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Customer-Driven vs. Retailer-Driven Search: Channel Performance and Implications

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A common phenomenon that occurs in any decentralized multilocation system is stock imbalance, whereby some locations have unsatisfied demands while others are overstocked. The system can be rebalanced by using a search process that is driven by either the customers or the retailers. In a customer-driven search (CDS), the customer with unmet demand may search for the product at another location and, if it is available, complete the purchase. In a retailer-driven search (RDS), the retailer with unsatisfied demand searches for product and schedules transshipment to fulfill the unmet demand at his location. Of course, the revenues generated through search in RDS need to be shared between the parties according to a transfer pricing scheme. In a setting of one manufacturer and two retailers with price-dependent and random demand, we explore the impact of the search method and the transfer price scheme used on the preferences of the manufacturer, the retailers, and the customers. With endogenous retail prices, we find that both the manufacturer and the retailers prefer RDS over CDS when they can design the transfer pricing scheme in RDS. Interestingly, neither party prefers the fixed transfer pricing scheme commonly assumed in the literature. Instead, transfer price that is proportional to the price of the retailer with either excess stock or excess demand is preferred. However, although both parties favor an RDS system when they can design the transfer pricing scheme in RDS, they may prefer RDS or CDS when the other party designs the RDS. Thus, the interests of the manufacturer and the retailers are rarely aligned. Customers benefit from a lower price in an RDS but at the expense of lower availability (as measured by the level of safety stock).

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1. Introduction

Multilocation distribution networks that keep inventory "close to the customers" are quite common. Because stock deployment usually occurs before the actual demand is known, such systems face a potential problem of stock *imbalance*, whereby some locations have unsatisfied demands while others are overstocked. The multilocation system can be rebalanced by matching unmet demand with available supply. This process necessarily involves "search," which refers to looking for product in the network. In practice, search can be driven in a variety of ways. For example, in a network with *customer-driven search* (CDS), customers who are unable to find a product (unmet demand) at their local retailer will search for it at another retailer and, if available, complete the purchase at that retailer; in a network with *retailer-driven search* (RDS), however, it is the retailer with excess demand who will search the network for the product and arrange for transshipment to his location. The RDS strategy has also been referred to as *locate to order* (Agrawal et al. 2001). Two examples from the automobile industry are used to illustrate that technology plays a critical role in facilitating either search method.

General Motors Corporation (GM) maintains a website that is updated with information furnished by participating GM dealers. Beyond customary product specification, the website provides a potential customer with a list of dealers and the ability to search a dealer's inventory for product availability. By providing inventory information to customers, GM facilitates a CDS environment. Ford Motor Company's websites offer similar functionality to the customers. Honda and Toyota, through their websites, also allow potential customers to locate local dealers; however, they do not make dealer inventory visible to them. In the event that someone cannot find the desired model at his chosen dealer, it is common practice for the dealer to offer to search an internal network for the product at other dealers. If the choice is available, the dealer will schedule a transshipment of the product. Both Honda and Toyota, with an internal information system that gives inventory information only to dealers, facilitate RDS.[1]

In a multilocation network with independently operating retailers, search creates a strategic interaction among retailers. The two methods of search discussed above raise some interesting questions. How do different search methods affect retailer performance? Which search method is preferable to the retailers and which does the manufacturer prefer? Are their preferences impacted by the choice of the transfer pricing scheme in RDS? How do the choices impact retail price and availability—issues of concern to the customer? We address these issues in this paper.

To capture the key trade-offs, we build a parsimonious model by considering a single-period supply chain of one manufacturer and two symmetric retailers. Retailers face a downward sloping linear demand curve that is a function of the retail prices at both retailers with an additive random shock.[2] Retailers determine prices and stock levels before the actual demand is observed. After observing the actual demand, each retailer satisfies his local demand up to stock availability. In the event of a stockout, a fraction of the customers with unmet demand switch to the other retailer for demand satisfaction. We call this fraction *search intensity* and denote it by α $(0 \leq \alpha \leq 1)$. The retailers are risk neutral and maximize expected profits. We abstract away from the costs of search and transshipment to focus on the strategic interactions between the retailers under the two search methods.

Under RDS, we assume that the surplus revenue generated through a search is shared between the two retailers as determined by a transfer pricing scheme. Transfers happen only when one retailer has excess stock and the other has excess demand; we call the former the *source* retailer and the latter the *sink* retailer. We consider three transfer pricing schemes. The first two are proportional schemes where the transfer price is a fraction of the (retail) price at one of the retailers; these two schemes differ in whether the transfer price is tied to the sink or the source retail price. In the third scheme, we consider a fixed transfer payment (independent of retail price) for the exchange of goods. Regardless of the transfer pricing scheme in use, we assume that a customer pays the price charged by the retailer that he chooses to visit first.

The main managerial insights are obtained through a comparative analysis of exogenous and endogenous price models under the CDS and RDS search methods and various transfer pricing schemes. Our comparative analysis assumes that the search intensity is the same across the various systems being compared. A search triggered by stockouts creates stock competition between the two retailers. A model with exogenous retail prices therefore exhibits *pure stock competition*. With endogenous retail pricing, however, retailers engage in both *price* and *stock competition*. We show that the insights obtained in the exogenous price models (the focus of the extant literature) do not necessarily carry over to the endogenous price models. In particular, although CDS is equivalent to RDS when the source retailer keeps all surplus revenue in an exogenous price model, a similar equivalence exists in an endogenous price model only when a fixed transfer payment equal to the CDS retail price is used in RDS. With endogenous pricing and for symmetric search intensity, we find that both the manufacturer and the retailers prefer RDS over CDS, as long as they select the transfer pricing scheme and payment parameters in RDS. A fixed transfer payment is generally assumed in the literature, yet we find that neither party will choose such a scheme in RDS. Instead,

[1] We do not claim that each of the companies mentioned above focuses exclusively on one type of search. There is anecdotal evidence to suggest that GM and Ford dealers offer to search other dealerships on their customers' behalf for a product they may not have in stock. Similarly, some Honda and Toyota dealers set up websites that include information regarding their vehicle inventory. The original equipment manufacturer (OEM) company initiatives, however, facilitate one or the other type of search.

[2] For simplicity, we assume a linear additive demand function, commonly used in the literature. An alternative specification is a multiplicative demand function in which the random factor enters as a scale parameter. Such a specification could significantly complicate equilibrium analysis.

the manufacturer prefers a transfer price proportional to the sink retailer's price, and the retailers prefer a transfer price proportional to the source retailer's price. Furthermore, although both the manufacturer and the retailers prefer RDS when they design RDS, they may prefer CDS over RDS when the other party designs RDS. Finally, we find that the retail price and the safety stock (as a proxy for availability) are usually lower in RDS than in CDS.

We study several extensions. First, the qualitative nature of the above results continues to hold even when the intensity of stock competition in CDS endogenously depends on the difference in the prices charged by the two retailers. Second, we show that even with a positive salvage value of leftover inventory, there are always transfer prices that are larger than the salvage value such that it is in the interest of the retailers to share inventory. Therefore, the key results of the paper continue to hold. Finally, although several factors such as search and transshipment costs, willingness to wait, etc. may lead to differing search intensities in the two systems, the preferences of the manufacturer and the retailers toward RDS when they design it continues to hold as long as the search intensity in RDS is above certain thresholds; otherwise, they would prefer the CDS.

The rest of the paper is organized as follows. In §2, we review relevant literature. We present the duopoly models in §3. For the analysis of RDS, we initially focus on a specific transfer pricing scheme whereby the transfer price is proportional to the price at the sink retailer. In §4, we conduct an equilibrium analysis and present comparative statics of CDS and RDS. In §5, we compare the performances of the duopoly under the two search methods. In §6, we study the robustness of our results to specific assumptions on search intensity, explore alternative transfer pricing schemes, and discuss the impact of a positive salvage value for leftover inventory. We close this section with a discussion of the factors that may influence the level of search between CDS and RDS. Section 7 concludes. All proofs as well as the technical results for the properties of the induced distribution functions are available online in an electronic companion to this paper.

2. Literature Review

The stream of literature that closely relates to our research is the analysis of decentralized multilocation systems. Anupindi et al. (2001) propose three attributes to classify literature in this area: *search* (customer or retailer driven), *system* (duopoly or oligopoly), and *interaction* (horizontal among retailers or vertical to also include the impact on the manufacturer). In this paper, we add a fourth attribute, *price*, which refers to whether the model treats retail price as exogenous or endogenous. Most papers in the extant literature assume *exogenous* retail prices. This paper considers *endogenous* retail pricing.

Parlar (1988), Karjalainen (1992), Lippman and McCardle (1997), and Netessine and Rudi (2003) analyze duopoly or oligopoly models with CDS to focus on horizontal interaction among the retailers. Anupindi and Bassok (1999) analyze a duopoly model with CDS and consider the vertical interaction between the manufacturer and the retailers to show that the geographic centralization of stock may not be in the best interest of the manufacturer; she may prefer a decentralized system when search intensity is high. Anupindi et al. (1999) characterize necessary and sufficient conditions for the existence of coordinating transfer prices in a duopoly model with RDS; they also study oligopoly models with RDS and derive alternative coordinating revenue sharing mechanisms. Rudi et al. (2001) study a duopoly model with RDS and identify transfer prices that induce the locations to choose the first-best inventory levels. Hu et al. (2007) study a duopoly model with RDS when retailers have capacity constraints. Anupindi et al. (2001) develop a general study framework for RDS in an oligopoly model and show that an allocation mechanism always exists by which the noncooperative retailers make first-best decisions.

