers (item (b.i)) is no surprise because Proposition 4 already demonstrated the sufficiency of this specific schedule. For symmetric retailers (item (b.ii)), taking away the ability to tie the wholesale payment to service renders the two-part tariff sufficient only under the restriction of $b_s\theta_p = b_p\theta_s$.

A key managerial implication of this section is that additional restraints may be necessary to eliminate system inefficiency. One possibility is to augment a quantity-based wholesale price schedule with a resale price restriction, empowering the manufacturer with sufficient control over the retail level decisions. However, such schemes may encounter legal obstacles (cf. Winter 1993, Desiraju and Moorthy 1997, Iyer 1998),[16] when restrictions on retail service (similar to price floors or ceilings) might be the only alternative. Desiraju and Moorthy (1997) came to this same conclusion for a retailer with no competition, but possessing private information about a market size parameter. They additionally pointed out that while service re-

[14] $b_s\theta_p = b_p\theta_s$ represents a reduction in the number of free environmental parameters, which is what enables a quantity-only price schedule to be a sufficient restraint.

[15] $D_i^* - D_j^* = b_p(L_i - L_j)$, while $W'(D_i^*) - W'(D_j^*) = (\theta_p/(b_p + \theta_p))(L_j - L_i)$. Hence, $D_i^* > D_j^*$ implies $W'(D_i^*) < W'(D_j^*)$. Although (9) restricts the shape of $W(Q)$ only at two points, if we make the mild assumption that the marginal cost $W'(Q)$ is nonincreasing in Q, (9) unequivocally implies quantity discounting.

[16] Desiraju and Moorthy (1997) note that bans on resale price maintenance (RPM) have largely been enforced with respect to price floors, rather than ceilings. However, our model demonstrates that circumstances exist under which each direction of restraint might be required.

quirements are perfectly legal, the monitoring necessary for enforcement may be costly. This will also be true of any effort to influence service that is built into the wholesale pricing mechanism, as in our Proposition 4. In the end this may provide one argument for manufacturers to distribute their products through company-owned stores, allowing direct control over price and service. Of course, such a channel design may suffer from a different set of problems.

7. Conclusion

Our primary objective has been to develop basic theory concerning the behavior of firms competing to sell to end customers who are sensitive to both price and service, and the consequences for system performance. To enable detailed formal analysis, we have used simple representations of market demand and individual firm behavior. This has yielded a number of insights and testable implications.

Enhancing the modeling framework to include competition along both price and nonprice dimensions has provided a richer representation of firm behavior. This has suggested a broader set of outcomes than could be concluded from traditional models that focus primarily on price-based competition. For instance, we have explained when the retailers will pursue low-price strategies, and when they will instead emphasize service. Coordination between retailers can actually lower retail prices, although services will decrease in the process. We have derived the manufacturer's optimal two-part tariff in such an environment, and showed how it reflects the prevailing conditions of market competition. Finally, we have concluded that even fairly general wholesale pricing mechanisms can coordinate the system only under very special conditions. As the most prevalent schemes (those based on quantity only, for reasons of practicality) are insufficient, additional restraints may be necessary.

Our results, of course, reflect our simplifying assumptions. This immediately suggests a number of opportunities to build upon this work. While our linear demand relationships are analytically tractable, more general demand relationships could be considered. These could include different functional forms and/or uncertainty. Also, the relative standing of service and price emphases in the resulting retail marketing strategies are certainly sensitive to the assumption of convexity in the service-related costs (implemented via the quadratic form), and do not necessarily persist for service that reflects economies of scale. Moreover, the individual service cost functions do not reflect any synergies that might result from retailer cooperation.

We have certainly suppressed much of the asymmetry that can potentially exist between retail competitors. In general, the cross-retailer demand effects could be nonsymmetric, as could the functional forms of the service cost terms.

A richer model of the manufacturer might include nonlinear production economics, to reflect scale economies and/or production capacity and materials availability issues. The consideration of multiple manufacturers could also deliver additional insights.

Our equilibrium analysis relies on common knowledge about all environmental parameters. This is especially salient to efforts to design a mechanism for coordinating the system. However, we have shown that even with this most simple of information structures, coordination can be achieved only under very limiting circumstances.

