Should Suppliers Allow Capacity Transfers?

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Abstract

This research considers situations in which buyers pay to reserve their suppliers' capacity for future use. The study specifically explores whether suppliers should provide transfer rights, allowing buyers unable to use all of their reserved capacity to transfer the excess to another buyer, and whether they should charge a transfer fee. The study finds that, in most cases, the supplier maximizes financial outcomes when the buyer releasing the excess capacity keeps most of the retail-level profit from the transfer and the supplier does not charge a transfer fee.

Key words: Capacity Management, Capacity Transfer Fees, Buyer-Supplier Negotiation

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1 Introduction

Capacity reservation arrangements have become popular in many industries in the last decade. In typical capacity reservation situations, a buyer reserves a supplier's capacity to make a product it needs by paying a capacity reservation fee. When the product demand is realized, the buyers request the supplier to use their reserved capacity to make the needed units; in return, they pay an execution fee to the supplier for each unit of product made. The arrangements give buyers the right to use only part of the supplier's available capacity, allowing the supplier to pool capacity and make products for various buyers.

What happens when a buyer requires more or less than its reserved capacity? Consider a real-world arrangement in the computer hard drive industry. Hard drives require suspension assemblies, critical components enabling precise recording head positioning and providing electrical connections. Only a handful of companies manufacture suspension assemblies, with one offering a dominant technology and enjoying greater market share than its competitors. Hard drive manufacturers provide bids to computer producers to be one of two or three suppliers for each computer model. When they bid, the hard drive manufacturers do not know how much of the buyer's demand they will receive; however, they reserve capacity at their preferred suspension assembly supplier, expecting to start manufacturing hard drives as soon as they are awarded a contract. Each hard drive manufacturer's suspension assemblies fit only its hard drives and cannot be used with another manufacturer's product.

When the hard drive manufacturers realize their demand, they ask their suspension assembly supplier to manufacture the needed parts. Some hard drive manufacturers realize demand exceeding their reserved capacity; others do not need all the capacity they reserved. Making minor adjustments to equipment, suspension assembly suppliers can make suspensions for any hard drive manufacturer. Therefore, the supplier can allocate unused reserved capacity from one customer to another.

Because suspension assembly suppliers can use the same capacity to satisfy excess demand from any customer, they must consider the best approach to controlling reserved capacity. In settings where a supplier sells inventory, buyers simply own the manufactured products and have complete control over it once they pay for it. When making capacity reservations, buyers pay a fee for the right to use the capacity in the future. Before signing a contract, the supplier can set the terms of the arrangement, maintaining ownership of reserved but unused capacity but informing buyers if and how they can benefit if another buyer can use the capacity. For example, the supplier could grant buyers the rights to transfer their unused reserved capacity but charge a transfer fee for each unit of transfer.

In this paper, we characterize whether and when suppliers should keep capacity transfer rights or grant them to the firm making the reservation. The supplier has full control of its capacity; if a buyer wants to transfer capacity rights to another, it cannot do so without the supplier's knowledge. Thus, the supplier can charge new buyers transfer fees. In inventory sharing, buyers always own the completed products they purchase and can share them with other buyers without informing their suppliers.

Various industry suppliers take different approaches to capacity transfer. For example, a hard drive suspension assembly supplier that we worked with informs buyers they will lose any capacity they do not use in a given time period and retains transfer rights itself (i.e., buyers lose all value from unused capacity). A different approach to capacity transfer is noted in Plambeck and Taylor (2007a): Taiwan Semiconductor Manufacturing Corporation, the world's largest contract semiconductor producer, is a pioneer in what have become known as "tradable capacity options" (LaPedus, 1995; Economist, 1996). The options give buyers the right to trade supplier capacity among themselves. Under the policy, suppliers collect no additional profit from transferred capacity; buyers divide the profit generated. In other words, the suppliers grant the buyers full capacity transfer rights. A different policy for capacity transfers is common when manufacturers reserve warehouse capacity from third party logistics providers. If the firm making the reservation does not need some of the space, it can sell it to another firm, though logistics providers typically charge execution fees for materials handling. Because the logistics firms typically pick up the warehoused items, which are differentiated across users, the manufacturers cannot exchange capacity among themselves without the logistics providers' knowledge. A similar application occurs in cloud based computing/web services. Amazon Web Services allow users to reserve computing capacity on its servers. Users can reserve what Amazon calls "instances," combinations of computer, memory and networking capacity, for particular applications. For users reserving instances they do not use, Amazon has created a marketplace where they can negotiate instance (i.e., capacity) transfers to other users. Amazon charges 12% of the trading price to transfer capacity on the marketplace.

While no model can capture the complexity of all real-world capacity transfer situations, this paper explores the primary trade-off common to the above examples. Specifically, our model describes when suppliers should or should not charge buyers a fee for transferring capacity among themselves.

Our work has several takeaways for managers. First, suppliers improve their outcomes if the buyers releasing their unneeded capacity to others receive most of the reward. Second, suppliers should not charge fees for capacity transfers from one buyer to another in most reasonable cases. Third, in other cases where it is optimal for the supplier to charge a fee for transfers, as long as the buyers with excess capacity accrue most of the profit from transfers, not charging a transfer fee would still perform close to optimal for suppliers. Fourth, these cases where the suppliers should charge buyers for transfers and keep capacity ownership happen when the buyers' profit margins on sales are very small compared to the suppliers' and it is relatively inexpensive to build capacity.

Our results seem counterintuitive. By not charging a fee, suppliers might be expected to lose money. But when suppliers do not charge transfer fees and grant buyers the financial rewards for giving up unneeded capacity, suppliers can charge a higher capacity reservation fee.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature. Section 3 introduces our model. In Section 4.1, we formulate the buyers' optimal decisions and in Section 4.2, we derive the optimal results for how the supplier should set the transfer fee to maximize his profit. In Section 4.3 and Section 4.4, we extend our result to a model with asymmetric buyers and a model with more than two buyers, respectively. Section 5 contains our numerical study. In Section 6, we check the robustness of our results by considering different variations of our model. The paper concludes in Section 7.

2 Literature Review

The rich inventory pooling and transshipment literature is relevant to our research question. Krishnan and Rao (1965), Karmarkar and Patel (1977), Tagaras (1989), Robinson (1989), and Archibald et al. (1997) have studied inventory transshipment models in which a central planner coordinates orders at various locations. Recent literature on inventory pooling and transshipment in decentralized systems, including Lippman and McCardle (1997), Anupindi et al. (2001), Rudi et al. (2001), Hu et al. (2007), Zhao et al. (2005), Zhao and Atkins (2009), is also of interest but does not consider suppliers' decisions and transshipment's impact on them.

Another literature stream studies the impact of inventory transshipment among downstream buyers on upstream suppliers' decisions and profits (Dong and Rudi, 2004; Zhang, 2005; Anupindi and Bassok, 1999; Jiang and Anupindi, 2010; Lee and Whang, 2002; Shao et al., 2009). Whether and how suppliers benefit from capacity transfer among buyers appears to be similar to the inventory transshipment problem. But the situations have a few key differences. First, in the inventory transshipment problem with decentralized buyers, transfer rights are not an issue because the buyers own the inventory. Suppliers have no control over transshipment, regardless of its benefits or downsides. In our paper, the question is not only whether buyers should be able to use excess capacity, but also how suppliers should divide the generated profit among supply chain members. Suppliers could charge the buyer using the excess capacity a transfer fee, then keep the transfer fee or use it to reimburse the buyer transferring excess reserved capacity. Because buyers own inventory outright, the transshipment literature does not address the same issue as our work. Second, the costs associated with the capacity transfer problem also differ from those in transshipment, where buyers purchase inventory before demand is realized and suppliers receive the wholesale price for each unit. Suppliers are not directly making profit when their buyers sell an inventory unit. In our problem, buyers pay suppliers a capacity reservation fee for each unit before demand realization but only remit the remaining (i.e., execution) cost for each unit actually demanded. In the model, suppliers profit both from each capacity unit (analogous to an inventory unit) the buyer sells to customers by charging an execution fee and each capacity reservation unit. In other words, buyers reserve capacity in the suppliers' facilities and later request execution of reserved capacity based on actual demand.These key differences result in managerial insights different from those of the previous literature.

Our work is also related to the rich literature on capacity reservation. Wu et al. (2005) provide an extensive review. Eppen and Iyer (1997), Van Mieghem (1999), Barnes-Schuster et al. (2002), Tomlin (2003), Erkoc and Wu (2005), and Spinler and Huchzermeier (2006) have studied capacity reservation contracts between single suppliers and buyers. Our work considers one supplier and multiple buyers. Furthermore, we focus on different capacity transfer fee strategies and study their impact on suppliers.

Similar to our paper, Plambeck and Taylor (2005, 2007a,b) examine a capacity reservation problem in a supply chain consisting of two buyers purchasing from a single supplier. However, these studies differ from our paper in their model setup and research questions. Plambeck and Taylor (2005) asks which member of the supply chain, the buyers or the supplier, should make capacity and production decisions to coordinate the capacity reservation and product innovation. In contrast, in our paper, only the buyers decide how much capacity to reserve from the supplier. We ask if a supplier should charge a fee when a buyer with excess reserved capacity transfers it to another with a reservation shortage. Plambeck and Taylor (2007a,b) are concerned with buyers' innovation investment. These studies model two different capacity reservation contracts and show a specific type of capacity contract, sometimes combined with a court ordered re-negotiation setting, can result in the buyers investing efficiently in innovation. Our study does not examine buyers' innovation investment decisions, but rather whether and when suppliers benefit from charging capacity reservation transfer fees.