Dong and Rudi (2004) study the vertical interaction between an upstream manufacturer and a centrally controlled group of retailers in a single-period setting. They show that, with an exogenous wholesale price, the transshipment between the retailers always improves the supply chain performance. With an endogenous wholesale price, however, the manufacturer will raise the price when the retailers transship, which hurts the retailers' profits. Our paper is similar to theirs in the sense of a comparative analysis of exogenous and endogenous price decisions. Dong and Rudi (2004) focus on the *wholesale* price decision with centrally controlled retailers, but we focus on the *retail* price decision with competing retailers. Zhang (2005) extends the key results in Dong and Rudi (2004) to general demand distributions. Zhao et al. (2005) allow the retailer an option to not share his inventory, recognizing that for a retailer to give up a unit (to another retailer) now means that he has less inventory to satisfy his own demand in the immediate future. Transfer price in their model, however, is exogenous. In an extension to our model, we include a positive salvage value to similarly allow for the possibility that a retailer may be unwilling to share his inventory. Under some reasonable assumptions, we show that there are always transfer prices at which it is indeed in the interest of the retailers to share inventory.

All of these papers study either CDS or RDS under an exogenous price setting. Analysis of price-setting newsvendor models (Mills 1959, Karlin and Carr 1962, Petruzzi and Dada 1999, Lariviere and Porteus 2001) mainly focuses on monopoly settings. Wang (2006) analyzes joint price and production decisions in an oligopoly model and evaluates the impact of the sequence of price and quantity decisions on channel performance. Her model, however, does not include stockout-triggered search. Dana (2001) analyzes price and stocking decisions in a duopoly setting, where customers make a purchase decision based on both price and expected stock availability. Cachon et al. (2005) explore the interactions between customer search behavior and assortment planning. Search in their model, however, is not triggered by temporary stockouts. In contrast, we analyze models of stockout-based substitution where competing retailers face price dependent demand.

Some recent work considers endogenous pricing decisions and substitution behavior in competitive settings. Cachon et al. (2008) study the impact of consumer search on assortment and price decisions in a competitive environment. Zhao and Atkins (2008)[3] consider an oligopoly model with endogenous prices. Their basic model generalizes our duopoly CDS model; however, our paper differs in several ways. First, by focusing on a symmetric duopoly we are able to offer more specific equilibrium and comparative statics results. Second, we extend the analysis for the CDS model to include endogenous search intensity. Finally, we compare CDS and RDS to investigate the preference of various parties over the search method.

3. Model

We consider a single-period model of a supply chain consisting of one manufacturer and two symmetric retailers. Market demands are price sensitive and uncertain. Before the actual demand curves are revealed, the two retailers simultaneously set retail prices and order stock. The manufacturer charges a wholesale price, w, to each retailer, and instantaneously delivers their orders. Based on the retail prices, people choose a retailer to visit, forming *local demand*. After the demand curve is revealed, each retailer satisfies local demand up to availability.

The second step of demand satisfaction is facilitated by *search*. Specifically, if one retailer has excess stock and the other has excess demand, a fraction $\alpha \in [0, 1]$ of the excess demand is satisfied by the excess stock. We call this fraction *search intensity*. We consider two methods of search driven respectively by customers (CDS) and retailers (RDS). In a CDS system, a fraction (determined by α) of customers with unmet demand at their local retailer searches for the product at the other retailer and, if it is available, completes the purchase. The revenue from such sales accrues solely to the retailer satisfying the demand. In an RDS system, however, to satisfy a fraction (determined by α) of its unmet demand, the retailer searches for the product at the other retailer and requests transshipment. The additional revenue thus generated is allocated between the retailers according to some transfer pricing scheme (to be discussed later).

Initially, we assume the search intensity (α) to be an exogenous parameter and identical in both systems. We also assume that there is no additional penalty for unsatisfied demand and that the holding cost and the salvage value are normalized to zero. We also abstract away from the costs of search and transshipment to focus on the strategic interactions between the retailers under the two search methods. In §6, we relax some of these assumptions to demonstrate the robustness of our methodology and results.

Sales generated by satisfying the local demand are called *local sales*. The portion of the excess demand at one retailer that "switches over" to the other is called the *spillover demand*. The *total demand* faced by a

[3] We thank the editor for bringing this paper to our attention.

retailer is the sum of the local and spillover demands, which we call the *effective demand*. The retailer with excess stock that satisfies the spillover demand is the source retailer; the retailer receiving the excess stock is the sink retailer. Additional sales generated through such a process are called the *spillover sales*. We model the local demand at retailer i by

$$D_i(p_i, p_j, \varepsilon_i) = y_i(p_i, p_j) + \varepsilon_i, \quad \text{for } i, j = 1, 2 \text{ and } i \neq j.$$

In particular:

$$y_i(p_i, p_j) = a - \frac{b}{1-r}p_i + \frac{br}{1-r}p_j, \quad \text{for } i, j = 1, 2 \text{ and } i \neq j, \tag{1}$$

where a is potential market size, b indicates price sensitivity, and $r \in (0, 1)$ is the substitution ratio. Under this demand function, the aggregate demand at the two retailers is unaffected by r (see McGuire and Staelin 1983, for details). We assume that ε_i follows a general distribution with a probability density function $f(\cdot)$ and a cumulative density function $F(\cdot)$ on support $[-B, B]$ for some $B > 0$. To ensure the nonnegativity of the local demand, we require that $a > bw + B$. Substitution ratio, r, reflects the intensity of the price competition. The larger its value, the more price competitive the market is. An alternative interpretation for r is the degree of product differentiation—a higher value of r indicates lesser product differentiation. Product differentiation can either be in geographic space (for example, we expect r to be large when the retailers are close to each other) or represent the similarity of the products in the attribute space (with a high r representing highly similar products).

We follow Petruzzi and Dada (1999) to define the stock at retailer i as $q_i = y(p_i, p_j) + z_i$, where z_i is the *safety stock* that buffers against the random effective demand. Thus, the problem of solving for the optimal price and stock is equivalent to that of solving for the optimal price and safety stock. We let $\mathbf{p} = (p_1, p_2)$ and $\mathbf{z} = (z_1, z_2)$ be the vectors of retail prices and safety stocks, respectively, at the two retailers, and $\mathbf{s}_i = (p_i, z_i)$ the decision vector of retailer i, for $i = 1, 2$.

In the notations that follow, we use indices i and j for retailers, and $t \in \{R, C\}$ to denote the search method with R representing RDS and C representing CDS. We first derive the expressions for local and spillover sales.

Local Sales. Suppose that retailer i sets stock q_i. His local sales satisfy both the price-dependent component $y_i(\mathbf{p})$ and the random component of local demand. We can express the expected local sales as

$$\begin{aligned}\mathrm{LS}_i(\mathbf{p}, \mathbf{z}) &= y_i(\mathbf{p}) + E[\mathrm{Min}\{z_i, \varepsilon_i\}] \\ &= a - \frac{b}{1-r}p_i + \frac{br}{1-r}p_j + z_i - \Lambda(z_i),\end{aligned} \tag{2}$$

where $\Lambda(x) = \int_{-B}^{x} (x - \varepsilon)\, dF(\varepsilon)$ is the expected leftover stock after satisfying local demand.

Spillover Sales. After the two retailers satisfy local demands up to stock availability, potential spillover sales exist. When either both retailers have excess stocks or both have excess demands, there is no opportunity for further stock search and no spillover sales will be realized. However, if retailer i has excess stock and retailer j ($j \neq i$) has excess demand, then a fraction of the excess demand at retailer j will be satisfied by the excess stock at retailer i; we can express the expected spillover sales as

$$\begin{aligned}\mathrm{IS}_{i,j}(\mathbf{z}) &= E[\mathrm{Min}\{(z_i - \varepsilon_i)^+, \alpha(\varepsilon_j - z_j)^+\}] \\ &= \alpha\Lambda(z_j)F(z_i) + \Lambda(z_i) \\ &\quad - \alpha\int_{-B}^{z_i} \Lambda\left(z_j + \frac{z_i - x_i}{\alpha}\right) dF(x_i) \\ &\qquad \text{for } i, j = 1, 2,\ i \neq j.\end{aligned} \tag{3}$$

3.1. Retailer-Driven Search

Define direct profit as the revenue accrued from local sales less the cost of the initial stock. Then by (2), the direct profit of retailer i is

$$\begin{aligned}\mathrm{DP}_i &\equiv p_i \cdot \mathrm{LS}_i(z_i) - wq_i \\ &= (p_i - w)\left(a - \frac{b}{1-r}p_i + \frac{br}{1-r}p_j + z_i\right) - p_i\Lambda(z_i).\end{aligned}$$