The game structures we have considered are only a subset of the possibilities that can occur with multiple firms and multiple decision variables. Other possibilities include ones in which the manufacturer serves as follower to the retail decisions, one retailer has Stackelberg leadership over the other, one retailer is operated by the manufacturer as a "company store" while the other is an independent distributor (this resembles the distribution methods used, for example, by manufacturers such as Nike and Levi-Strauss). Or, the manufacturer controls retail price but not service (or vice versa). Similarly, we could also consider competition between distinct channels, each of which consists of a manufacturer and a retailer. Our modeling framework can easily be extended to illuminate the dynamics in such structures.

Finally, the paradigm of single-period equilibrium analysis has certain limitations. This obviously suppresses any temporal dynamics, and will fail to detect strategies that are rational in transition. Indeed, in rapidly moving business environments, there is the very real possibility that equilibrium might never be achieved. Nevertheless, as illustrated in this paper and many others in a vast number of literatures, this approach can provide insights into basic economic behavior and serve as the foundation for empirical study.

Appendix

Conditions for Model Parameters. To ensure that the various profit expressions will be well behaved and possess a unique optimum, we impose the following conditions on the parameters:

$$\alpha_i/b_p > w,\ c \text{ for } i \in \{1, 2\} \tag{10}$$

$$A_i > 0 \text{ for } i \in \{1, 2\} \tag{11}$$

$$V_i > 0 \text{ for } i \in \{1, 2\} \tag{12}$$

$$A_iA_j > B^2 \tag{13}$$

Without Condition (10), at least one of the retailers could not have both positive demand and positive unit profit margin, ruling out profitability. Note that (10) does not *guarantee* nonnegative profits to Retailer i, because the fixed cost and cost of providing service might overwhelm the sales revenue. We do not presume $w > c$ a priori because with a two-part tariff the manufacturer can conceivably sustain a unit wholesale price below the production cost. (11), (12), and (13) are simply mathematical conditions to ensure nonnegativity of the decision variables and boundedness and convexity of the profit function of the coordinated system. These have no obvious precise economic interpretation.

Figure 5 **Summary of Notation**

Var	Definition
p_i	Retailer i retail price
s_i	Retailer i service
D_i	Retailer i demand
α_i	Retailer i market base
b_p	Sensitivity of a retailer's demand to its own retail price
b_s	Sensitivity of a retailer's demand to its own service
θ_p	Intensity of price competition
θ_s	Intensity of service competition
η_i	Retailer i service cost factor
f_i	Retailer i fixed cost
w	Unit wholesale price
ϕ	Fixed fee component of wholesale payment
c	Manufacturer unit cost
F	Manufacturer fixed cost
π_i^R	Retailer i profit
π^M	Manufacturer profit
U_i	$2(b_p + \theta_p) - (b_s + \theta_s)^2/\eta_i$
V_i	$\theta_p - \theta_s(b_s + \theta_s)/\eta_i$
A_i	$U_j - (\theta_s)^2/\eta_i$
B	$V_i + V_j$
M_i	$(U_j(\alpha_i - wb_p) + V_j(\alpha_j - wb_p))/(U_iU_j - V_iV_j)$
N_i	$(A_i(\alpha_i - wb_p) + B(\alpha_j - wb_p))/(A_iA_j - B^2)$
L_i	$(A_i(\alpha_i - cb_p) + B(\alpha_j - cb_p))/(A_iA_j - B^2)$

Derivation of Expressions in Figure 2. (Outcome for the Horizontal Retail Level Interaction)

Noncooperative equilibrium: For Retailer i, the first derivatives of profit are

$$\partial\pi_i^R/\partial s_i = (b_s + \theta_s)(p_i - w) - \eta_i s_i \text{ and}$$

$$\partial\pi_i^R/\partial p_i = \alpha_i - wb_p - 2(b_p + \theta_p)(p_i - w) + \theta_p(p_j - w) + (b_s + \theta_s)s_i - \theta_s s_j,$$

and the Hessian is

$$\begin{pmatrix} \partial^2\pi_i^R/\partial p_i^2 & \partial^2\pi_i^R/\partial p_i\partial s_i \\ \partial^2\pi_i^R/\partial s_i\partial p_i & \partial^2\pi_i^R/\partial s_i^2 \end{pmatrix} = \begin{pmatrix} -2(b_p + \theta_p) & b_s + \theta_s \\ b_s + \theta_s & -\eta_i \end{pmatrix}.$$

Second order conditions for profit maximization by each retailer will be satisfied if $2\eta_i(b_p + \theta_p) - (b_s + \theta_s)^2 > 0$, which is implied by (11). The equilibrium price and service decisions are obtained by solving the system of four linear equations composed of the two first order conditions for each of the two retailers. The equilibrium demand and profit follow directly.