3 Problem Description

We consider a one-period setting with one risk-neutral supplier and two risk-neutral buyers. The buyers face stochastic demand and reserve capacity to ensure that the supplier has the capacity to execute their orders once they realize their demand.

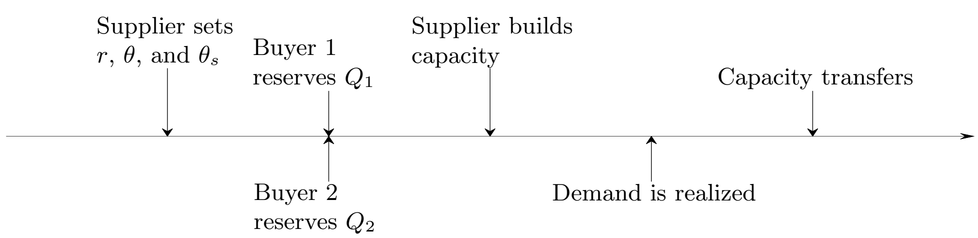

Figure 1: The sequence of events.

Figure 1 shows the sequence of our main model. First, the supplier announces a capacity reservation fee r to reserve a capacity unit and describes how any capacity transfer will be handled. Each buyer $i \in \{1, 2\}$ then reserves capacity Q_i by paying the total reservation fee rQ_i. The supplier then creates required capacity at a cost h per unit. Next, the buyers observe their demands D_i and order the supplier to produce up to it. The supplier must produce up to each buyer's reserved capacity Q_i. For demand beyond one buyer's reserved level, the model allocates available capacities according to the supplier's stated transfer policies.

The supplier uses one capacity unit to produce one product unit and pays production cost c per unit. The buyers must pay an execution fee w per unit when they receive one. The buyers use the units purchased to create their own products and sell them in the marketplace. Without loss of generality, we normalize the buyers' production cost using the supplier's part to zero. Each buyer receives v for each unit delivered to a customer.

Capacity building cost h, production cost c, and the price the buyers receive for their product v are exogenous parameters. To incentivize each supply chain member to participate, we require that $h + c \leq v$, $w \leq v$, and $r + w \leq v$. In our model, the demands of buyers D_1 and D_2 can be correlated. We use $D_t = D_1 + D_2$ to denote total demand. Each buyer chooses its capacity reservation level Q_i. The supplier decides the capacity reservation fee r and transfer policy.

Based on the available research, we assume in our work that execution fees are exogenous, but suppliers can set their capacity reservation fees. As an example, the wholesale price contract, a common contract between suppliers and buyers, is a special case of our model. In a wholesale price contract, the supplier charges a wholesale price to reserve and execute each unit of capacity reserved, whether it is executed or not. Since the wholesale price is charged on each unit of capacity reserved, whether it is executed or not, it is analogous to the capacity reservation fee in our model when there is no additional execution fee ($w = 0$).

For another example, consider the third party logistics warehousing industry, where execution (e.g., moving material in and out of warehouses) is essentially a commodity and most firms charge market prices for it. The logistics companies have more control over warehouse reservation pricing because it is influenced by unique factors like location and available capacity.

Similarly, many OEMs select a tier-two supplier for their tier-one supplier of a particular component and set the execution fee between them. In these arrangements, the execution fee is fixed, but the tier-two supplier can charge a capacity reservation fee. In their review of the capacity management literature, Wu et al. (2005) suggest that exogenous wholesale prices (analogous to our model's execution fees)[1] are common in the high-tech industry, where manufacturers enter agreements with suppliers to develop technology (i.e., the design-win phase) before negotiating

[1] In Wu et al. (2005), the contracts considered are more sophisticated than typical wholesale pricing contracts in the literature. What Wu et al. (2005) label as wholesale price is charged on each unit of capacity executed, not reserved, making it analogous to our execution fee.

capacity reservations. In addition, the researchers point out that charging side fees on each unit of reserved capacity (analogous to our capacity reservation fees) is usually possible and practical.

When one buyer uses another buyer's single unit of unused capacity to fulfill its demand, it expects to earn v from a customer and must pay execution fee w to the supplier. That is, the new buyer expects to earn net profit $v - w$ for each unit of capacity transferred. Because the supplier still holds the capacity, it could decide to keep a portion of the retail level profit by charging a transfer fee. We denote the portion of generated profit $v - w$ that the supplier keeps as $\theta_s \in [0, 1]$. We call θ_s the *Supplier's Transfer Share*. The remaining profit $(1 - \theta_s)(v - w)$ is divided among the buyers: (i) the buyer who has extra demand and receives the unused capacity realizes $\theta \in [0, 1]$ portion of the remaining profit $(1 - \theta_s)(v - w)$, and (ii) the buyer transferring its unused capacity receives $(1-\theta)$ portion of the remaining profit $(1-\theta_s)(v-w)$. We define θ as the *Receiving Buyer's Transfer Share*.

In the first part of the paper, we assume the supplier decides θ_s and θ. In other words, we assume the supplier decides and informs the buyers whether and how they can benefit if their excess capacity can be used by the other before they reserve capacity. This situation occurs when suppliers have significant supply chain leverage. For example, the supplier might be the only firm producing a particular part. According to *The Economist* in "Invisible but Indispensable" (Economist, 2009), supplier Mabuchi makes 90% of the micro-motors used to adjust automobile rear-view mirrors, and Tokyo Electron LTD makes 80% of the etchers used in LCD panel production. Computer manufacturers still rely on Intel for a large percentage of their microprocessor chips. In all such situations, suppliers have leverage due to their near monopoly and can decide what to charge buyers for capacity received and refund other buyers for capacity transferred.

To check the robustness of our model, we also study (i) the case in which the supplier does not decide θ, making it a parameter of the model based on market standards, and (ii) the case in which buyers decide θ. In the next section, we discuss how the reservation quantities Q_1 and Q_2 depend on the parameters v, w, h, demand distribution, and the variables θ, θ_s, and r.

4 Model Analysis

In this section, we analytically study our main model.

4.1 Buyers' Problem: Equilibrium Order Quantities

Based on our model, buyer i's expected profit Π_{B_i} is a function of reserved quantity Q_i and the other buyer's reserved quantity Q_j as follows:

$$\Pi_{B_i} = -rQ_i + (v-w)S_i(Q_i) + (1-\theta_s)\theta(v-w)T_i(Q_i,Q_j) + (1-\theta_s)(1-\theta)(v-w)T_j(Q_j,Q_i)\,,$$

where $S_i(Q_i) = \mathbb{E}\big[\min(Q_i, D_i)\big]$ is buyer i's expected sales if it reserves quantity Q_i, excluding transfers. $T_i(Q_i,Q_j)$ is buyer i's expected transfer quantity when it has reserved Q_i and the other buyer has reserved Q_j. We must therefore have $T_i(Q_i,Q_j) = \mathbb{E}\Big[\min(Q_j - D_j, D_i - Q_i) \times \mathbb{1}(D_i > Q_i, D_j < Q_j)\Big]$, where $\mathbb{1}(\cdot)$ is the indicator function.

In Lemma A.1 in our Online Supplement, we simplify $T_i(Q_i,Q_j)$ and $S_i(Q_i)$ and obtain expressions for the derivatives of $T_i(Q_i,Q_j)$ with respect to reservation quantities. The following proposition specifies the conditions for finding equilibrium reservation quantities.

Proposition 1. *We find equilibrium reservation quantities Q_1 and Q_2 by solving: $H_1(Q_1,Q_t) = \frac{r}{v-w} = H_2(Q_2,Q_t)$ and $Q_1+Q_2=Q_t$, where,*

$$H_i(Q_i,Q_t) = Pr(D_i > Q_i) - (1-\theta_s)\theta Pr(D_i > Q_i, D_t < Q_t) + (1-\theta_s)(1-\theta)Pr(D_i < Q_i, D_t > Q_t)\,.$$

For symmetric buyers, $Q_1 = Q_2 = Q$ at equilibrium. Consequently, each buyer's reserved equilibrium quantity Q satisfies $H_1(Q, 2Q) = \frac{r}{v-w}$.

We present all proposition proofs in our Online Supplement.

4.2 Supplier's Problem: Optimal Capacity Reservation Fees and Transfer Profit Division

For suppliers, we derive the capacity reservation fee r and fractions θ_s and θ that maximize expected profit. Where buyers' demand distributions are symmetric, the supplier's profit is

$$\Pi_s = (r-h)\,Q_t + (w-c)\mathbb{E}\big[\min(Q_t, D_t)\big] + \theta_s(v-w)\Big(T_i(Q_i,Q_j) + T_j(Q_j,Q_i)\Big)\,.$$

Equivalently,

$$\tfrac{1}{v-c}\Pi_s = s_l Q_t - m_r\left(1 - \tfrac{r}{v-w}\right)Q_t - (1-m_r)\left(\int_{-\infty}^{Q_t} Pr(D_t < y)\,\mathrm{d}y\right) + \theta_s m_r\Big(T_i(Q_i,Q_j) + T_j(Q_j,Q_i)\Big)\,,$$

where $s_l = \frac{v-c-h}{v-c}$ and $m_r = \frac{v-w}{v-c}$.