The revenue earned from spillover sales depends on the price at which the excess demand is satisfied and the transfer pricing scheme in use. Suppose that retailer i is the sink retailer and charges price p_i. Because the customer initially visited retailer i, it is reasonable to assume that the spillover sales will be made at price p_i. Several possibilities exist for the transfer pricing scheme to allocate the spillover sales revenue between the two retailers. We first assume the sink retailer pays a fraction β of his price to the source retailer, so that each unit of spillover sales $\mathrm{IS}_{j,i}(\mathbf{z})$ brings revenue p_i, out of which retailer i remits $\beta \cdot p_i$ to retailer j and keeps the remainder. Similarly, each unit of spillover sales $\mathrm{IS}_{i,j}(\mathbf{z})$ brings unit revenue p_j, out of which a fraction β is allocated to retailer i as the source retailer. Hence, the expected *indirect* profit of retailer i in RDS under this transfer pricing scheme, consisting of total revenue earned through spillover sales, is

$$IP_i^R(\mathbf{z},\mathbf{p}) = (1-\beta)p_i \cdot \mathrm{IS}_{j,i}(\mathbf{z}) + \beta \cdot p_j \cdot \mathrm{IS}_{i,j}(\mathbf{z}).$$

The expected profit of retailer i is the sum of direct and indirect profits, as follows:

$$\Pi_i^R(\mathbf{z},\mathbf{p}) = (p_i - w)\left(a - \frac{b}{1-r}p_i + \frac{br}{1-r}p_j + z_i\right) + p_i[(1-\beta)\mathrm{IS}_{j,i}(\mathbf{z}) - \Lambda(z_i)] + p_j\beta\mathrm{IS}_{i,j}(\mathbf{z}). \quad (4)$$

Other transfer pricing schemes are possible. One alternative is to set the transfer price to be in proportion to the price charged by the source retailer. Another is a fixed transfer payment regardless of the retail prices. We consider these alternatives in §6.2.

3.2. Customer-Driven Search

The two search models differ only at the second stage of stock search that influences the indirect profits of the retailers. The direct profit of retailer i in a CDS system is identical to what he could earn in an RDS system. In addition, retailer i earns revenue from customer search only when he is the source retailer. The relevant spillover sales are $\mathrm{IS}_{i,j}(\mathbf{z})$, and that retailer's expected indirect profit is $p_i \cdot \mathrm{IS}_{i,j}(\mathbf{z})$. The expected profit of retailer i, as the sum of direct and indirect profits, can be written as

$$\Pi_i^C(\mathbf{z},\mathbf{p}) = (p_i - w)\left(a - \frac{b}{1-r}p_i + \frac{br}{1-r}p_j + z_i\right) + p_i[\mathrm{IS}_{i,j}(\mathbf{z}) - \Lambda(z_i)]. \quad (5)$$

Based on the profit functions of the retailers under the two search methods, an RDS system differs from a CDS system in two important ways: (a) the unit revenue from the spillover sales through search and (b) the allocation of the revenue thus generated between the retailers. In particular, each unit of the spillover sales brings revenue equal to the price at the *source* (*sink*) retailer in a CDS (RDS) system. In terms of revenue allocation, although the source retailer retains all the spillover sales revenue in a CDS system, the retailers share such revenue in an RDS system. When retail prices are exogenous and identical across retailers, an RDS with $\beta = 1$ is equivalent to CDS. This is not so, however, under the current transfer pricing scheme and when retail prices are endogenous. The revenue accrued through search is allocated in the same way in both systems, but the price affecting spillover revenue is set by different retailers—the source retailer in CDS and the sink retailer in RDS—which leads to different prices, and hence the equivalence of CDS with RDS at $\beta = 1$ breaks down.

4. Analysis

We now present an equilibrium analysis of the duopoly under the two search methods. We first derive sufficient conditions for the existence and uniqueness of the Nash equilibrium solutions. Subsequently, we do comparative statics to evaluate the impact of search intensity, the substitution ratio, and the transfer price on prices, stocks, and sales. With an explicit goal to isolate the effects of the search method on system performance in endogenous price settings, we focus on symmetric equilibria.[4] With the equilibrium results, we then examine the preferences of the manufacturer and the retailers between the two search methods. We use CDS(α) and RDS(α, β) to denote the dependence of CDS and RDS on respective system parameters.

4.1. Equilibrium Characterization

For a retailer in RDS, there are three sources of sales from random effective demand. The first two are the local sales and a share of the spillover sales he makes by having his unmet demand satisfied by the excess stock at the other (source) retailer. We express the sales from these two sources as $\mathrm{ESL}_i^R(\mathbf{z}) \equiv z_i - \Lambda(z_i) + (1-\beta)\mathrm{IS}_{j,i}(\mathbf{z})$. The third source of revenue comes from the spillover sales he makes by using excess stock to

[4] Asymmetric equilibria may exist; however, without the assumption of symmetric equilibrium, it would be hard to proceed with comparative analysis to show the effects of endogenous pricing. Most literature on joint pricing and stocking decisions focuses on symmetric solutions (see Cachon 2003, Dong and Rudi 2004). We continue to follow the precedence.

satisfy the spillover demand from the other retailer in stockout; we express this as $\mathrm{ESN}_i^R(\mathbf{z}) \equiv \beta \cdot \mathrm{IS}_{i,j}(\mathbf{z})$. When the retail prices at the two retailers are identical, we can combine the sales from the three sources to give

$$\begin{aligned}\mathrm{ES}_{\alpha,\beta}(\mathbf{z}) &= \mathrm{ESL}_i^R(\mathbf{z}) + \mathrm{ESN}_i^R(\mathbf{z}) \\ &= z_i - \Lambda(z_i) + (1-\beta)\cdot \mathrm{IS}_{j,i}(\mathbf{z}) + \beta \cdot \mathrm{IS}_{i,j}(\mathbf{z}). \quad (6)\end{aligned}$$

In a CDS system, there are only two sources of revenue for retailer i: the local sales and the sales by satisfying the spillover demand from the other retailer. The combined sales from these sources are given by

$$\mathrm{EST}_i^C(\mathbf{z}) \equiv z_i - \Lambda_i(z_i) + \mathrm{IS}_{i,j}(\mathbf{z}) = \mathrm{ES}_{\alpha,1}(\mathbf{z}).$$

Next, consider the effect on sales of a marginal increase in the safety stock at retailer i; this can be broken down into three parts:

1. Marginal increase in his local sales:

$$M_1(\mathbf{z}) \equiv \Pr\{\varepsilon_i > z_i\} = 1 - F(z_i) \quad (7a)$$

2. Marginal decrease in the spillover sales from his excess demand made by the other retailer:

$$\begin{aligned}M_2(\mathbf{z}) &\equiv \alpha \Pr\{\varepsilon_i > z_i, \varepsilon_j + \alpha(\varepsilon_i - z_i) < z_j\} \\ &= \alpha \int_{-B}^{z_j} \left[F\left(z_i + \frac{z_j - x_j}{\alpha}\right) - F(z_i)\right] dF(x_j) \quad (7b)\end{aligned}$$

3. Marginal increase in the spillover sales he makes by satisfying the excess demand at retailer j:

$$\begin{aligned}M_3(\mathbf{z}) &\equiv \Pr\{\varepsilon_i < z_i, \varepsilon_i + \alpha(\varepsilon_j - z_j) < z_i\} \\ &= F(z_i) - \int_{-B}^{z_i} F\left(z_j + \frac{z_i - x_i}{\alpha}\right) dF(x_i) \quad (7c)\end{aligned}$$

Using these definitions, the marginal increase in $\mathrm{ESL}_i^R(\mathbf{z})$ with respect to z_i is equal to $M_1(\mathbf{z}) - (1-\beta)M_2(\mathbf{z}) \equiv 1 - N_R(\mathbf{z})$; and the marginal increase in $\mathrm{ESN}_i^R(\mathbf{z})$ with respect to z_i is $\beta \cdot M_3(\mathbf{z}) \equiv R_R(\mathbf{z})$. Let $n_R(\mathbf{z})$ be the marginal increase of $N_R(\mathbf{z})$ with respect to z_i, and define $H_{N_R}(\mathbf{z}) \equiv n_R(\mathbf{z})/(1 - N_R(\mathbf{z}))$. Similarly, $r_R(\mathbf{z})$ is the marginal increase of $R_R(\mathbf{z})$ with respect to z_i.

Likewise, in a CDS system, the marginal increase in $\mathrm{EST}_i^C(\mathbf{z})$ with respect to z_i is given by $M_1(\mathbf{z}) + M_3(\mathbf{z}) \equiv 1 - N_C(\mathbf{z})$. Let $n_C(\mathbf{z})$ be the marginal increase of $N_C(\mathbf{z})$ with respect to z_i, and define $H_{N_C}(\mathbf{z}) \equiv n_C(\mathbf{z})/(1 - N_C(\mathbf{z}))$. Lemma 1 offers sufficient conditions to guarantee the existence of a symmetric pure strategy Nash equilibrium in RDS and CDS systems.