Cooperative profit maximization: The objective is to maximize the total retail profit, $\pi_i^R(p_i, s_i; w, \phi, p_j, s_j) + \pi_j^R(p_j, s_j; w, \phi, p_i, s_i)$. For $i \in \{1, 2\}$,

$$\partial[\pi_i^R + \pi_j^R]/\partial s_i = (b_s + \theta_s)(p_i - w) - \theta_s(p_j - w) - \eta_i s_i$$

$$\partial[\pi_i^R + \pi_j^R]/\partial p_i = -(b_p + \theta_p)(p_i - w) + D_i + \theta_p(p_j - w).$$

It is straightforward to show that the Hessian assures concavity of the objective whenever (11) and (13) are assumed. The first-order conditions then constitute a system of four equations in four unknowns whose solution is as stated in Figure 2.

Proof of Proposition 1. (a) Differentials between the competing retailers' decisions and outcomes for the case of $\eta_i = \eta_j$ are described below.

	Noncooperating Retailers	Cooperating Retailers
$p_i - p_j$	$\dfrac{1}{U_i + V_i}(\alpha_i - \alpha_j)$	$\dfrac{1}{A_i + B}(\alpha_i - \alpha_j)$
$s_i - s_j$	$\dfrac{b_s + \theta_s}{\eta_i(U_i + V_i)}(\alpha_i - \alpha_j)$	$\dfrac{b_s + 2\theta_s}{\eta_i(A_i + B)}(\alpha_i - \alpha_j)$
$D_i - D_j$	$\dfrac{b_p + \theta_p}{U_i + V_i}(\alpha_i - \alpha_j)$	$\dfrac{b_p + 2\theta_p}{A_i + B}(\alpha_i - \alpha_j)$

Under Assumptions (10)–(13), all differences in the table are positive functions of $(\alpha_i - \alpha_j)$ that increase with α_i. As a result, when the service-cost factors are the same, the retailer with the larger market base will generate greater profits (not considering fixed costs).

(b) Differentials between the competing retailers' decisions and outcomes for the case of $\alpha_i = \alpha_j$ are described below.

	Noncooperating Retailers	Cooperating Retailers
$p_i - p_j$	$(\alpha_i - wb_p)\dfrac{(b_s + \theta_s)(b_s + 2\theta_s)}{U_iU_j - V_iV_j}\left(\dfrac{1}{\eta_i} - \dfrac{1}{\eta_j}\right)$	$(\alpha_i - wb_p)\dfrac{b_s(b_s + 2\theta_s)}{A_iA_j - B^2}\left(\dfrac{1}{\eta_i} - \dfrac{1}{\eta_j}\right)$
$s_i - s_j$	$(\alpha_i - wb_p)\dfrac{(b_s + \theta_s)(2b_p + 3\theta_p)}{U_iU_j - V_iV_j}\left(\dfrac{1}{\eta_i} - \dfrac{1}{\eta_j}\right)$	$(\alpha_i - wb_p)\dfrac{2b_s(b_p + 2\theta_p)}{A_iA_j - B^2}\left(\dfrac{1}{\eta_i} - \dfrac{1}{\eta_j}\right)$
$D_i - D_j$	$(\alpha_i - wb_p)\dfrac{(b_p + \theta_p)(b_s + \theta_s)(b_s + 2\theta_s)}{U_iU_j - V_iV_j}\left(\dfrac{1}{\eta_i} - \dfrac{1}{\eta_j}\right)$	$(\alpha_i - wb_p)\dfrac{b_s(b_s + 2\theta_s)(b_p + 2\theta_p)}{A_iA_j - B^2}\left(\dfrac{1}{\eta_i} - \dfrac{1}{\eta_j}\right)$

Under Assumptions (10)–(13), all differences in the table are positive functions of $(1/\eta_i - 1/\eta_j)$. As a result, when the market bases are the same, the retailer that can provide service more cheaply will generate greater profits (not considering fixed costs).