In our analysis, we use $s_l = \frac{v-c-h}{v-c}$ to denote *Supply Chain Service Level* and $m_r = \frac{v-w}{v-c}$ for

Fraction Retail Sales Margin. The two parameters can take values only between zero and one and have an intuitive meaning as follows:

- *Supply Chain Service Level s_l:* When a supply chain is centralized, we can obtain optimal capacity $Q_t = Q_1 + Q_2$ using a newsvendor model with capacity overage cost h and capacity shortage cost $v - c - h$. The service level under optimal capacity is $s_l = (v - c - h)/(v - c)$, a number between zero and one depending on v, c, and h. Supply Chain Service level therefore represents the probability that the supply chain would have enough capacity to satisfy all demand under optimal capacity. For example, if the supply chain's service level is $s_l = 0.9$, agents should reserve enough capacity to give themselves a 90% probability of satisfying all demand. Supply Chain Service Level s_l is large when suppliers can build capacity inexpensively (i.e., h is small) and the supply chain's marginal profit on sales is high (i.e., $v - c$ is large).
- *Fraction Retail Sales Margin $m_r = (v - w)/(v - c)$:* In our model, $(v - w)$ represents buyers' marginal profit from each sales unit, and $(v - c)$ represents the supply chain's marginal profit from each sales unit. Thus, $m_r = (v - w)/(v - c)$ represents the buyers' profit margin as a percentage of the supply chain's margin and is a number between zero and one. When m_r is more than 0.5, buyers make more profit per sale than suppliers. When m_r is less than 0.5, buyers make less profit per sale than suppliers.

By fixing the value of $s_l = 1 - \frac{h}{v-c}$, we determine the cost of reserving a unit of capacity relative to the supply chain's marginal profit on a sale $v - c$. By fixing the value of m_r, we determine what percentage of the supply chain's marginal profit on a sale $v - c$ the buyer collects.

The two metrics help us recognize realistic cases. For example, a supply chain with a service level of $s_l \leq 0.5$ or $m_r \leq 0.1$ is unrealistic. The parameters have intuitive meanings, allowing us to better explain our results and summarize our cost parameters v, w, c, and h.

4.2.1 Symmetric Demand Distributions

In Theorem 1, we show that $\theta = 0$ maximizes supplier profit. In Theorem 2, we specify the optimal value of θ_s for the supplier.

Theorem 1. *For two buyers with symmetric demand distribution, supplier's profit is maximized when the buyer with excess demand receives no profit from a capacity transfer (i.e., $\theta = 0$).*

The supplier's profit increases as θ decreases. Since $(1-\theta)$ determines the portion of the profit a buyer with excess capacity retains, the buyers' marginal profit of reserving an additional capacity unit is higher when θ is smaller. Consequently, the supplier can charge a higher reservation fee r to induce each buyer to reserve the same capacity quantity Q. As a result, the supplier's profit increases as θ decreases, suggesting the supplier's profit is maximized when the buyer with excess demand receives no profit from a capacity transfer.

To characterize the supplier's optimal θ_s, we first assume the buyers' demands D_1 and D_2 follow a symmetric bivariate normal distribution with mean μ, standard deviation σ, and correlation ρ. That is

$$(D_1, D_2) \sim \mathcal{N}\left(\begin{pmatrix}\mu \\ \mu\end{pmatrix}, \begin{pmatrix}\sigma^2 & \rho\sigma^2 \\ \rho\sigma^2 & \sigma^2\end{pmatrix}\right). \tag{1}$$

We assume μ/σ is large enough to make the probability of negative demand negligible.

Theorem 2. *For two buyers with symmetric demand distributions, supplier profit is maximized either when*

(i) the supplier does not charge for capacity transfer, and the buyer with excess capacity receives all transfer-generated profit (i.e., $\theta_s = 0$ and $\theta = 0$), or

(ii) the supplier receives all transfer-generated profit (i.e., $\theta_s = 1$).

Furthermore, $\theta_s = 0$ is optimal for small s_l values, and $\theta_s = 1$ is optimal for large s_l values and small m_r values.

Theorem 2 suggests suppliers should never try to obtain only a portion of the retail level value generated by a capacity transfer by charging a fee. The supplier should seek all of the value ($\theta_s = 1$) or none of it ($\theta_s = 0$). Also of note, $\theta_s = 1$ is optimal only when both *Supply Chain Service Level* s_l is relatively large and the retailer's profit margin on sales m_r is relatively small. We explain the intuition of our results in Section 4.2.2.

In Proposition 2, we provide expressions for optimal capacity reservation fee r and the conditions under which $\theta_s = 1$ and $\theta_s = 0$ are optimal. We let $\Phi(z)$ be CDF and $\phi(z)$ be PDF of standard normal distribution. $\Phi_\alpha(z)$ represents CDF of bivariate standard normal distribution, with correlation α calculated at z and z/α, where $\alpha \stackrel{def}{=} \sqrt{\frac{1+\rho}{2}} < 1$. Note that $\Phi(x) = Pr(D_i < \mu + \sigma x)$, $\Phi(\frac{x}{\alpha}) = Pr(D_t < 2(\mu + \sigma x))$, and $\Phi_\alpha(x) = Pr(D_i < \mu + \sigma x, D_t < 2(\mu + \sigma x))$. As defined by $\alpha = \sqrt{(1+\rho)/2} = \sigma_t/(2\sigma)$, α is (i) a simple transformation of ρ taking positive values between 0 and 1 and (ii) the fraction of total demand σ_t's standard deviation over the sum of the standard deviations of each buyer's demand distribution $\sigma + \sigma = 2\sigma$.

Proposition 2. *The optimal θ_s and capacity reservation fee r can be represented by the following:*

- *If $\Pi_s^0(z^0) \geq \Pi_s^1(z^1)$, then $\theta_s^* = 0$, and $r^* = \left(1 - \Phi_\alpha(z^0)\right)(v - w)$ and*
- *If $\Pi_s^0(z^0) < \Pi_s^1(z^1)$, then $\theta_s^* = 1$, and $r^* = \left(1 - \Phi(z^1)\right)(v - w)$,*

where z^0 is the solution to $m_r(z + \frac{\mu}{\sigma})\Phi'_\alpha(z) + m_r\Phi_\alpha(z) + (1 - m_r)\Phi(\frac{z}{\alpha}) - s_l = 0$, z^1 is the solution to $m_r(z + \frac{\mu}{\sigma})\phi(z) + \Phi(\frac{z}{\alpha}) - s_l = 0$, $\Pi_s^0(z) = (s_l - m_r\Phi_\alpha(z))(z + \frac{\mu}{\sigma}) - (1 - m_r)\int_{-\infty}^{z} \Phi(\frac{x}{\alpha})\,\mathrm{d}x$, and $\Pi_s^1(z) = (s_l - m_r\Phi(z))(z + \frac{\mu}{\sigma}) - \int_{-\infty}^{z} \Phi(\frac{x}{\alpha})\,\mathrm{d}x + m_r\int_{-\infty}^{z} \Phi(x)\,\mathrm{d}x$.

Proposition 2 specifies that suppliers must determine what capacity quantity they want buyers to reserve when setting $\theta_s = 0$ ($Q^0 = \sigma z^0 + \mu$) or $\theta_s = 1$ ($Q^1 = \sigma z^1 + \mu$) to find their optimal capacity reservation fee r. They then compare profit when setting $\theta = 0$ versus $\theta = 1$ to determine optimal θ_s and r values. Generally, if capacity building cost h is large, suppliers want buyers to reserve less capacity and should set higher capacity reservation fees r. When capacity building cost h is small and suppliers' profit margins on sales are large, they should encourage higher capacity reservation rates using lower fees r.

4.2.2 Intuition for Results

In Theorem 2, we characterize how suppliers should structure capacity transfer rights for buyers. We conclude they should either take all the transfer benefit (i.e., optimal $\theta_s = 1$) or give all retail level profits generated by the transfer to the buyer with excess capacity (i.e., optimal $\theta = 0$ and optimal $\theta_s = 0$).

Why is the optimal θ_s always at the boundary?

Figure 2 shows the supplier can incentivize the buyers to reserve a specific capacity Q with many different values of the pair (θ_s, r). For example, if the supplier reduces transfer fee θ_s, it can charge a higher capacity reservation fee r and keep Q fixed. Next, we explain among all the (θ_s, r) pairs resulting in a specific Q (e.g., equilibrium Q, the red line in the figure), the pair with θ_s set to zero or 1 generates the most supplier profit; hence, the optimal θ_s is always at the boundary.