Lemma 1. *With endogenous retail prices*:

1. *If* $2H_{N_R}^2(x, z_j) + dH_{N_R}(x, z_j)/dx \geq 0$ *for any* z_j *and* $r_R(x, z_j)/n_R(x, z_j)$ *decreases in* x *for* $j = 1, 2$, *then there exists a symmetric pure strategy Nash equilibrium in* RDS(α, β).
2. *If* $2H_{N_C}^2(x, z_j) + dH_{N_C}(x, z_j)/dx \geq 0$ *for any* z_j, *then there exists a symmetric pure strategy Nash equilibrium in* CDS(α).

The sufficient conditions given in Lemma 1 ensure the unimodality of the relevant profit functions. The conditions on the failure rate are similar to those needed by a monopolistic price-setting newsvendor, as discussed in Petruzzi and Dada (1999). The additional condition needed for RDS (Lemma 1, Part 1) ensures that, for a small change in the safety stock at one retailer, an increase in the rate of the sales from his own demand is higher than that from the other retailer's demand.

By (6), in a symmetric equilibrium, the marginal increase in the overall sales from the effective demand can be expressed as

$$\left.\frac{\partial \mathrm{ES}_{\alpha,\beta}(\mathbf{z})}{\partial z_i}\right|_{\mathbf{z}=(z,z)} = 1 - A_{\alpha,\beta}(z),$$

where $A_{\alpha,\beta}(z) \equiv 1 - M_1(z,z) + (1-\beta)M_2(z,z) - \beta M_3(z,z)$. We present the detailed properties of $A_{\alpha,\beta}(z)$ in the electronic companion (Lemma EC.1). A special property is that it increases in z with $A_{\alpha,\beta}(-B) = 0$ and $A_{\alpha,\beta}(B) = 1$. Thus, we can consider $A_{\alpha,\beta}(z)$ as a distribution function on $[-B, B]$ that captures the impact of the search intensity and the transfer price on the effective demand. To simplify exposition, we denote the sales generated by a retailer from the random effective demand in CDS when retailers select the same safety stock by $L_\alpha(z) = \mathrm{ES}_{\alpha,1}(z,z)$.

Proposition 1 below characterizes the symmetric equilibria, denoted by $\mathbf{s}^t = (p^t, z^t)$, for $t \in \{R, C\}$, under the two search methods.

Proposition 1. *With endogenous retail prices, suppose the sufficient conditions for* RDS(α, β) *and* CDS(α) *in Lemma* 1 *hold. Then*

1. *If* $A_{\alpha,\beta}(\cdot)$ *satisfies the increasing failure rate* (IFR) *property, then the symmetric Nash equilibrium in*

RDS(α, β) *is unique and satisfies*

$$a - bp^R + z^R - \Lambda(z^R) + (1-\beta)[L_\alpha(z^R) - (z^R - \Lambda(z^R))] = b(p^R - w)/(1-r). \quad (8)$$

$$A_{\alpha,\beta}(z^R) = (p^R - w)/p^R. \quad (9)$$

2. *If* $A_{\alpha,1}(\cdot)$ *satisfies the IFR property, then the symmetric Nash equilibrium in* CDS(α) *is unique and satisfies*

$$a - bp^C + L_\alpha(z^C) = b(p^C - w)/(1-r). \quad (10)$$

$$A_{\alpha,1}(z^C) = (p^C - w)/p^C. \quad (11)$$

The IFR property on $A_{\alpha,\beta}(\cdot)$ guarantees the uniqueness of a symmetric equilibrium. The IFR property is widely used as a regularity condition for joint production and pricing decisions.[5] Distributions such as normal and uniform, as well as gamma and Weibull families subject to parameter restrictions (Barlow and Proschan 1965) satisfy this property. The induced distribution function $A_{\alpha,\beta}(\cdot)$, however, may not belong to one of these families. We can show that, when $F(\cdot)$ is uniform, $A_{\alpha,\beta}(\cdot)$ satisfies the IFR property. Numerical studies further reveal that $A_{\alpha,\beta}(\cdot)$ satisfies the IFR property when $F(\cdot)$ is normal or exponential.

With exogenous and identical retailer prices, it is easy to show that the unique equilibria in safety stocks exist and are given by the newsvendor-type Equations (9) and (11), respectively for RDS and CDS.[6] With endogenous retail prices, the equilibrium prices are further determined by the balance Equations (8) and (10) for the two systems. In making pricing decisions, retailers in either system consider the impact of their prices on the revenues derived from the local sales, as well as a portion of the spillover sales. Specifically, each retailer in RDS earns revenue from the local sales, $a - bp + z - \Lambda(z)$, and from the spillover sales, $(1-\beta)[L_\alpha(z) - (z - \Lambda(z))]$. In contrast, each retailer in CDS earns revenue based on his total sales, $a - bp + L_\alpha(z)$. The differing total sales affected by the retailers' pricing decisions ultimately lead to different equilibrium prices with the two search methods and cause the equivalence of CDS with RDS at $\beta = 1$ to break down.

To facilitate comparisons later, it is more useful to rewrite Equations (8) and (10) as equating marginal revenue to marginal cost. Recall that the marginal cost $\mathrm{MC} = w$. Define, for $p \ge w$ and $z \in [-B, B]$,

$$E^C(p,z) \equiv -\frac{bp/(1-r)}{a - bp + L_\alpha(z)} \quad \text{and}$$

$$E^R(p,z) \equiv -\frac{bp/(1-r)}{a - bp + (1-\beta)L_\alpha(z) + \beta(z - \Lambda(z))},$$

as the price elasticity of sales in CDS and RDS respectively. In a deterministic model, sales equal demand so that the elasticity of sales with respect to price is equal to the (standard) elasticity of demand with respect to price.[7] With demand uncertainty, total sales include a deterministic price-dependent component and a stochastic component. For a given p, the absolute value of the sales elasticity decreases in z and hence in sales. The marginal revenues in CDS and RDS can be expressed, respectively, as

$$\mathrm{MR}^C(p,z) \equiv p\left(1 - \left|\frac{1}{E^C(p,z)}\right|\right) = p - \frac{a - bp + L_\alpha(z)}{b/(1-r)} \quad \text{and} \quad (12)$$

$$\mathrm{MR}^R(p,z) \equiv p\left(1 - \left|\frac{1}{E^R(p \cdot z)}\right|\right) = p - \frac{a - bp + (1-\beta)L_\alpha(z) + \beta(z - \Lambda(z))}{b/(1-r)}. \quad (13)$$

It can be verified that $\mathrm{MR}^C(p,z) < \mathrm{MR}^R(p,z)$ because of the higher stochastic component of sales in CDS. We can then rewrite (8) and (10), respectively, as $\mathrm{MR}^C(p,z) = \mathrm{MC}$ and $\mathrm{MR}^R(p,z) = \mathrm{MC}$. In later sections, Equations (12) and (13) will facilitate our explanations of price movements under the two search models.

4.2. Comparative Statics

Before we proceed further, we assume the existence of a unique pure strategy Nash equilibrium in price

[5] For a single-agent problem considered by Petruzzi and Dada (1999), the IFR property is implied by the conditions outlined in Theorem 1 of their paper, which are similar to those in Lemma 1 of our paper.

[6] Conditions outlined in Lemma 1 are not required for this case.

[7] For example, for the demand function in (1), (own) price elasticity of the demand function is $b/(1-r)$.

and stock for RDS and CDS. That is, the conditions in Lemma 1 and Proposition 1 hold. To avoid trivial solutions, we further assume that all the failure rate functions defined earlier are bounded from below by $1/(bw)$. We next evaluate the impact of search intensity (α), substitution ratio (r), and transfer price (β) on prices, stocks, and sales. These comparative statics facilitate the comparisons between the two search methods.

4.2.1. Impact of Search Intensity. Proposition 2 characterizes the behavior of stock, retail price, and sales with respect to the search intensity in CDS(α).

Proposition 2. *In* CDS(α) *with endogenous retail prices, equilibrium safety stock, retail price, and sales increase in search intensity.*

Consider the setting with exogenous retail prices. For a given stock level, an increase in the search intensity leads to an increase in spillover demand. Because a retailer in CDS keeps all the spillover sales revenue, he has the incentive to stock more; hence, stock and consequently sales increase with search intensity. When retail price is endogenous, there is, in addition, an opposing effect. The higher sales lower the price elasticity of sales (see Equation (12)). The lower elasticity allows the retailers to raise prices, which draws down the deterministic component of sales. The incentive to stock more is, however, stronger so that the increase in safety stock and hence the stochastic component of sales is enough to offset the decrease in the deterministic sales, resulting in a net increase in sales. That price and sales increase simultaneously is counterintuitive. We next consider RDS(α, β).