(c) When $\alpha_i = \alpha_j$ and $\eta_i = \eta_j$, under noncooperation Retailer i's margin, service, demand, and profit all increase with M_i, which in turn decreases with w. Retailer i's retail price is $\alpha_i + w(b_p + \theta_p - b_s(b_s + \theta_s)/\eta_i)(U_i - V_i)$, hence, the sign of $(b_p + \theta_p - b_s(b_s + \theta_s)/\eta_i)$ determines the effect of w. With cooperation, Retailer i's margin, service, demand, and profit all increase with N_i, which in turn decreases with w. Retailer i's price is $\alpha_i + w(b_p - (b_s)^2/\eta_i)\,(A_i - B)$, so what matters here is the sign of $(b_p - (b_s)^2/\eta_i)$. □

Proof of Proposition 2. Figure (6) reports the head-to-head comparison between the noncooperative and cooperative outcomes for symmetric retailers ($\alpha_i = \alpha_j$ and $\eta_i = \eta_j$).
These expressions follow directly from Figure 2, and items (a) and (b) can be subsequently obtained in a straightforward fashion.

For (c), denote each retailer's non-cooperative retail profit as $\hat{\pi}^R$. It is easy to show that $\hat{\pi}^R$ achieves the cooperative profit only when $\theta_p = \theta_s = 0$. Next, consider the derivatives:

$$\frac{d\hat{\pi}^R}{d\theta_p} = \frac{\theta_s(b_s + \theta_s)/\eta_i - \theta_p}{(2b_p + \theta_p - b_s(b_s + \theta_s)/\eta_i)^3}(\alpha_i - wb_p)^2,$$

$$\frac{d\hat{\pi}^R}{d\theta_s} = \frac{b_s\theta_p - \theta_s(2b_p + \theta_p)}{\eta_i(2b_p + \theta_p - b_s(b_s + \theta_s)/\eta_i)^3}(\alpha_i - wb_p)^2.$$

Because $B^2 > V_iV_j$ and $A_iA_j < U_iU_j$ by definition of these entities, (13) implies $U_iU_j - V_iV_j > 0$. When the retailers are symmetric, this is equivalent to $(U_i)^2 - (V_i)^2 > 0$. Because (11) and (12) together imply $U_i + V_i > 0$, it must be the case that $U_i - V_i$, the term whose cube appears in the denominator of the above derivatives, is also positive. Clearly, when $\theta_s > 0$ and $\theta_p = 0$, $d\hat{\pi}^R/d\theta_p > 0$, meaning that adding some price competition would actually make both retailers better off. In fact, $\hat{\pi}^R$ is increasing in θ_p whenever $\theta_p < \theta_s(b_s + \theta_s)/\eta_i$, which falls along the right boundary of regions II and III in Figure 3, where service competition dominates. And when $\theta_p > 0$ and $\theta_s = 0$, $d\hat{\pi}^R/d\theta_s > 0$. This will hold true whenever $\theta_s < b_s\theta_p/(2b_p + \theta_p)$, or equivalently $\theta_p > 2b_p\theta_s/(b_s - \theta_s)$. This is a sliver on the left side of Region I, where price competition dominates. □

Proof of Proposition 3. The objective function, $\pi^M(w, \phi) = (w - c)(b_p + \theta_p)(M_i(w) + M_j(w)) + 2\phi - F$, is clearly jointly concave in w and ϕ. With the dependence on w suppressed for clarity, the Kuhn-Tucker conditions are:

$$(b_p + \theta_p)\left[(w - c)\frac{d(M_i + M_j)}{dw} + M_i + M_j\right] + \lambda_iU_iM_i\frac{dM_i}{dw} + \lambda_jU_jM_j\frac{dM_j}{dw} = 0 \tag{14}$$

$$\lambda_i[U_iM_i^2/2 - f_i - \phi] = 0 \tag{15}$$

$$\lambda_j[U_jM_j^2/2 - f_j - \phi] = 0 \tag{16}$$

$$0 = 2 - \lambda_i - \lambda_j \tag{17}$$

$$\lambda_i, \lambda_j \geq 0$$

where λ_i and λ_j are the Lagrange multipliers for the profitability constraints for Retailers i and j, respectively. The general solution to Equation (14) is given in Equation (18).