For any specific Q in Figure 2, the supplier compares whether (i) increasing θ_s and collecting fees on transfers or (ii) reducing θ_s and charging higher capacity reservation fees yields a higher profit. For a given Q (denoted by the figure's isolines), the comparison favors one direction, meaning

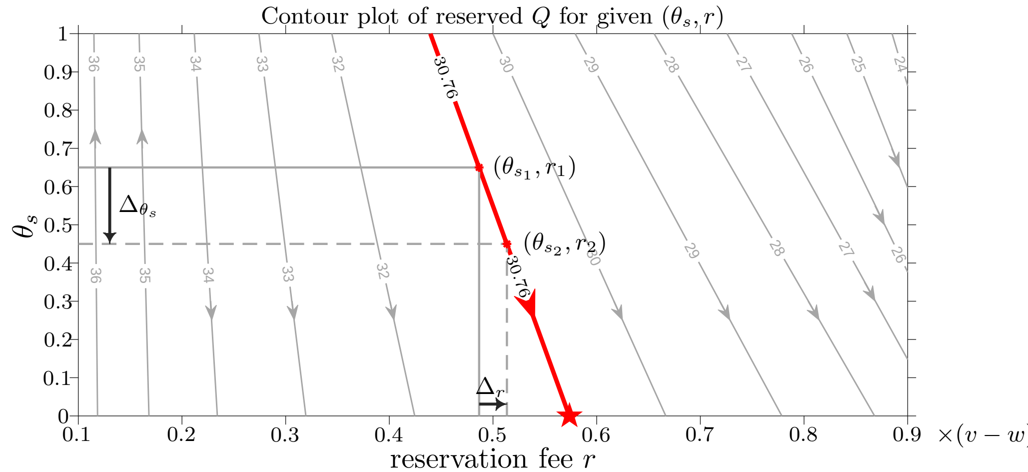

Figure 2: The contour plot of capacity Q reserved by each buyer for different (θ_s, r) values is shown. In the example, a red star indicates the optimal supplier decision, $\theta_s^* = 0$ and $r^* = 0.5738 \times (v - w)$, which results in each buyer reserving $Q^* = 30.76$. The supplier can induce each buyer to reserve $Q^* = 30.76$ with many sub-optimal (θ_s, r) values, represented by the red line. The figure also shows that a decrease of Δ_{θ_s} in θ_s and appropriate increase of Δ_r in r does not impact capacity reservation quantities ($Q^* = 30.76$). On each of the isolines (e.g., the red line), the supplier's profit increases only in the direction specified by the arrows. The parameters used are $s_l = 0.8$, $m_r = 0.05$, $\mu = 30$, $\sigma = 5$, $\rho = -0.5$. The X axis is scaled down by a factor of $(v - w)$.

supplier profit increases in only one way. Hence, the best pair (θ_s, r) will have θ_s equal to zero or 1.

To further understand the figure, let $V = v - w$ be the buyers' marginal profit of selling a product. The supplier has three profit sources: (i) buyers reserving capacity, denoted by reservation-profit, (ii) fees for capacity transfers among buyers, denoted by transfer-profit, and (iii) reserved capacity execution, denoted by execution-profit. We denote T as expected transfer quantity and g as the chance of buyers being able to transfer an additional capacity unit and consider the following:

- A decrease of Δ_{θ_s} in transfer fee θ_s results in an increase in the buyers' marginal benefit of reserving capacity by $\Delta_{\theta_s} gV$.[2]
- If the supplier increases the buyers' marginal cost of reserving capacity r by the same amount that the marginal benefit increases (i.e., by $\Delta_r = -\Delta_{\theta_s} gV$ in Figure 2), their reserved capacity Q^* does not change.

With these changes in θ_s and r, the equilibrium capacity reserved Q^* does not change, and the supplier's profit sources react as follows: (i) Reservation-profit increases by $\Delta_r Q^* = -\Delta_{\theta_s} g\, Q^* V$,

[2]Buyers reserve an additional capacity unit only if (i) they have a high probability of using it and making profit V (which does not depend on θ_s) or (ii) they have a high probability of transferring it (i.e., g) and making a profit of $(1 - \theta_s)V$. Therefore, a buyer's marginal benefit of reserving an additional capacity unit is related to θ_s by the term $(1 - \theta_s)gV$.

(ii) transfer-profit decreases by $\Delta_{\theta_s} TV$, and (iii) execution-profit does not change. Therefore, if $g\,Q^* \geq T$, the process of coordinated change $(\Delta_{\theta_s}, \Delta_r = -\Delta_{\theta_s} gV)$ in (θ_s, r) weakly generates profit for the supplier. In this inequality, (i) g determines the impact of a change in θ_s on the buyers' marginal benefit of reserving capacity and how much r must change to fix Q, (ii) Q determines the impact of a change in r on supplier profit, and (iii) T determines the impact of a change in θ_s on supplier profit. Notice that if the equilibrium capacity reserved Q^* does not change, the inequality does not change. This implies the direction of the inequality stays the same on each of the isolines in Figure 2, meaning supplier profit increases in only one direction.

In short, θ_s is optimal at the boundary because: (i) the transfer fee and the capacity reservation fee r is charged *per unit*; more generally, the supplier's and the buyers' profit functions are the sum of functions of the form $r \times f_1(Q)$ and $\theta_s \times f_2(Q)$, where f_1, f_2 can be non-linear functions of Q; and (ii) the supplier *decides* the capacity reservation fee r. We emphasize that the supplier's profit is nonlinear in θ_s, because the equilibrium Q depends on θ_s. However, the supplier's profit is linear in θ_s in *certain directions* where the pair (θ_s, r) changes simultaneously to keep Q fixed. As a result, the optimal θ_s is at the boundary.

Under what specific conditions is $\theta_s = 0$ or $\theta_s = 1$ optimal?

When it is relatively inexpensive for the supplier to build capacity (i.e., $s_l = 1 - \frac{h}{v-c}$ is large) and its profit margin on sales is large (i.e., $m_r = 1 - \frac{w-c}{v-c}$ is small), the supplier would want each buyer to reserve a large capacity quantity Q, and consistent with Theorem 2, $\theta_s = 1$ would be optimal.

By setting a small reservation fee r, the supplier can induce the buyers to reserve a large capacity Q. The supplier can encourage the buyers to reserve even more capacity by further decreasing r and/or charging a smaller transfer fee θ_s. A reduction in r would also decrease the supplier's reservation-profit, and a reduction in θ_s would decrease the supplier's transfer-profit. We argue reducing θ_s would be a weak incentive to reserve capacity when Q is large, as both buyers would likely have excess capacity and be unable to transfer it to the other. Hence, when Q is large (i.e., the suppliers' profit margin on sales is large and it is relatively inexpensive to build capacity), the supplier should focus on reducing reservation fee r to encourage buyers to reserve more capacity.

When it is relatively expensive for the supplier to build capacity (i.e., s_l is small), the supplier would like the buyers to reserve less (Q will be smaller) and instead encourage the buyers to trade their excess capacity among them. Hence, they set $\theta_s = 0$. With relatively small Q, it is likely each buyer would need excess capacity and their incentives would be sensitive to θ_s. As a result, the supplier would want to give transfer rights to the buyers (i.e., set $\theta_s = 0$) and charge a greater reservation fee r.

4.3 Asymmetric Demand Distributions

With symmetric demand distributions, the supplier's profit is maximized either when $\theta_s = 0$ and $\theta = 0$, or when $\theta_s = 1$ and the value of θ is irrelevant. When demand distributions are asymmetric, θ can be optimal at either boundary or its value is irrelevant.

Using Proposition 1, with asymmetric demand distributions, the equilibrium capacity quantities Q_i, Q_j, and Q_t satisfy the following two equations: (i) $\frac{r}{v-w} = H_i(Q_i, Q_t) = H_j(Q_j, Q_t)$ and (ii) $Q_i + Q_j = Q_t$, where $H_i(Q_i, Q_t) = 1 - \Phi_i - (1-\theta_s)\theta(\Phi_t - \Phi_{it}) + (1-\theta_s)(1-\theta)(\Phi_i - \Phi_{it})$, $\Phi_i = Pr(D_i < Q_i)$, $\Phi_t = Pr(D_t < Q_t)$, and $\Phi_{it} = Pr(D_i < Q_i, D_t < Q_t)$ for $i = \{1, 2\}$. The supplier maximizes profit Π_s by choosing θ, θ_s, and r with the constraint that Q_i, Q_j, and Q_t must satisfy the equilibrium conditions.

Theorem 3. *If D_i and D_j are bivariate normal distributions*

$$(D_i, D_j) \sim \mathcal{N}\left(\begin{pmatrix}\mu_i \\ \mu_j\end{pmatrix}, \begin{pmatrix}\sigma_i^2 & \rho\sigma_i\sigma_j \\ \rho\sigma_i\sigma_j & \sigma_j^2\end{pmatrix}\right),$$

then $\theta_s = 1$ is optimal and θ is irrelevant, or optimal θ is zero or 1.

While Theorem 3 narrows down the optimal θ and θ_s, in Section 5.1, we further characterize the optimal decisions θ and θ_s.

4.4 Three Symmetric Buyers

We now extend our model to a supply chain with three symmetric buyers, Buyer x, Buyer 1, and Buyer 2.[3] Similar to our main model, if one buyer has reserved excess capacity and another needs it, the supplier allows a transfer. The supplier charges the buyers $\theta_s(v-w)$ for each capacity unit transfer, the buyer with excess capacity profits $(1-\theta_s)(1-\theta)(v-w)$ from each unit, and the buyer with excess demand profits $(1-\theta_s)\theta(v-w)$. Unlike in our two buyer model, we specify (i) how

[3] If the average of the buyers' demands is different but their standard deviations are the same, we can use the same analysis with slight modification.

excess buyer capacity is allocated when two buyers are in need and (*ii*) which of two buyers with excess capacity can transfer first.