Proposition 3. *In* RDS(α, β) *with endogenous retail prices, there exists* $\beta_0 \in [0, 1]$ *such that if* $\beta \geq \beta_0$, *then the equilibrium safety stock and price increase in search intensity. Furthermore, whenever* $2(M_2(z, z) - M_3(z, z)) \geq M_1(z, z)$, *sales also increase in search intensity.*

In RDS(α, β), the presence of a transfer price complicates matters by affecting retailers' strategic decisions. Transfer price exerts two countervailing forces on the stocking behavior of a retailer in RDS. The source retailer earns additional revenue by satisfying the excess demand of the other retailer using his excess stock; this salvage opportunity gives the retailer an incentive to stock more, and we call it the *salvage effect*. The sink retailer, however, still earns revenue for his excess demand that is satisfied by the other retailer's stock. Effectively, he can satisfy his excess demand without buying additional stock. It gives the retailer an incentive to stock less; we call this the *borrow effect*. Which effect will dominate depends on the transfer price. Naturally, the salvage effect intensifies with an increase in the transfer price. At a high enough transfer price, the retailer has a strong incentive to respond with higher safety stock because search intensity increases the spillover demand, which also increases sales when the retail prices are exogenous.[8] When the retail prices are endogenous, however, the higher safety stock lowers the price elasticity of sales (see Equation (13)), allowing the retailers to raise prices. Because of the dampening effect of the higher prices on the deterministic component of stock and hence sales, it is unclear how the overall sales will change with the search intensity. The additional sufficient condition in Proposition 3 ensures that the loss in the deterministic component from a higher price is sufficiently offset by the gain in the stochastic component that is due to higher safety stock so that the overall sales increase. This result appears to be in contrast to what we observed for CDS, where sales unconditionally increase with the search intensity. The difference can be attributed to the lower retail price in RDS and the difference in the rates of the changes in the deterministic and the stochastic components of stock (and hence sales) with respect to the search intensity. Our numerical studies indicate that the sufficient condition outlined in Proposition 3 is always satisfied.

4.2.2. Impact of Substitution Ratio. Substitution ratio r captures the intensity of price competition. Recall that the aggregate demand in our model is invariant to r, which allows us to proceed with comparative statics. We have the following result.

[8] We cannot conclusively prove that, for a transfer price below a certain threshold, an increase in search intensity will lower stocks. Although there is an incentive to lower stock when the transfer price is low, it comes at the expense of potentially losing one's local sales, especially when α rises to a high level. This trade-off makes it hard to prove the directional movement conclusively. Indeed, in our numerical studies we observe that for low transfer prices, safety stock is decreasing-increasing with α.

Proposition 4. *With endogenous retail prices, the equilibrium safety stock and retail price decrease, whereas stock and sales increase in substitution ratio r, in both* RDS *and* CDS *systems.*

In both RDS and CDS, price competition intensifies with an increase in the substitution ratio and results in a drop in the retail price. This is intuitive. However, the lowered price induces a lower service level [given by the right-hand sides of Equations (9) and (11)], so that safety stock also decreases. This could potentially decrease sales. The lowered price, however, causes the price-dependent components of stock and sales to increase, apparently at rates higher than the rates of decrease in the stochastic components. As a result, overall stock and sales increase in the substitution ratio.

4.2.3. Impact of Transfer Price. Transfer price is only applicable for an RDS system. Proposition 5 considers the case when retail prices are exogenous.

Proposition 5. *With exogenous and identical retail prices, the safety stock and sales in* RDS *increase with transfer price and are equal to those in* CDS *when transfer price equals* 1; *that is, $z^R(\alpha, \beta)$ and $S^R(\alpha, \beta)$ increase in β, with $z^R(\alpha, 1) = z^C(\alpha)$ and $S^R(\alpha, 1) = S^C(\alpha)$.*

With exogenous prices, as the share of spillover sales revenue increases in RDS, so does the stock. When $\beta = 1$, the source retailer gets full credit for spillover sales, which is exactly the same as in CDS. Consequently, the stock and sales in RDS at $\beta = 1$ are equal to those in CDS. In effect, CDS(α) is equivalent to RDS(α, 1). With endogenous retail prices, however, it is hard to carry out a similar analysis for both retail price and safety stock. Instead, in Proposition 6 we first derive bounds for them and then examine the behavior of these bounds with respect to the transfer price.

Proposition 6. *With endogenous retailer prices, $\forall\, \alpha > 0$, $\beta \in [0, 1]$, define the two systems of equations as follows*:

$$\text{[B1]} \quad a - bp + L_\alpha(z) = b(p - w)/(1 - r) \quad \text{and} \quad A_{\alpha,\beta}(z) = (p - w)/p.$$

$$\text{[B2]} \quad a - bp + z - \Lambda(z) = b(p - w)/(1 - r) \quad \text{and} \quad A_{\alpha,\beta}(z) = (p - w)/p.$$

Then

(1) *Both* [B1] *and* [B2] *admit unique solutions, denoted by $(\bar{p}_{\alpha,\beta}, \bar{z}_{\alpha,\beta})$ and $(\underline{p}_{\alpha,\beta}, \underline{z}_{\alpha,\beta})$, respectively.*

(2) *The solutions to* [B1] *and* [B2] *give lower and upper bounds, respectively, on the equilibrium in* RDS. *Specifically, $\underline{p}_{\alpha,\beta} \le p^R(\alpha, \beta) \le \bar{p}_{\alpha,\beta}$ and $\underline{z}_{\alpha,\beta} \le z^R(\alpha, \beta) \le \bar{z}_{\alpha,\beta}$, with*

$$(p^R(\alpha, 1), z^R(\alpha, 1)) = (\underline{p}_{\alpha,1}, \underline{z}_{\alpha,1})$$

and

$$(p^R(\alpha, 0), z^R(\alpha, 0)) = (\bar{p}_{\alpha,0}, \bar{z}_{\alpha,0}).$$

(3) *The solutions to* [B1] *and* [B2] *increase in the transfer price. That is, $(\bar{p}_{\alpha,\beta}, \bar{z}_{\alpha,\beta})$ and $(\underline{p}_{\alpha,\beta}, \underline{z}_{\alpha,\beta})$ increase in β.*

(4) *The equilibrium solution in* CDS(α) *can be obtained by solving* [B1] *with $\beta = 1$. That is, $(p^C(\alpha), z^C(\alpha)) = (\bar{p}_{\alpha,1}, \bar{z}_{\alpha,1})$.*

The first set of equations in [B1] and [B2] are obtained from (8) by setting $\beta = 0$ and 1 respectively; the second set are the same as (9). Parts 1 and 2 of the proposition establish the uniqueness of the solutions to [B1] and [B2] and show that they indeed are the bounds to the equilibrium price and safety stock in RDS(α, β). Part 3 shows that these bounds increase in β. As long as these bounds are tight, the sensitivity of the equilibrium with respect to β can be inferred (approximately) by the behavior of these bounds. Numerical studies reveal that the percentage difference between the upper and the lower bounds is less than 1%, with the worst case arising when the search intensity is high. We expect the equilibrium price and safety stock to have a general increasing pattern, which is uniformly supported by numerical results. Numerical studies also reveal that the overall sales and stock increase in the transfer price. Part 4 of the proposition shows that the equilibrium solution in CDS is equal to the upper bound solution in RDS with a transfer price of one. This implies that both the price and the safety stock are higher in a duopoly with CDS than with RDS at any transfer price, including when the transfer price is one.

5. Performance Comparisons and Discussions

In this section, we compare the performance of the duopoly under the two search methods. The manufacturer cares about total sales, the retailers about profits, and customers about price and availability (with safety stock as proxy). We present analytical results for the comparisons of total sales, prices, and safety stocks. We use numerical studies for profit comparisons. The comparative results inform us about the preferences of the manufacturer and the retailers on the method of search as well as the impact of search method on the customers.

5.1. CDS vs. RDS

In this subsection, we compare total sales, prices, and safety stocks between CDS and RDS for exogenous and endogenous prices, as illustrated in Proposition 7.

Proposition 7.

(1) *With exogenous and identical retail prices, safety stock and sales are higher in* CDS *than in* RDS; *that is,* $\forall\, \alpha > 0$, $z^C(\alpha) \geq z^R(\alpha, \beta)$, *and* $S^C(\alpha) \geq S^R(\alpha, \beta)$.

(2) *With endogenous retail prices, given* $\alpha > 0$,

(a) *Safety stock and price are higher in* CDS *than in* RDS; *that is,* $z^C(\alpha) \geq z^R(\alpha, \beta)$ *and* $p^C(\alpha) \geq p^R(\alpha, \beta)$ *for any* $\beta \in [0, 1]$;

(b) *Sales are higher (lower) in* CDS *when the transfer price in* RDS *is* 0 (1); *that is,* $S^C(\alpha) > S^R(\alpha, 0)$ *and* $S^C(\alpha) < S^R(\alpha, 1)$.

Search mechanisms allow matching of the excess stock at one retailer with the excess demand at the other. The salvage effect gives a retailer the incentive to stock more, although there is incentive for a retailer to stock less under the borrow effect. In CDS, there is only the salvage effect. In RDS, the salvage effect is weaker than in CDS and, in addition, there is a borrow effect, leading to an overall lower stock than in CDS. The higher safety stock in CDS leads to higher sales. This is Part 1 of Proposition 7. Suppose retailers "cooperatively" choose transfer price in RDS (in the spirit of the two-stage analysis in Anupindi et al. 2001). It is straightforward to see they will select a transfer price to maximize total profit, and the resulting profit is higher than what they can obtain in CDS. Thus, in a duopoly with exogenous retail prices and stockout-based substitution, the retailers prefer RDS over CDS. The manufacturer, who is not responsible for the inventory at the retailers, has a profit stream proportional to total sales and hence prefers CDS over RDS.