Figure 6 Horizontal Analysis for a Given w, with Symmetric Retailers

	Noncooperating Retailers	Cooperating Retailers
Retailer i Retail Price	$\dfrac{1}{2b_p + \theta_p - b_s(b_s + \theta_s)/\eta_i}(\alpha_i - wb_p) + w$	$\dfrac{1}{2b_p - (b_s)^2/\eta_i}(\alpha_i - wb_p) + w$
Retailer i Service	$\dfrac{b_s + \theta_s}{(2b_p + \theta_p)\eta_i - b_s(b_s + \theta_s)}(\alpha_i - wb_p)$	$\dfrac{b_s}{2b_p\eta_i - (b_s)^2}(\alpha_i - wb_p)$
Retailer i Demand	$\dfrac{b_p + \theta_p}{2b_p + \theta_p - b_s(b_s + \theta_s)/\eta_i}(\alpha_i - wb_p)$	$\dfrac{b_p}{2b_p - (b_s)^2/\eta_i}(\alpha_i - wb_p)$
Retailer i Profit	$\dfrac{b_p + \theta_p - (b_s + \theta_s)^2/(2\eta_i)}{(2b_p + \theta_p - b_s(b_s + \theta_s)/\eta_i)^2}(\alpha_i - wb_p)^2 - f_i - \phi$	$\dfrac{1}{4(b_p - (b_s)^2/(2\eta_i))}(\alpha_i - wb_p)^2 - f_i - \phi$

$$w = \frac{\left[\begin{array}{l}(\alpha_i/b_p - c)\left[(b_p + \theta_p)(U_j + V_i) - b_p \dfrac{[\lambda_i U_i U_j (U_j + V_j) + \lambda_j U_j V_i (U_i + V_i)]}{U_i U_j - V_i V_j}\right] \\ +(\alpha_j/b_p - c)\left[(b_p + \theta_p)(U_i + V_j) - b_p \dfrac{[\lambda_i U_i V_j (U_j + V_j) + \lambda_j U_i U_j (U_i + V_i)]}{U_i U_j - V_i V_j}\right]\end{array}\right]}{2(b_p + \theta_p)(U_i + U_j + V_i + V_j) - b_p \dfrac{[\lambda_i U_i (U_j + V_j)^2 + \lambda_j U_j (U_i + V_i)^2]}{U_i U_j - V_i V_j}} + c. \tag{18}$$

The two complementary slackness constraints (15) and (16) can be satisfied three possible ways: (i) $\lambda_i \neq 0$, $\lambda_j = 0$; (ii) $\lambda_i = 0$, $\lambda_j \neq 0$; or (iii) $\lambda_i \neq 0$, $\lambda_j \neq 0$. In case (i), because $\lambda_i = 2$ by (17), (18) yields the expression defined as $w(i)$ in (5). This also requires $U_i[M_i]^2/2 - f_i - \phi = 0 \leq U_j[M_j]^2/2 - f_j - \phi$ at $w = w(i)$, which is consistent with the ϕ^* defined in (3). Similarly, case (ii) requires $\lambda_j = 2$, so that (18) yields the expression defined as $w(j)$ in (5). In this case $U_j[M_j]^2/2 - f_j - \phi = 0 \leq U_i[M_i]^2/2 - f_i - \phi$ at $w = w(j)$. Case (iii) requires that $U_j[M_j]^2/2 - f_i - \phi = 0 = U_i[M_i]^2/2 - f_j - \phi$. After considerable algebra, this equality solves to the $w(ij)$ defined in (6).