In both cases, we assume the buyers are equally likely to have the priority to receive or transfer excess capacity at the appropriate fee. We make D_x, D_1, and D_2 the demands of Buyer x, Buyer 1, and Buyer 2. We let the expected transfer to Buyer x be denoted $T_{x+}(Q_x, Q)$, where it has reserved capacity Q_x and Buyer 1 and Buyer 2 each have reserved capacity Q.[4] Also, we let the expected transfer from Buyer x with reserved capacity Q_x to Buyer 1 and Buyer 2 with reserved capacity Q be $T_{x-}(Q_x, Q)$. The derivation of $T_{x+}(Q_x, Q)$, $T_{x-}(Q_x, Q)$, and their derivatives are presented as reduced forms in our Online Supplement, Lemma A.6.

When Buyer x has reserved capacity Q_x and the other buyers each have reserved capacity Q, Buyer x's profit function is

$$\Pi_{B_x} = -rQ_x + (v-w)\mathbb{E}[Q_x, D_x] + (1-\theta_s)\theta(v-w)T_{x+}(Q_x, Q) + (1-\theta_s)(1-\theta)(v-w)T_{x-}(Q_x, Q)\,.$$

Proposition 3. *At equilibrium, each of three symmetric buyers reserves capacity Q to satisfy $\frac{r}{v-w} = Pr(D_x > Q) + (1-\theta_s)\theta dT_{x+}(Q) + (1-\theta_s)(1-\theta)dT_{x-}(Q)$, where*

$$dT_{x+}(Q) = -Pr(D_x > Q, D_1 > Q, D_x + D_2 < 2Q) - Pr(D_x > Q, D_1 < Q, D_x + D_1 + D_2 < 3Q) < 0$$

$$dT_{x-}(Q) = Pr(D_x < Q) - Pr(D_x < Q, D_x + D_1 < 2Q, D_x + D_1 + D_2 < 3Q) > 0\,.$$

Next, we examine the supplier's optimal decisions regarding θ and θ_s. The supplier's profit is

$$\Pi_s = (r-h)(3Q) + (w-c)\mathbb{E}\big[min(D_1 + D_2 + Q_x, 3Q)\big] + 3\theta_s(v-w)\Big(T_{x+}(Q,Q) + T_{x-}(Q,Q)\Big)\,,$$

where Q satisfies the equilibrium condition specified in Proposition 3.

Theorem 4. *With three symmetric buyers, the supplier's profit is maximized when either $\theta = 0$ and $\theta_s = 0$ or $\theta_s = 1$.*

Theorem 4 confirms that the supplier benefits most either keeping all retail-level transfer benefits or giving them all to buyers (i.e., $v - w$). The same intuition provided in Section 4.2.2 explains Theorem 4.

[4] We must show Buyer x cannot unilaterally deviate from the equilibrium in which each buyer orders the same specified quantity Q and make a profit; hence, we find the expected transfers when Buyer x has reserved a random quantity Q_x and the other two buyers each have reserved quantity Q.

5 Numerical Study

We know that when the buyers' demand distributions are symmetric, the supplier maximizes its profit by either (*i*) charging a fee capturing all transfer-related profits (and leaving buyers just their participation profit) or (*ii*) charging no fee and letting buyers transferring capacity away capture all retail-level profits. Now, we further characterize the supplier's optimal policy for transfer fees.

First, is it still optimal to keep buyers with excess demand from profiting from a transfer (i.e., is $\theta = 0$ optimal) with asymmetric buyers? Second, can we numerically extend the analytical result of Theorem 2 regarding the impact of s_l and m_r on optimal θ_s to our asymmetric or three symmetric buyer models? Third, how do demand parameter values (i.e., correlation ρ and coefficient of variation cv) impact suppliers' optimal decisions?

We explore two more issues related to our findings: (*i*) How likely is not charging a transfer fee ($\theta_s = 0$) optimal? and (*ii*) if $\theta_s = 0$ is not optimal, how does it compare to the optimal policy?

In our numerical study, we change our parameter values as follows:

- *Supply Chain Service Level* $s_l \in \{0.51, 0.52, 0.53, \ldots, 0.99\}$ (49 instances).
- *Fraction Retail Sales Margin* $m_r \in \{0.01, 0.02, 0.03, \ldots, 0.99\}$ (99 instances).

  In our analysis, v, w, h, and c appear only as $s_l = \frac{v-c-h}{v-c}$ and $m_r = \frac{v-w}{v-c}$; hence, we set only s_l and m_r instead of individual values.
- demand correlation $\rho \in \{-0.95, -0.90, -0.85, \ldots, +0.95\}$ (39 instances);
- coefficient of variations $cv = \frac{\sigma}{\mu} \in \{0.05, 0.10, 0.15, \ldots, 0.3\}$ (6 instances).

  With normal distribution, we require the coefficient of variation to be less than 0.333 to make the probability of negative demand negligible. With asymmetric buyers, we choose the largest coefficient of variation.

To study the asymmetric buyer model, we also choose $\frac{\mu_1}{\mu_1+\mu_2} \in \{0.25, 0.5, 0.75\}$ and $\frac{\sigma_1}{\sigma_2} \in \{0.25, 0.5, 0.75\}$. Our analytical results show that the supplier's decisions depend only on the fractions $\frac{\mu_1}{\mu_1+\mu_2}$ and $\frac{\sigma_1}{\sigma_2}$; thus, we do not set each σ_1, σ_2, μ_1, and μ_2 value. The parameter design accounts for 1,135,134 cases with symmetric buyers and 10,216,206 cases with asymmetric buyers.

For the model with two symmetric buyers and two asymmetric buyers, we also study the impact of demand parameters on optimal decisions. For this study, we analyze an additional 600,000 cases for the two symmetric buyer model and 5,400,000 more cases for the two asymmetric buyer model by expanding our demand parameter set and limiting our cost parameters as follows:

- *Supply Chain Service Level* $s_l \in \{0.51, 0.56, 0.61, \ldots, 0.96\}$ (10 instances).
- *Fraction Retail Sales Margin* $m_r \in \{0.01, 0.06, 0.11, \ldots, 0.96\}$ (20 instances).
- Demand correlation $\rho \in \{-0.99, -0.97, -0.95, \ldots, +0.99\}$ (100 instances).
- Coefficient of variation $cv = \frac{\sigma}{\mu} \in \{0.01, 0.02, 0.03, \ldots, 0.3\}$ (30 instances).

With three symmetric buyers, we assume their demand consists of market specific term Γ and buyer specific term ϵ_j for $j \in \{i, 1, 2\}$. Specifically, we assume $D_j = \Gamma + \epsilon_j$ for $j \in \{i, 1, 2\}$ and ϵ_j and Γ are independent random variables. Γ specifies market conditions and dictates buyer demand. If Γ has no variability, each buyers' demand is independent; otherwise, the demands are positively correlated.[5] Furthermore, we assume that ϵ_j and Γ are normally distributed. Specifically, $\epsilon_j \sim \mathcal{N}(0, \sigma_\epsilon)$ and $\Gamma \sim \mathcal{N}(\mu, \sigma_\gamma)$. Therefore, each buyer's demand is $D_j \sim \mathcal{N}(\mu, \sigma)$, where $\sigma = \sigma_\epsilon \sqrt{1 + \left(\frac{\sigma_\gamma}{\sigma_\epsilon}\right)^2}$. For our parameter values, we consider $\frac{\sigma_\gamma}{\sigma_\epsilon} \in \{0, 0.1, 0.2\}$; $s_l \in \{0.51, 0.52, 0.53, \ldots, 0.99\}$ (49 instances); $m_r \in \{0.01, 0.02, 0.03, \ldots, 0.99\}$ (99 instances); and $cv = \frac{\sigma}{\mu}$ varies from 0.05 to 0.3 in increments of 0.05 (6 instances). The three symmetric buyer model therefore has 87,318 cases. Overall, the parameter design accounts for 17,438,658 cases.

5.1 Optimal θ and θ_s With Asymmetric Demand

In Theorem 3, we partially characterize how suppliers can optimally ration capacity transfer-generated profit in the presence of buyers with asymmetric demand. We now further characterize the supplier's optimal θ and θ_s values for the asymmetric buyer model.

We numerically solve $15,616,206$ asymmetric buyer model instances with our specified parameters. Similar to the symmetric buyer model, the study shows it is optimal for the supplier to (i) not allow the buyer with excess demand to profit from the transfer (i.e., $\theta = 0$) and (ii) either collect all transfer-generated profit or give it all to the buyer with excess capacity (i.e., θ_s is either zero or 1).

5.2 Impact of Parameters on Supplier's Decisions

Impact of Cost Parameters: In Theorem 2, we analytically show that optimal θ_s is 1 for a model with two symmetric buyers when s_l is relatively large and m_r is relatively small. In this section, we test whether the result holds for our models with two asymmetric and three symmetric

[5]Three symmetric buyers cannot have negative demand correlations.