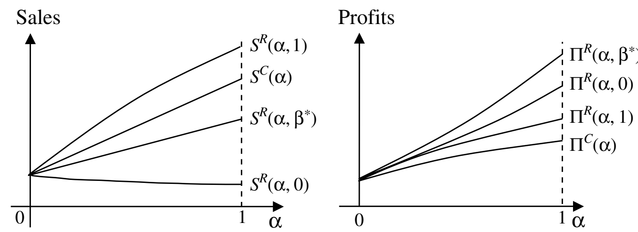
In Part 2 of Proposition 7, we compare total sales, prices, and safety stocks in CDS and RDS under endogenous prices. Part 2(a) states that the safety stock and retail price are always lower in RDS. Recall from our earlier discussions that the retailers in CDS have a greater incentive to keep a larger safety stock. Further from (12) and (13), for a fixed price, the marginal revenue in CDS is lower than that in RDS, allowing the retailers in CDS to charge higher prices. A higher retail price reinforces the behavior to increase safety stock in CDS. Although safety stock is higher in CDS, the higher price lowers the deterministic components of stock and sales, making it hard to conclusively compare total stock and sales between CDS and RDS. Part 2(b) illustrates that total stock, and sales are higher (lower) in CDS than those in RDS at a low (high) transfer price. When the transfer price in RDS is low (e.g., $\beta \to 0$), the retailers have little incentive to carry safety stock for spillover demand. The lower retail price in RDS contributes to the higher price-dependent components of total stock and sales, but it does not compensate for the loss from lower safety stock, leading to lower total stock and hence sales in RDS. When the transfer price in RDS is high (e.g., $\beta \to 1$), the compensation to the retailers from spillover sales in RDS is comparable to that in CDS. By Proposition 6, retail price increases with transfer price, which, through a higher critical fractile, induces a higher safety stock. The retail price, though high overall compared to when the transfer price is low, is still lower in RDS than in CDS. However, at high retail prices, the critical ratio is less sensitive to a change in the retail price. Thus, although the stochastic component of sales remains higher in CDS, the lower retail price in RDS gives it a higher deterministic component, more than enough to offset the decline in safety stock levels, leading to overall higher sales in RDS. By continuity arguments, it is straightforward to see that there are transfer prices at which sales in RDS are equal to those in CDS.

5.2. Preferences of the Manufacturer and the Retailers

Which search system is preferred by the manufacturer and the retailers is influenced by who sets the transfer price in RDS. The retailers want to attain the highest profit and, for a given wholesale price, the manufacturer aims to maximize sales.[9] Let $\beta^*(\alpha)$ be the transfer price that maximizes the retailers' profits in RDS. We represent such an RDS system by RDS(α, β^*) and simply refer to the optimal transfer price as β^*. Although our analytical results thus far shed light on the behavior of sales as a function of transfer price, we are unable to characterize the sales and profits in RDS at β^*. We turn to numerical studies to gain further insight into the preferences of both the manufacturer and the retailers. For our numerical studies, we let the random demand factor follow a uniform $[-B, B]$ distribution. Because the wholesale price does not crucially affect the comparative outcomes, we fix it at $w = 1$ and vary the other parameters. For each problem instance, we use certain combinations of $a \in \{10, 20, 40, 60, 80, 100\}$, $b \in \{5, 10, 20, 30\}$, and $B \in \{5, 10, 20, 30, 40\}$ to obtain the equilibrium solutions under either search method and conduct sensitivity studies with respect to stock search intensity α, price competition intensity r, and transfer price β in RDS.

Recall from Propositions 2 and 3 that sales in both CDS(α) and RDS$(\alpha, 1)$ increase in α. Moreover, by Proposition 7, sales in CDS(α) are always lower than those in RDS$(\alpha, 1)$. From our numerical studies, we observe that the relative behaviors of sales and profit at the optimal transfer price, denoted by $S^R(\alpha, \beta^*)$ and $\Pi^R(\alpha, \beta^*)$, respectively, are influenced by search intensity and substitution ratio. We make the following observations. For small r and for all α (see Figure 1), sales (profits) are lower (higher) in RDS(α, β^*) than those in CDS(α). Thus, with transfer price β^* in RDS, the retailers favor RDS, but the manufacturer favors CDS. If the manufacturer can choose the transfer price in RDS, she will set $\beta = 1$, which is not in the best interests of the retailers. In contrast, for large r (see Figure 2), when α is small (large), the sales in CDS are lower (higher) than those in RDS(α, β^*). Profit, however, is higher in CDS for

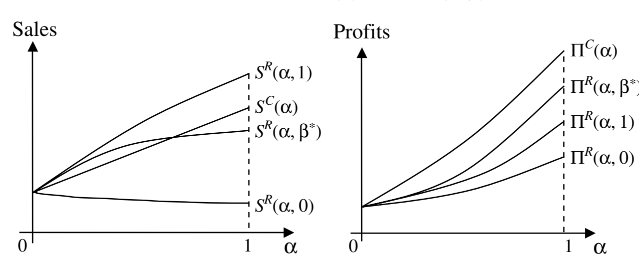
Figure 1 **Sales and Profits in CDS(α) and RDS(α, β) for Small r**



all α; thus, retailers prefer CDS over RDS(α, β^*). If the manufacturer can select the transfer price in RDS, she still prefers RDS with $\beta = 1$ over CDS.

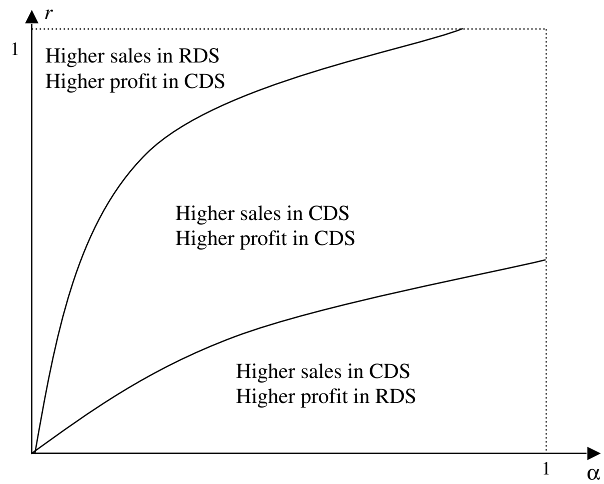
Transfer price is a doubled-edged sword. On one hand, a higher transfer price will dampen price competition; this occurs indirectly through an increase in safety stock, which in turn exerts an upward pressure on prices. On the other hand, with higher safety stock, retailers run the risk of overstocking and loss in profits. Which path the retailers choose will depend on the values of r and α. Small values of r (low price competition intensity) allow the retailers to choose relatively higher retail prices that induce higher service levels. Keeping the transfer price low helps the retailers minimize the damaging effect of overstocking, which is more intense at higher service levels (and at all values of α). Thus a low r that implies weaker price competition, coupled with the ability to keep the transfer price low to dampen the overstocking behavior, brings higher profits to the retailers in RDS. The low transfer price, however, keeps sales in RDS lower than those in CDS (Figure 1). In contrast, larger values of r imply more intense price competition and drive down the retailers' prices and profits. Transfer price is used as a compensating instrument. When α is low, the overstocking risk is low and the retailers choose a higher transfer price, which, coupled with a lower retail price, leads to higher sales in RDS. When α is

Figure 2 **Sales and Profits in CDS(α) and RDS(α, β) for Large r**



[9] If the wholesale price were made endogenous, then the manufacturer would manipulate it to maximize its profits. A complete analysis of the models under contractual terms that include wholesale price as well as transfer price schemes is beyond the scope of this paper.

Figure 3 Comparisons Between CDS and RDS when Retailers Set Transfer Price



high, the overstocking risk is high and retailers lower the transfer price that reduces stock and hence sales below that in CDS. The higher price in CDS (Proposition 7), however, allows the retailers to earn higher profits (Figure 2).

Combining our observations from Figures 1 and 2, Figure 3 illustrates the preferences of the manufacturer and the retailers when the latter select a transfer price in RDS. We observe that, unlike the case with exogenous prices, no single search method is uniformly preferable when the retail prices are endogenously determined. The intensity of price competition (captured through r) and the intensity of stock competition (generated through α) jointly influence the preference pattern. The quadrant is divided into three regions. In the lower region, where the intensity of price competition is low, the manufacturer prefers CDS, whereas the retailers prefer RDS. In the intermediate region, featured by a moderate price and an intense stock competition, both the manufacturer and the retailers prefer CDS. In the upper region, defined by a strong price competition but a weak stock competition, the manufacturer prefers RDS, whereas the retailers prefer CDS.