The value of $w(ij)$ lies between $w(i)$ and $w(j)$ by the following logic. Under the condition that $\lambda_j = 2 - \lambda_i$, (18) indicates that the solution to (14) is continuous and monotone in λ_i. By construction, $Z(w(j)) \leq f_j - f_i$ corresponds to $\lambda_i = 0$, and $Z(w(i)) \geq f_j - f_i$ corresponds to $\lambda_i = 2$. Because $Z(\,)$ is continuous, there exists some w between $w(i)$ and $w(j)$ such that $Z(w) = f_j - f_i$. This is our $w(ij)$, and can be obtained from (18) for some λ_i between 0 and 2, although the specific λ_i is unimportant for our purposes. □

Proof of Proposition 4. For completely asymmetrical retailers ($\alpha_i \neq \alpha_j$, $\eta_i \neq \eta_j$), a general $W(Q,s)$ coordinates the NC system only if it satisfies the following conditions:

$$W'_Q(D_i^*, s_i^*) = \Psi_i/\Phi \text{ for } i \in \{1, 2\}, \text{ and} \tag{19}$$

$$W'_s(D_i^*, s_i^*) = \theta_s(p_j^* - c) - (b_s + \theta_s)(W'_Q(D_i^*, s_i^*) - c) \quad \text{for } i \in \{1, 2\},\ j = 3 - i, \tag{20}$$

where

$$\begin{aligned}\Psi_i \equiv{} & \Delta^3(b_p + \theta_p)[(b_s + \theta_s)(cb_s + p_j^*\theta_s)/\eta_i + p_i^* U_i - p_j^* V_j - \alpha_i] \\ & - \Delta^2\theta_s(b_p + \theta_p)(U_i U_j/\eta_j - V_i V_j/\eta_i)(cb_s + p_i^*\theta_s) - \Delta^2 V_i(V_i - V_j) \\ & \left[\begin{array}{l}(cb_s + p_j^*\theta_s)(V_j\theta_s/\eta_j - U_j(b_s + \theta_s)/\eta_i) - p_i^*\Delta + \alpha_i U_j \\ + \alpha_j V_j + (cb_s + p_i^*\theta_s)(\theta_s(b_p + \theta_p) + (b_p\theta_s - b_s\theta_p))/\eta_j\end{array}\right],\end{aligned}$$

$\Phi \equiv \Delta^2[\Delta(b_p + \theta_p)^2 + (b_p + \theta_p)(V_i - V_j)(U_j V_i - U_i V_j) - V_i V_j (V_i - V_j)^2]$, and $\Delta \equiv U_i U_j - V_i V_j$. This can be established as follows.

We determine the Nash equilibrium between retailers by developing each retailer's best response to the other's behavior, given the wholesale price scheme. Retailer i's profit is

$$\pi_i^R = p_i \cdot D_i - W(D_i, s_i) - \eta_i s_i^2/2,$$

and the first derivatives are

$$\partial\pi_i^R/\partial s_i = (b_s + \theta_s)p_i - (b_s + \theta_s)W'_Q(D_i, s_i) - W'_s(D_i, s_i) - \eta_i s_i, \text{ and} \tag{21}$$

$$\partial\pi_i^R/\partial p_i = \alpha_i - 2(b_p + \theta_p)p_i + \theta_p p_j + (b_s + \theta_s)s_i - \theta_s s_j + (b_p + \theta_p)W'_Q(D_i, s_i). \tag{22}$$

Let us use "hats" on variables to represent the equilibrium outcome for a given $W(Q, s)$ (i.e., $\hat{p}_i$, $\hat{s}_i$, and $\hat{D}_i$ for $i = 1, 2$). Supposing that Retailer j sets $\hat{p}_j = p_j^*$ and $\hat{s}_j = s_j^*$, we can see from (21) and (22) and some algebra that if Retailer i sets $\hat{p}_i = p_i^*$ and $\hat{s}_i = s_i^*$ (so that $\hat{D}_i = D_i^*$ and $\hat{D}_j = D_j^*$) and $W(Q, s)$ satisfies (19) and (20), first order conditions for maximizing Retailer i's profit will be satisfied. A similar argument holds for Retailer j. So, the globally optimal combination of retail prices and service levels is a candidate for the retail Nash equilibrium when such a $W(Q, s)$ is used. Because of the freedom available in designing $W(Q, s)$, any further structure needed to satisfy second-order conditions does not appear to be prohibitive.