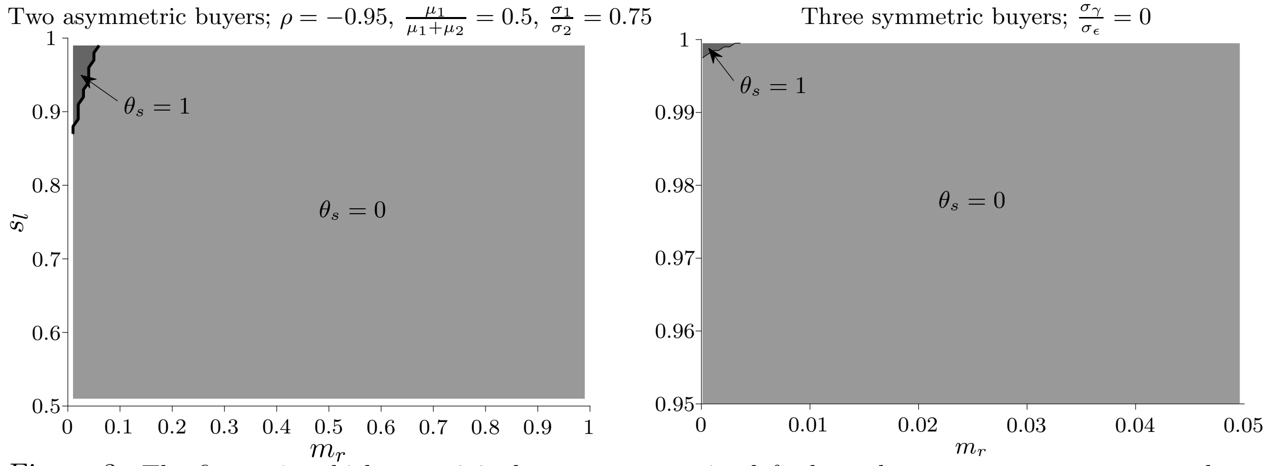

Figure 3: The figure, in which $cv = 0.3$, demonstrates optimal θ_s depends on cost parameters s_l and m_r when the supplier sets θ to zero. The X-axis features m_r; the Y-axis shows s_l. The left plot corresponds to the two asymmetric buyer model; the right plot shows the three symmetric buyer model.

buyers. We generate 2,124 plots similar to those shown in Figure 3. Among them, 2,106 correspond to our model with two asymmetric buyers and 18 correspond to our model with three symmetric buyers. In all plots generated, $\theta_s = 1$ occurs in the top left corner; that is, $\theta_s = 1$ when *Supply Chain Service Level* s_l is large and *Fraction Retail Sales Margin* m_r is small. We confirm that when $m_r \geq 0.08$ or $s_l \leq 0.82$, optimal θ_s cannot be 1. For the model with two asymmetric buyers, our numerical studies suggest that smaller $\frac{\mu_1}{\mu_1+\mu_2}$ and larger $\frac{\sigma_1}{\sigma_2}$ contribute to larger regions of $\theta_s = 1$ in the $m_r \times s_l$ space. In other words, when the variance of demand of the two buyers are similar but average demand of one buyer is substantially smaller than the other buyer, the region with $\theta_s = 1$ is larger.

For our model with three symmetric buyers, $\theta_s = 0$ is optimal for all our described parameters. We can observe optimal $\theta_s = 1$ only by focusing on very large s_l and very small m_r, i.e., with $s_l \in [0.95, 0.999]$ in increments of 0.001 and $m_r \in [0.001, 0.05]$ in increments of 0.001.

Impact of Demand Parameters: Theorem 2 does not address the impact of demand parameters ρ and cv on optimal θ_s. To numerically study the demand parameters' impact on both θ_s and optimal capacity reservation fee r, we focus on our models with two symmetric and two asymmetric buyers. We generate plots showing the supplier's optimal θ_s for each pair of demand parameters ρ and cv. Figures 4 and 5 show examples in which we observe the following:

- The right panel of Figure 5 suggests that the supplier charges a relatively high capacity reservation fee r when the correlation of demand ρ, or coefficient of variation cv is small. However, in the left panel of the same figure, we observe some disturbance of this general

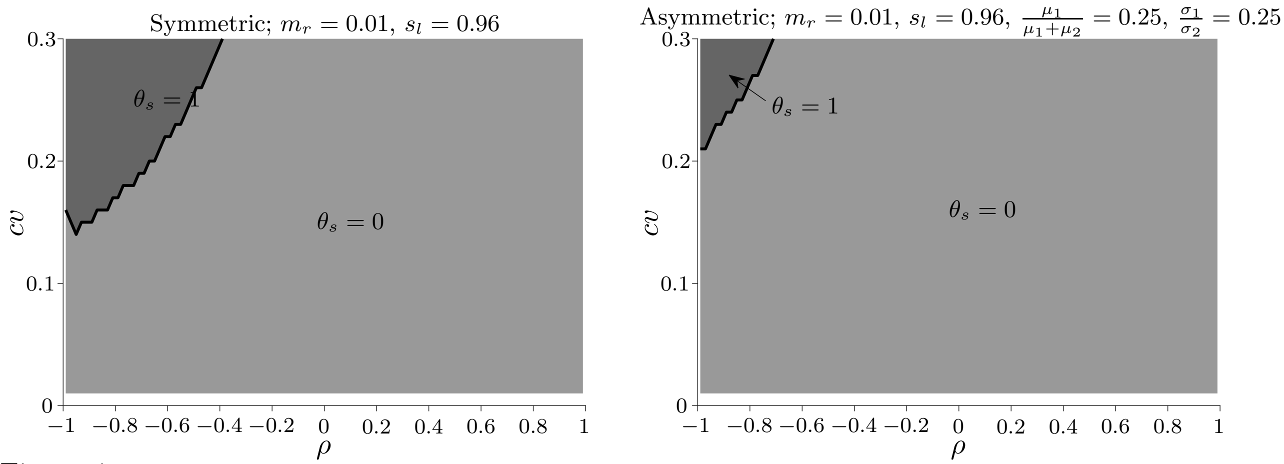

Figure 4: The figure shows optimal θ_s depends on the demand parameters ρ and cv when the supplier sets θ to zero. The X-axis features ρ; the Y-axis shows cv. The left plot corresponds to the two symmetric buyer model; the right plot shows the two asymmetric buyer model.

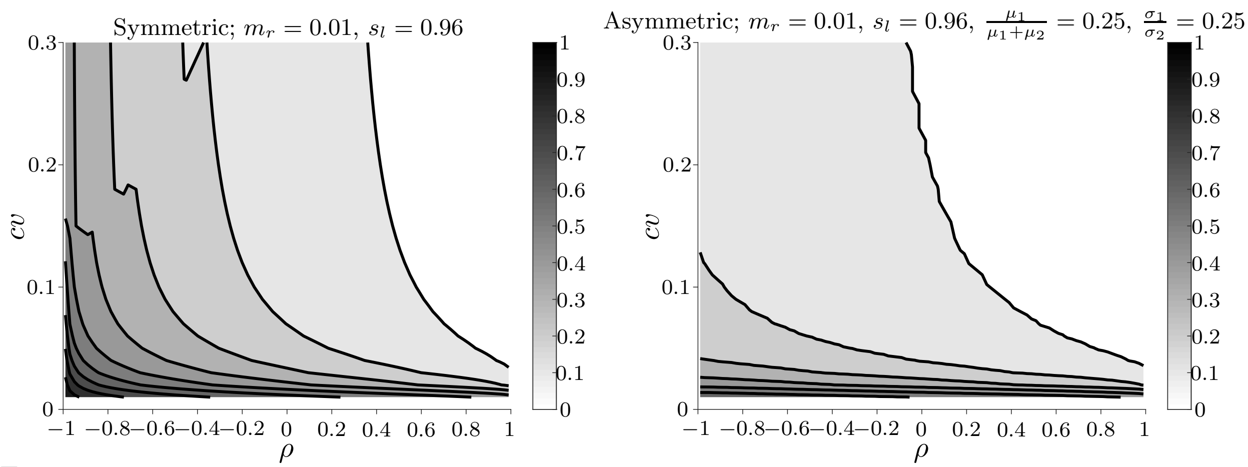

Figure 5: The figure shows optimal r depends on the demand parameters ρ and cv when the supplier sets θ to zero. The X-axis features ρ; the Y-axis shows cv. The left plot corresponds to the model with two symmetric buyers; the right plot shows the model with two asymmetric buyers.

observation. By comparing this panel with the left panel of Figure 4, we can conclude, the disturbance is due to the change in policy regarding θ_s. Specifically, with a smaller θ_s, the supplier charges a relatively high capacity reservation fee r.

- Figure 4 suggests the supplier should be more confident choosing $\theta_s = 0$ as the coefficient of variation becomes smaller.
- The left panel of Figure 4 suggests the impact of ρ on optimal θ_s is not monotonic. As ρ increases, optimal θ_s can switch from zero to one and back.

The first observation is intuitive. When ρ becomes smaller or more negative, it is more likely a buyer can transfer excess capacity to another and generate profit. In other words, the buyer's marginal benefit of reserving capacity increases. Hence, the supplier could increase the marginal cost of reserving capacity, charging a higher fee r. When the coefficient of variation cv is relatively small, demand variability is also low, creating little risk in reserving capacity. Here, the supplier can charge the buyers an amount approaching their sales profit margin $v - w$. Furthermore, when θ_s is relatively small, the buyers can profit from their excess capacity and the supplier can charge a higher capacity reservation fee r.

Addressing the second and third observations, we first define the z-value of reserved quantity Q as $z = \frac{Q-\mu}{\sigma}$. The value indicates how many standard deviations above or below expected demand each buyer's reserved capacity is. Recall that when deciding θ_s, the supplier compares expected transfer T with $g \times Q$, where g is additional transfer probability and Q is capacity quantity. The supplier compares whether increasing θ_s and collecting fees on expected transfers T or reducing θ_s and charging a higher reservation fee (i.e., adding $g \times (v - w)$ to the capacity reservation fee) is more beneficial. We can argue that because z-value determines expected transfer probabilities in normal distributions, $\frac{T}{\sigma}$ (expected transfers in standard deviation units) and g (additional transfer probability) depend on z-value and demand correlation, and $\frac{Q}{\sigma} = z + 1/cv$ depends on z-value and coefficient of variation cv.