6. Extensions and Discussion

The analyses thus far were undertaken with several assumptions regarding the search intensity parameter, the transfer pricing scheme used in RDS, and the salvage value of leftover inventory. In this section, we reconsider these to explore the robustness of our results. Specifically, we first allow the search intensity in CDS to endogenously depend on the price differential at the two retailers to show that the results remain largely unchanged. Next, we explore two alternative transfer pricing schemes in RDS to demonstrate that the strategic preferences of the various stakeholders toward CDS and RDS may depend on the choice of the transfer pricing scheme in RDS. We then discuss the impact of a positive salvage value on the stakeholders' preferences. Finally, we conclude with a discussion of the factors that may impact search intensity under the two search methods and their influence on the comparative analyses.

6.1. Endogenous Search Intensity

So far we have assumed that search intensity (α) is an exogenous parameter. This assumption is justifiable in an RDS system, because customers only pay the price charged by the retailer they visit, regardless of whether the product is available locally or transshipped. In a CDS system, however, because customers with unmet demand go to the retailer with excess stock and pay the price charged by that retailer, their willingness to search and switch to purchase from the other retailer can be affected by the price differential between the two retailers. Are the results obtained thus far, then, robust to this new, more realistic, scenario? In this section, although we continue to assume that the search intensity in RDS is exogenous, we allow for the search intensity in CDS to be a function of the price differential at the two retailers. We derive the equilibrium conditions for CDS and demonstrate that the qualitative nature of the phenomenon observed in §§4 and 5 remain unchanged.

Specifically, for given prices at the two retailers, $\mathbf{p} = (p_1, p_2)$, we let the fraction of the customers with unmet demand at retailer j who switch to retailer i in CDS be $\alpha_{i,j}(\mathbf{p}) = \alpha_C(p_j - p_i)$ for $i, j = 1, 2$ and $i \neq j$, where $\alpha_C(\cdot)$ is defined on $(-\infty, +\infty)$, increasing and bounded in $[0, 1]$. Therefore, in the event of a stockout, the fraction of customers who switch from j to i increases with price p_j at the sink retailer but decreases with price p_i at the source retailer. The search intensity in RDS is exogenous and denoted by α_R. Expressions for the quantities of interest, including local sales, spillover sales, and profits under the two search methods, remain similar to those derived in §3, except that α_R is now the search intensity in RDS and $\alpha_{i,j}(\mathbf{p})$ is the search intensity in CDS.

In the model with exogenous (and identical) retail price (see §4), search intensity in CDS is a constant parameter, given by $\alpha_C(0)$. The equilibria and the comparative statics for RDS and CDS with exogenous retail prices remain unchanged as long as $\alpha_R = \alpha_C(0)$. We next consider the model with endogenous retail price. To characterize the symmetric equilibrium in CDS, we introduce a function $\Theta(\alpha, z)$ as follows:

$$\Theta(\alpha, z) = \Lambda(z)F(z) - \int_{-B}^{z} \Lambda\left(z + \frac{z-x}{\alpha}\right) dF(x) + \frac{1}{\alpha}\int_{-B}^{z} F\left(z + \frac{z-x}{\alpha}\right)(z-x)\, dF(x). \quad (14)$$

$\Theta(\alpha, z)$ represents a marginal change in the stochastic component of sales ($L_\alpha(z)$) with respect to α. Proposition 8 characterizes the symmetric equilibrium in CDS, and presents comparison results.

Proposition 8. *In* CDS(α) *with endogenous retail price decision and endogenous search intensity*:

(1) *If $H^2_{N_C}(x, z_j) + \partial H_{N_C}(x, z_j)/\partial x \geq 0$ for any z_j, then there exists a symmetric Nash equilibrium. If $A_{\alpha,1}(\cdot)$ satisfies the IFR property, then the symmetric Nash equilibrium is unique and given by*

$$a - bp + L_{\alpha_C(0)}(z) - \alpha_C^{(1)}(0)\Theta(\alpha_C(0), z)p = b(p-w)/(1-r). \quad (15)$$

$$A_{\alpha_C(0),1}(z) = (p-w)/p. \quad (16)$$

(2) *Compared to a* CDS *with exogenous search intensity with $\alpha = \alpha_C(0)$, the safety stock and price are lower but sales are higher.*

Part 1 of Proposition 8 is the counterpart of Lemma 1 (Part 1) and Proposition 1 (Part 1). Comparing with (10)–(11), we now need to include an additional term, $\alpha_C^{(1)}(0)\Theta(\alpha_C(0), z)p$, in (15), which accounts for the change in the revenue caused by the impact of a marginal change in the retail price on search intensity and hence sales. Note that the intensity function $\alpha_C(\cdot)$ affects the equilibrium only through $\alpha_C^{(1)}(0)$ and $\alpha_C(0)$. Part 2 shows that the effect of endogenizing search intensity is to lower the price further, leading to higher stock and hence higher sales.

Below we summarize our main observations from comparative statics.[10] The equilibrium price and safety stock increase with $\alpha_C(0)$, which mirrors the results in Proposition 2, excluding the impact on sales. Recall from our discussion there that the overall impact on sales depends on the impact on both the deterministic and the stochastic components of sales. With endogenous search intensity, the overall effect is unclear in general. However, in numerical studies, we find that sales increase with $\alpha_C(0)$. Proposition 4 continues to hold; that is, equilibrium safety stock and retail price decrease, while stock and sales increase in substitution ratio r. With $\alpha_R = \alpha_C(0)$, the comparative results in Proposition 7 are still valid. Finally, using the insights in Proposition 8, we can infer that the shapes of Figures 1–3 remain the same. Hence, the main qualitative results derived in the previous sections for an exogenous search intensity model hold even when search intensity is made to endogenously depend on the difference in the prices charged by the retailers.

6.2. Alternative Transfer Pricing Schemes

In §§4 and 5 we considered a specific transfer pricing scheme for RDS under which the transfer price was proportional to the price at the sink retailer. Clearly, other possibilities exist. Are our results robust to alternative transfer pricing schemes? In this section, we propose two alternatives: (a) a transfer price in proportion to the price charged by the source retailer and (b) a fixed transfer payment regardless of the retail price at either retailer. For the purpose of subsequent discussions, we will refer to the original transfer pricing scheme as *proportional scheme* I, the alternative scheme in (a) as *proportional scheme* II, and the one in (b) as *fixed transfer pricing scheme*. Regardless of transfer payment, however, we continue to make the reasonable assumption that a customer pays the prevailing price at the retailer where he obtains the product.

6.2.1. Proportional Scheme II. The expected direct profit of retailer i in RDS under this alternative transfer pricing scheme is the same as that under proportional scheme I, but his expected indirect profit is changed to

$$\mathrm{IP}_i^R(\mathbf{z}, \mathbf{p}) = (p_i - \beta p_j) \cdot \mathrm{IS}_{j,i}(\mathbf{z}) + \beta p_i \cdot \mathrm{IS}_{i,j}(\mathbf{z}).$$

[10] A formal proof is available on request.

The expected total profit of retailer i, given by the sum of direct and indirect profits, can be written as

$$\begin{aligned}\Pi_i^R(\mathbf{z},\mathbf{p}) &= (p_i - w)\left(a - \frac{b}{1-r}p_i + \frac{br}{1-r}p_j + z_i\right) \\ &\quad + p_i[\mathrm{IS}_{j,i}(\mathbf{z}) - \Lambda(z_i)] + \beta[p_i \mathrm{IS}_{i,j}(\mathbf{z}) - p_j \mathrm{IS}_{j,i}(\mathbf{z})].\end{aligned}$$

Comparing the above for $\beta = 1$ with (5), we observe that even under proportional scheme II, RDS at $\beta = 1$ is not equivalent to CDS. This arises because of the difference in prices at which the customer obtains the good; he pays the sink retail price in RDS, whereas he pays the source retail price in CDS.

The symmetric equilibrium can be determined by a set of equations similar to (8) and (9). We can show that the comparative static results (of Propositions 3–6)[11] continue to hold for RDS under proportional scheme II. Safety stock and retail price in RDS are higher (lower) when $\beta = 1$ ($\beta = 0$) than they are in CDS. Overall sales, however, are *always* lower under RDS. These results differ slightly from Proposition 7 in that the safety stock and price comparisons can only be shown at the extremes (cf. Part 1), whereas the stock and sales comparisons hold uniformly (cf. Part 2). A direct consequence of the latter is that the manufacturer dominantly prefers CDS under the new scheme in RDS, regardless of who selects the transfer price. To study the preference of the retailers, as before, we supplement our insights with numerical studies to evaluate the maximal profit in RDS. We observe that, at the optimal transfer price in RDS, retailers *uniformly* prefer RDS over CDS. Effectively, Figure 3 reduces to a single region, with the manufacturer preferring CDS and the retailers preferring RDS. Notably, the preference pattern with RDS under proportional scheme II is significantly different from that with RDS under proportional scheme I but coincides with what we observed when retail prices are exogenous and identical. Finally, at the retailer-chosen optimal transfer price, retail price and safety stock in RDS are lower than those in CDS.