Part (a) then follows directly from setting $\eta_i = \eta_j$ in (19) and (20). For part (b), we first note that the second-order conditions for each retailer's profit maximization hold conclusively for any three-part tariff. For retailers differing in market base, the two equations in (7) become

$$w = c + \frac{\theta_p}{b_p + \theta_p}(p_j^* - c) \text{ and } w = c + \frac{\theta_p}{b_p + \theta_p}(p_i^* - c).$$

These can be true simultaneously if and only if $\theta_p(\alpha_i - \alpha_j) = 0$, which requires $\theta_p = 0$ because $\alpha_i \neq \alpha_j$. Likewise, the two equations in (8) become

$$k = \frac{b_p\theta_s - b_s\theta_p}{b_p + \theta_p}(p_j^* - c) \text{ and } k = \frac{b_p\theta_s - b_s\theta_p}{b_p + \theta_p}(p_i^* - c).$$

These can be true simultaneously if and only if $(b_p\theta_s - b_s\theta_p)(\alpha_i - \alpha_j) = 0$, which requires $\theta_s = 0$ (because $\alpha_i \neq \alpha_j$, $\theta_p = 0$, and $b_p > 0$). Hence, (7) and (8) will be simultaneously satisfied if and only if $\theta_s = \theta_p = 0$, in which case $w = c$ and $k = 0$, as stated in Part (b.i). When the retailers are symmetrical in market base, (7) and (8) are each only a single condition, i.e., $w = c + (\alpha_i - cb_p)\theta_p/[(b_p + \theta_p)(2b_p - b_s^2/\eta_i)]$ and $k = (\alpha_i - cb_p)(b_p\theta_s - b_s\theta_p)/[(b_p + \theta_p)(2b_p - b_s^2/\eta_i)]$, as stated in Part (b.ii). □

Proof of Proposition 5. To show Part (a), note that (19) and (20), along with the results in Figure 4, indicate a necessary condition of

$$\frac{b_p\theta_s - b_s\theta_p}{(b_p + \theta_p)(b_s + \theta_s)}(p_j^* - c) = 0.$$

Because $p_j^* \neq c$, this holds only when $b_p\theta_s = b_s\theta_p$.

For part (b), we first note that the second-order conditions for each retailer's profit maximization hold conclusively for any two-part tariff. For retailers differing in market base, the two equations represented by setting (21) equal to zero become

$$w = c + \frac{\theta_p}{b_p + \theta_p}(p_j^* - c) \text{ and } w = c + \frac{\theta_p}{b_p + \theta_p}(p_i^* - c).$$

These can be true simultaneously if and only if $\theta_p(\alpha_i - \alpha_j) = 0$, which requires $\theta_p = 0$ because $\alpha_i \neq \alpha_j$. Because Part (a) established the necessity of $b_s\theta_p = b_p\theta_s$, this implies $\theta_s = 0$. Hence, (21) becomes $w = c$, as in Part (b.i). When the retailers are symmetrical in market base, (21) is only a single condition, i.e., $w = c + (\alpha_i - cb_p)\theta_p/[(b_p + \theta_p)(2b_p - b_s^2/\eta_i)]$, as stated in Part (b.ii). □

References

Banker, R. D., I. Khosla, K. K. Sinha. 1998. Quality and competition. *Management Sci.* **44**(9) 1179–1192.

Cachon, G. P. 1997. Stock wars: Inventory competition in a two-echelon supply chain with multiple retailers. Working paper. Fuqua School of Business, Duke University. *Oper. Res.* Forthcoming.

——. 1999. Competitive supply chain inventory management. S. Tayur, R. Ganeshan, M. Magazine, eds. *Quantitative Models for Supply Chain Management.* Kluwer Academic Publishers, Norwell, MA.

——, M. A. Lariviere. 1999a. Capacity allocation using past sales: When to turn-and-earn. *Management Sci.* **45**(5) 685–703.

——, ——. 1999b. Capacity choice and allocation: Strategic behavior and supply chain performance. *Management Sci.* **45**(8) 1091–1108.

Chen, F., A. Federgruen, Y. Zheng. 1998. Coordination mechanisms for a distribution system with one supplier and multiple retailers. Working paper. Graduate School of Business, Columbia University, New York.

Choi, S. C. 1996. Price competition in a duopoly common retailer channel. *J. Retailing.* **72**(2) 117–134.