For a fixed z-value, $\frac{Q}{\sigma}$ decreases as cv increases, but $\frac{T}{\sigma}$ and g remain the same. As a result, it is more likely that $\frac{T}{\sigma} > g \times \frac{Q}{\sigma}$, implying $\theta_s = 1$ is optimal. As demand correlation increases for a fixed z-value, both expected transfer $\frac{T}{\sigma}$ and additional transfer probability g decrease while $\frac{Q}{\sigma}$ remains fixed. Therefore, a higher demand correlation can result in optimal θ_s switching from 1 to zero or vice-versa. Changing cv or ρ also impacts z-value at the optimal solution, which complicates the comparisons.

5.3 A Simple Policy for Transfer Fees

The optimal value of θ_s, which determines whether a supplier should charge a transfer fee, can be zero or 1 and depends on several model parameters. Next, we explain $\theta_s = 1$ is optimal for only a small parameter set, and even in those cases, $\theta_s = 0$ performs well. Always choosing $\theta_s = 0$ and collecting no transfer fee is therefore a simple policy that is not far from optimal. On the other hand, we show choosing $\theta_s = 1$ by mistake can result in great profit loss.

We define an optimality gap of $\theta = \tau$, denoted Gap_τ for $\tau \in \{0, 1\}$, as the supplier's percentage profit loss if the firm sets θ_s as τ instead of optimal. Specifically, $Gap_\tau = \frac{\Pi_s^\tau - \Pi_s^*}{\Pi_s^*} \times 100\%$, where Π_s^*

Model	Policy	Count optimal	Optimality gap (if not optimal) Mean	Median	Max
Symmetric buyers	$\theta_s = 0$	99.93%	0.02%	0.02%	0.17%
	$\theta_s = 1$	0.07%	6.67%	5.05%	42.82%
Asymmetric buyers	$\theta_s = 0$	99.99%	0.01%	0.01%	0.11%
	$\theta_s = 1$	0.01%	4.63%	3.33%	46.4%

Table 1: Shown is the optimality gap for the symmetric and asymmetric two buyer models in which the supplier sets θ and r optimally after deciding θ_s. The "Count optimal" column specifies the percentage of 1,735,134 symmetric buyer model instances and 15,616,206 asymmetric buyer model instances considered, depending on whether $\theta_s = 0$ or $\theta_s = 1$ is optimal.

is the supplier's profit when optimizing θ_s, as well as r and θ, and Π_s^τ is the supplier's profit when setting θ_s sub-optimally but optimizing r and θ.

In the two symmetric buyer model, $\theta_s = 0$ is optimal in 99.93% of $1,735,134$ cases (see Table 1). In cases where $\theta_s = 0$ is not optimal (0.07%), the average optimality gap is 0.02% and the maximum gap is 0.17%. $\theta_s = 1$ is optimal in only 0.07% of the cases. When $\theta_s = 1$ is not optimal (99.93% of cases), the average optimality gap is 6.67%. The gap can be as high as 42.82%. We observe similar numbers for our two asymmetric buyer model.

We conclude that a simple policy that performs well for the supplier is to never charge the buyers any transfer fee (and instead charge a higher capacity reservation fee). The reason for this observation is as follows: $\theta_s = 1$ is optimal only when s_l is relatively large and m_r is relatively small, equivalently, when capacity Q reserved by each buyer is relatively large. With a large Q, buyers are unlikely to require transfers; therefore, transfer-generated profits are insubstantial when $\theta_s = 1$ is optimal. As a result, $\theta_s = 0$ would perform close to $\theta_s = 1$.

6 Robustness Checks

We find suppliers perform best by either keeping all capacity transfer-generated benefits or charging buyers transfer fees but letting those with excess capacity keep all the profit generated. We now consider our primary result's robustness with respect to model changes.

6.1 Nonlinear Cost Structure

To confirm our primary result is not due to linear costs, we study two new models with nonlinear cost structures based on our two symmetric buyer model.

6.1.1 Capacity Building Cost as a Step Function

Building capacity often involves adding new machines to a production facility. The supplier spends a fixed amount on each machine to increase capacity by a certain quantity. We can model the situation by assuming the capacity building cost is an increasing step function expressed as follows:

$$h(Q) = \begin{cases} 0 & \text{if } Q = 0 \\ h_i & \text{if } q_{i-1} \leq Q < q_i \text{ for } i \in \{1, 2, 3, \dots\}, \end{cases}$$

where h_i is non-decreasing in i and capacity building cost jumps at thresholds q_i. Similar to our original model, the supplier charges r per unit of capacity reserved. Theorem 5 confirms our primary result.

Theorem 5. *When capacity building cost is a step function, the supplier's optimal $\theta = 0$ and θ_s is either zero or 1.*

Optimal θ_s is more likely to be zero with larger jumps in the capacity building cost function (i.e., $h_i - h_{i-1}$), as the supply chain would resist investing in capacity. That is, Q would be relatively smaller with larger jumps in the capacity building cost function. When Q is small, buyers are likely to be able to transfer their excess capacity; therefore, the buyers would be sensitive to the value of transfer fee θ_s. As explained earlier, this implies θ_s is more likely to be zero.

6.1.2 Convex Capacity Building Costs and Reservation Fees

We also check our primary result's robustness by allowing capacity building cost to be a nonlinear function of Q. Similar to Erkoc and Wu (2005) and Huang et al. (2018), we let capacity building cost be a convex function. According to Erkoc and Wu (2005), "the capacity expansion in the context of high-tech industry demonstrates diseconomy of scale", which the convex function captures.

We give the capacity reservation fee function a similar convex shape. Specifically, we assume capacity building cost is $\beta \times h(Q)$ for some convex increasing function $h(Q)$ and $\beta > 0$, and capacity reservation fee is $r \times R(Q)$ for some convex increasing function $R(Q)$, where the supplier decides r. Note that $h(\cdot)$ and $R(\cdot)$ can also be linear. For example, we can construct the model in Erkoc and Wu (2005) by allowing $h(\cdot)$ to be convex and $R(\cdot)$ to be linear. Theorem 6 summarizes our new model's results, which are consistent with those of our main model.

Theorem 6. *At equilibrium, each buyer's reservation Q satisfies $Pr(D_i > Q) - (1 - \theta_s)\theta Pr(D_i >$*

$Q, D_t < 2Q) + (1-\theta_s)(1-\theta)Pr(D_i < Q, D_t > 2Q) = \frac{r}{(v-w)}\frac{R(Q)}{R'(Q)}$. *For the supplier, the optimal* θ *is zero and* θ_s *is either zero or* 1.

6.2 θ as an Exogenous Parameter

In Theorem 2, we show the optimal θ_s is either zero or 1 when θ is set optimally at zero. While the supplier can easily set θ_s, it may not be able to impose a particular θ value. Here, we study the optimal value of θ_s and capacity reservation fee r when θ is an exogenous parameter based on market standards. The sequence of events is shown in Figure 6.

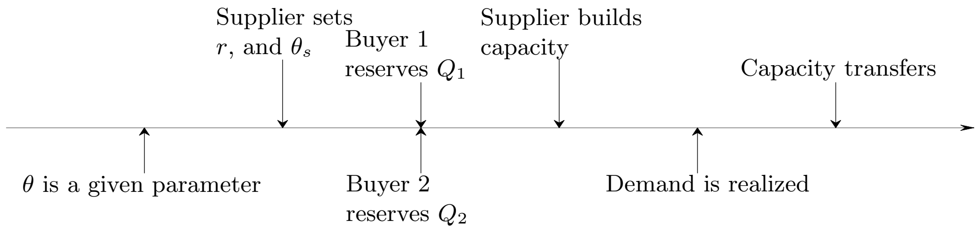

Figure 6: The model's event sequence when θ is an exogenous parameter.

Theorem 7. *For two buyers with symmetric demand distributions where* D_i *and* D_j *follow bivariate normal distribution as specified in (1), optimal* θ_s *is zero or* 1 *even if* θ *is a non-zero parameter (i.e.,* $0 < \theta \leq 1$*).*

Theorem 7 shows that the supplier should set θ_s as zero or 1 even when it has no control over θ, which can be any arbitrary value.

In Table 1, where θ is optimally set to zero, the supplier should almost always grant capacity transfer rights and charge no fee. But should the supplier grant buyers capacity transfer rights and not charge a fee even when θ is a non-zero parameter? We numerically investigate the effect of non-zero θ on the optimal θ_s value using the same set of parameters used previously to study the impact of cost parameters. In addition, we consider $\theta \in \{0.1, 0.2, 0.3, 0.4, 0.6, 0.8\}$. The parameter design accounts for 6,810,804 cases.

Table 2 shows, in our numerical study, as long as $\theta \leq 0.4$, $\theta_s = 0$ is optimal in most cases, with an optimality gap of at most 1.73% when it is not. Furthermore, $\theta_s = 1$ is not optimal in most cases and has a relatively large optimality gap. Hence, we conclude, in our numerical study, for cases where $\theta \leq 0.4$, not charging for the transfers is either optimal or it is a simple policy that performs close to optimal for the supplier.