6.2.2. Fixed Transfer Pricing Scheme. Under the fixed transfer pricing scheme, the transfer price in RDS is a constant, say $\tau \geq 0$, independent of the price at either retailer. The sink retailer pays τ for each unit obtained from the source retailer to satisfy his unmet demand. Naturally, the transfer payment is bounded above by the sink retailer's price. The symmetric equilibrium can be determined by a set of equations similar to (8) and (9). For brevity, we omit the details. We can show that the comparative statics results of Propositions 4–6 continue to hold. Unlike the case with the proportional pricing schemes, we are unable to characterize the behavior of safety stock and retail price with respect to search intensity, as in Proposition 3. Numerically, however, we observe that the result holds whenever the fixed transfer price is high. As a counterpart to Proposition 7, sales and prices in RDS are always lower than in CDS for any fixed transfer price below the retail price. However, when the fixed transfer payment equals the equilibrium retail price in CDS, RDS and CDS are equivalent; that is, the two search methods result in the same equilibrium price, sales, and profits.

If the manufacturer can select the fixed transfer price in RDS, then she will set it equal to the retail price in CDS. Because RDS at this transfer price is equivalent to CDS, both the manufacturer and the retailers are indifferent between the two search methods. But if the retailers can select the fixed transfer price in RDS, using numerical studies we can show that they weakly prefer RDS and the manufacturer weakly prefers CDS; the weak preference occurs when the profit-maximizing fixed transfer price in RDS makes it equivalent to CDS.

6.2.3. Discussion. Table 1 summarizes the preferences of the retailers and the manufacturer across the three transfer pricing schemes. Comparing across the three schemes, we find that both the retailers and the manufacturer prefer RDS over CDS[12] as along as they select the transfer pricing scheme, as well as the transfer payment terms. Interestingly, neither prefers the fixed transfer pricing scheme, as is commonly assumed in the literature. Instead, the retailers (manufacturer) prefer(s) a transfer price that is proportional to the source (sink) retailer's price. However, although the retailers and the manufacturer prefer

[11] In contrast to Proposition 6, under the new transfer pricing scheme, the comparative statics with respect to the transfer price can be shown directly without resorting to bounds.

[12] Statements about preferences of the retailers rely on numerical studies because they are based on profit comparisons.

RDS when they design RDS, they may prefer CDS over RDS when the other party designs RDS. Regardless of the transfer pricing scheme used, the retail price and safety stock (as a proxy for availability) are usually lower with RDS.

6.3. Salvage Value

Thus far we have assumed that the salvage value of leftover goods at a retailer is zero. What if there is a positive salvage value so that excess inventory is not worthless? It is straightforward to see that, because CDS does not involve stock transfer by the retailers, a positive salvage value affects the equilibrium only in that the leftover stock is less costly now. Consequently, safety stock, price, total stock, and sales all increase with salvage value. In RDS, however, because the leftover inventory is worth more, retailers may reconsider their decision to share excess stock unilaterally, as before. Thus, whether trade will occur between retailers depends on the relative magnitudes of the salvage value and the transfer price.

We extend our analysis to include salvage value $v \le w$ in RDS. We find that, because the feasible set of transfer prices may in general be different across the three transfer pricing schemes, the relative performances of the system under the various schemes may differ from the case with zero salvage value. We omit the details. Despite these differences, for each scheme we can show the existence of transfer prices at which trade *will* occur in equilibrium, regardless of whether the manufacturer or the retailers choose the transfer price. The presence of a positive salvage value, therefore, does not fundamentally alter the comparisons of RDS under the three schemes; neither does it affect the preferences of the manufacturer and the retailers between CDS and RDS.[13]

[13] The $v \le w$ assumption has some limitations. If salvage value is a proxy for the value of leftover inventory in a multiperiod problem, then the assumption will hold whenever there is a guarantee that the retailer will be able to obtain replenishment in the next period. However, if this cannot be guaranteed (based on the model settings), then it could be at least as high as the (discounted) margin a retailer earns less holding cost; furthermore, if a retailer faces penalty costs for unsatisfied local demand, the salvage value needs to account for these too. Under these circumstances, it is not guaranteed that there is a transfer price such that trade will always occur.

6.4. Asymmetric Search Intensity

In the preceding comparative analyses of CDS and RDS and of RDS under different transfer pricing schemes, we have assumed that the levels of search intensity are identical across the systems being compared. In practice, however, the search intensities could be different in CDS and RDS, as they are influenced by several factors (discussed later). These differing search levels will obviously impact the sales and the profit comparisons and hence the preferences of the manufacturer and the retailers.

Then how valid are our comparisons? One way to think about the issue is to investigate the required search intensities at which the expected profits and the sales are *equivalent* in CDS and RDS. This would allow us to establish thresholds on the level of search intensity at which the preferences of the players may shift between the systems. Comparison of sales can be based on analytical studies; profit comparisons, however, need to be based on numerical studies. Earlier we found that when the manufacturer designed the RDS, she preferred the RDS system and chose a pricing scheme proportional to the sink retailer's price; this will continue to be her preference unless the search intensity in RDS drops below a threshold (at which sales in CDS equal those in RDS), and then she will prefer CDS. Similarly, when the retailers design the RDS and choose a pricing scheme proportional to the source retailer's price, they will continue to choose RDS, as before, as long as the search intensity in RDS is above a certain threshold level (at which profits in CDS equal those in RDS); otherwise they will prefer CDS.

Several factors may influence the actual level of search in a network. These include search cost, customers' willingness to wait, or retailers' willingness to search. Search cost is affected by the physical distance between the retailers (influencing transshipment cost), as well as the availability of information regarding the stock in the network. Dense networks lead to lower physical cost; better use of information technology can minimize information-related costs. Both these contexts should increase search in either system. In contrast, search requires both time and effort. In CDS, customers go directly to the retailer that has the product in stock and thus incur little wait time to obtain the product, whereas in RDS they may have to

Table 1 **Preferences of Manufacturer and Retailers Toward CDS and RDS Under Endogenous Pricing**

	Retailer selects transfer payment in RDS		Manufacturer selects transfer payment in RDS	
Transfer price mechanism ↓	Retailers' preference	Manufacturer's preference	Retailers' preference	Manufacturer's preference
Proportional to the sink retailer's price (scheme I)	CDS for high r or low r *and* low α; RDS otherwise	CDS for high α; RDS for low α and high r	RDS for small r; CDS for large r	RDS
Proportional to the source retailer's price (scheme II)	RDS	CDS	RDS	CDS
Fixed transfer price	(Weakly) RDS	(Weakly) CDS	Indifferent (CDS or RDS)	Indifferent (CDS or RDS)

wait for the arrival of the product. Their willingness to wait will be impacted by factors such as brand reputation, quality, etc. Hence, wait time may dampen the search intensity in RDS. Finally, in an RDS system, the availability of stock information is not sufficient to enable trade. Retailers may prefer to have the customers switch to an alternative product at their own location rather than exert effort and incur costs to find and transship the product. Whether they will engage in transshipment with another retailer may depend on the relative margins of the products they carry, the share of the spillover revenue they receive on transshipment, and the relationship between them.[14] Ultimately, which search method leads to higher search intensity is an interesting empirical question. The answer to it can solidify our understanding of customer purchasing behavior as well as the rational responses of the various players in the supply chain and is a potential topic of future research.

7. Conclusion

We analyze a supply chain consisting of one manufacturer and two retailers to compare the two search methods driven by retailers (labeled RDS) and customers (labeled CDS). We explore how the preferences of the retailers and the manufacturer toward the two systems are affected by whether retail prices are exogenous or endogenous and the choice of transfer pricing scheme in RDS that allocates spillover sales revenue. We demonstrate that the insights obtained from the study of exogenous price models do not necessarily carry over when retail prices are chosen endogenously. In the endogenous model, we highlight the critical roles of the transfer pricing scheme in RDS, as well as the intensities of price and stock competitions captured, respectively, through the substitution ratio and the search intensity. In general, their preferences toward CDS or RDS are rarely aligned. Specifically, we observe that although both the manufacturer and the retailers prefer RDS when they design it, they may prefer CDS or RDS when the other party designs RDS. The customers, however, usually benefit in RDS with lower prices—but at the expense of lower product availability (as measured by the level of safety stock).

Either system—CDS or RDS—is facilitated by an information system that grants access to information to respective parties—the customers or the retailers. Our analysis suggests that the choice of an information system, as well as the design of an incentive mechanism, has strategic implications on supply chain behavior. We highlight the general incongruence in the preferences of the manufacturer and those of the retailers. Naturally, one would conjecture that appropriately structured incentives can align the preferences of various parties. To address this issue at sufficient depth, one needs to analyze a metagame in which the manufacturer behaves as the Stackelberg leader, who makes strategic decisions on at least wholesale price and parameters for a transfer pricing scheme. Such a model will entail the analysis of a noncooperative game in both price and quantity between the retailers embedded within a leader-follower Stackelberg game and can be the subject matter for future research.

Electronic Companion

An electronic companion to this paper is available on the *Manufacturing & Service Operations Management* website (http://msom.pubs.informs.org/ecompanion.html).

[14] There is anecdotal evidence to suggest that automotive dealers trade within their preferential relationship network.

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