Coughlan, A. T., B. Wernerfelt. 1989. On credible delegation by oligopolists: A discussion of distribution channel management. *Management Sci.* **35**(2) 226–239.

Demange, G., J.-P. Ponssard. 1985. Asymmetries in cost structures and incentives towards price competition. *Internat. J. Indust. Organ.* **3** 85–100.

Desiraju, R., S. Moorthy. 1997. Managing a distribution channel under asymmetric information with performance requirements. *Management Sci.* **43**(12) 1628–1644.

Dixit, A. 1979. Quality and quantity competition. *Rev. Econom. Stud.* **46** 587–599.

Ginsburg, D. H. 1993. Nonprice competition. *The Antitrust Bull.* **38**(1) 83–111.

Ingene, C. A., M. E. Parry. 1995. Channel coordination when retailers compete. *Marketing Sci.* **14**(4) 360–377.

——, ——. 1998. Manufacturer-optimal wholesale pricing when retailers compete. *Marketing Lett.* **9**(1) 65–77.

Iyer, G. 1998. Coordinating channels under price and non-price competition. *Marketing Sci.* **17**(4) 338–355.

Jeuland, A. P., S. M. Shugan. 1983. Managing channel profits. *Marketing Sci.* **2** 239–272.

Karmarkar, U. S., R. C. Pitbladdo. 1997. Quality, class, and competition. *Management Sci.* **43**(1) 27–39.

Katz, M. L. 1989. Vertical contractual relations. R. Schmalensee, R. D. Willig eds. *Handbook of Industrial Organization: Volume 1.* Elsevier Science Publishers B. V., New York.

Lippman, S. A., K. F. McCardle. 1997. The competitive newsboy. *Oper. Res.* **45**(1) 54–65.

Mathewson, G. F., R. A. Winter. 1984. An economic theory of vertical restraints. *Rand J. Econom.* **15**(1) 27–38.

McGuire, T. W., R. Staelin. 1983. An industry equilibrium analysis of downstream vertical integration. *Marketing Sci.* **2**(2) 161–191.

——, ——. 1986. Channel efficiency, incentive compatibility, transfer pricing, and market structure: An equilibrium analysis of channel relationships. L. P. Bucklin, J. M. Carmen, eds. *Research in Marketing: Distribution Channels and Institutions.* **8** JAI Press, Greenwich, CT 181–223.

Moorthy, K. S. 1987. Managing channel profits: Comment. *Marketing Science.* **6**(4) 375–379.

Nahmias, S. 1997. *Production and Operations Analysis, Third Edition.* Irwin, Homewood, IL.

Padmanabhan, V., I. P. L. Png. 1997. Manufacturer's returns policies and retail competition. *Marketing Sci.* **16**(1) 81–94.

Parlar, M. 1988. Game theoretic analysis of the substitutable product inventory problem with random demands. *Naval Res. Logist.* **35** 397–409.

Perry, M. K., R. H. Porter. 1990. Can resale price maintenance and franchise fees correct sub-optimal levels of retail service. *Internat. J. Indus. Organ.* **8** 115–141.

Shapiro, C. 1989. Theories of oligopoly behavior. R. Schmalensee, R. D. Willig eds. *Handbook of Industrial Organization: Volume 1.* Elsevier Science Publishers B. V., New York.

Spence, A. M. 1975. Monopoly, quality, and regulation. *Bell J. Econom.* **6** 417–429.

Spengler, J. J. 1950. Vertical restraints and antitrust policy. *J. Political Econom.* **58** 347–352.

Tirole, J. 1988. *The Theory of Industrial Organization.* The MIT Press, Cambridge, MA.

Trivedi, M. 1998. Distribution channels: An extension of exclusive retailership. *Management Sci.* **44**(7) 896–909.

Tsay, A. A., S. Nahmias, N. Agrawal. 1999. Modeling supply chain contracts: A review. *Quant. Models for Supply Chain Management*. S. Tayur, R. Ganeshan, M. Magazine eds., Kluwer Academic Publishers, Norwell, MA 299–336.

Winter, R. 1993. Vertical control and price versus nonprice competition. *Quart. J. Econom.* **108**(1) 61–76.

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