Exogenous θ	Policy	Count optimal	Optimality gap (if not optimal) Mean	Median	Max
$\theta = 0.1$	$\theta_s = 0$	99.63%	0.06	0.04	0.38
	$\theta_s = 1$	0.37%	5.78	4.37	34.89
$\theta = 0.2$	$\theta_s = 0$	98.75%	0.11	0.07	0.70
	$\theta_s = 1$	1.25%	4.75	3.50	29.55
$\theta = 0.3$	$\theta_s = 0$	96.63%	0.18	0.11	1.14
	$\theta_s = 1$	3.37%	3.77	2.70	23.63
$\theta = 0.4$	$\theta_s = 0$	91.83%	0.28	0.17	1.73
	$\theta_s = 1$	8.17%	2.88	1.99	17.52
$\theta = 0.6$	$\theta_s = 0$	58.38%	0.68	0.51	3.44
	$\theta_s = 1$	41.62%	1.69	1.18	7.38
$\theta = 0.8$	$\theta_s = 0$	26.96%	1.67	1.32	5.91
	$\theta_s = 1$	73.04%	0.60	0.49	1.58

Table 2: Shown is the optimality gap for the model with two symmetric buyers when θ is exogenous and the supplier sets r optimally after θ_s is decided. The "Count optimal" column specifies the percentage of 1,135,134 instances considered for each θ, $\theta_s = 0$, or $\theta_s = 1$.

Comparing Tables 1 and 2, we conclude the parameter set for which $\theta_s = 0$ is optimal shrinks when θ is an exogenous parameter. The reason is that with large θ, the buyers prefer to receive capacity transfers; hence, they reserve less up front. As a result, with large θ, the supplier requires a reduced reservation fee r to induce the buyers to reserve a certain capacity quantity Q. However, the supplier can cease this adverse effect of θ being large by setting $\theta_s = 1$, i.e., by leaving no transfer profit to the buyers. Indeed, when θ is relatively large, the supplier has even more incentive to keep $\theta_s = 1$.

6.3 When Buyers Decide θ

To further check our primary result's robustness, we investigate our model when buyers decide θ. We consider three models:

1. The buyers agree on θ before demand is realized, i.e., before they know if they have a capacity shortage or excess.
2. The buyer with excess capacity sets θ after realizing demand.
3. The buyer with a capacity shortage sets θ after realizing demand.

We detail the latter two models in Section A.4 of our Online Supplement. In Theorem A.1, we show that allowing the buyer with excess capacity to set θ yields a model equivalent to that in which the supplier sets θ. In both models, θ, θ_s, and r are the same at equilibrium, and the supplier's and buyers' expected profits are the same. In Theorem A.2, we show that optimal θ is 1 for the buyer and optimal θ_s is 1 for the supplier (i.e., the supplier receives all transfer benefits) if the buyer with a shortage of capacity sets θ. The result of this last model is different from our recommended policy $\theta_s = 0$. However, it is not very realistic to assume the buyer with a shortage of capacity sets the value of θ.

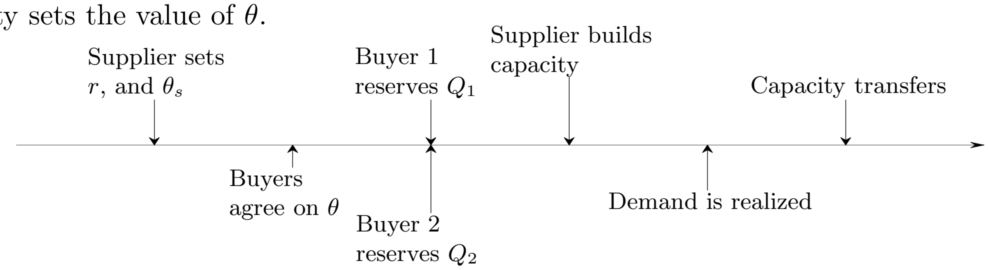

Figure 7: The model's event sequence when the buyers determine θ.

Next, we focus on the first model in which the buyers collectively decide and agree on the θ value that maximizes their profits. We assume symmetric buyers so there is no disagreement among them. Figure 7 details the sequence of events: First, the supplier sets the optimal capacity reservation fee r and θ_s and announces them to the buyers. Then, each buyer finds the θ value maximizing its own profit. Since the buyers are symmetric, they agree on the optimal value. Based on the values of r, θ_s, and θ, Buyer 1 and Buyer 2 simultaneously reserve quantities Q_1 and Q_2. The buyers then realize their demand and make initial sales based on their reserved capacity. Any capacity transfers then occur, and the buyer receiving excess capacity makes additional sales. Proposition 4 provides expressions for the optimal θ value for buyers, as well as equilibrium quantities.

Proposition 4. *For a given $\theta_s < 1$ and r, the buyers choose $\theta = \frac{Pr(D_i > Q^*, D_t < 2Q^*)}{Pr(D_i < Q^*, D_t > 2Q^*) + Pr(D_i > Q^*, D_t < 2Q^*)}$, where Q^* is the solution to $1 - \frac{r}{v-w} = \theta_s Pr(D_i < Q^*) + (1-\theta_s)Pr(D_t < 2Q^*)$. At equilibrium, each buyer reserves capacity $Q = Q^*$.*

$Pr(D_i > Q^*, D_t < 2Q^*)$ is the probability that a buyer has a capacity shortage the other buyer's excess can satisfy. Equivalently, it is the probability that the buyer could reserve one less unit of capacity and receive one more transfer from the other buyer and profit proportional to θ. Similarly, $Pr(D_i < Q^*, D_t > 2Q^*)$ is the probability that the buyer could reserve one more unit of capacity to transfer to the other and profit proportional to $1 - \theta$. Theorem 8 characterizes the supplier's optimal θ_s and optimal reservation fee r.

Theorem 8. *The supplier's optimal θ_s is either zero or 1. When s_l is relatively large and m_r is relatively small, $\theta_s = 1$ is optimal; when s_l is small, $\theta_s = 0$ is optimal. The optimal capacity reservation fee r and optimal θ_s can be obtained as follows:*

- *If* $\Pi_{0\theta^*}(z^{0\theta^*}) \geq \Pi_{1\theta^*}(z^{1\theta^*})$, *then* $\theta_s^* = 0$, *and* $r^* = \left(1 - \Phi(\frac{z^{0\theta^*}}{\alpha})\right)(v - w)$, *and*
- *If* $\Pi_{0\theta^*}(z^{0\theta^*}) < \Pi_{1\theta^*}(z^{1\theta^*})$, *then* $\theta_s^* = 1$ *and* $r^* = \left(1 - \Phi(z^{1\theta^*})\right)(v - w)$,

where $z^{0\theta^*}$ *is the solution to* $m_r \frac{1}{\alpha}\phi(\frac{z}{\alpha})(z + \frac{\mu}{\sigma}) + \Phi(\frac{z}{\alpha}) - s_l = 0$ *and* $z^{1\theta^*}$ *is the solution to* $m_r\phi(z)(z + \frac{\mu}{\sigma}) + \Phi(\frac{z}{\alpha}) - s_l = 0$. *Also,* $\Pi_{0\theta^*}(z) = (s_l - m_r\Phi(\frac{z}{\alpha}))(z + \frac{\mu}{\sigma}) - (1 - m_r)\int_{-\infty}^{z} \Phi(\frac{x}{\alpha})\,\mathrm{d}x$ *and* $\Pi_{1\theta^*}(z) = \Pi_{0\theta^*}(z) + m_r\left(\int_{-\infty}^{z}(\Phi(x) - \Phi(\frac{x}{\alpha}))\,\mathrm{d}x - (\Phi(z) - \Phi(\frac{z}{\alpha}))(z + \frac{\mu}{\sigma})\right)$.

Here, the intuition for θ_s is similar to that of our original model. The supplier compares whether increasing θ_s and collecting fees on expected transfers T or reducing θ_s while charging a higher reservation fee r is more beneficial. In the new model, lowering θ_s has a different impact on the buyers' profit because they can receive a portion even with a capacity shortage. Hence, the value by which the supplier can increase r when decreasing θ_s is related not only to the probability the buyers can transfer an additional unit of capacity (denoted $g = Pr(D_i < Q, D_t > 2Q)$), but also on the probability one buyer can make a profit from the transfers by reserving one less marginal capacity unit and receiving the other's excess capacity (denoted $\tilde{g} = Pr(D_i > Q, D_t < 2Q)$). Here, the supplier compares expected transfers T with $(g - \tilde{g}) \times Q$ and decides whether $\theta_s = 1$ or $\theta_s = 0$ is optimal for each Q. The supplier can then choose the optimal Q and set θ_s and r to achieve the desired Q. We numerically investigate the optimal values of θ, θ_s, and r using the same set of parameters discussed previously.

The left panels of Figure 8 show an example of how optimal θ_s, r, and θ values depend on cost parameters m_r and s_l. Similar to our main model, we observe that $\theta_s = 1$ is optimal only when m_r is relatively small and s_l is relatively large (see top left panel of Figure 8) and the optimal capacity reservation fee r is small when m_r is small and s_l is large (see middle left panel of Figure 8).

From plots similar to the bottom left panel of Figure 8, we observe that θ is relatively large when m_r is small and s_l is large [6] (i.e., the cost of building capacity is small and the supplier's sales profit margin is large compared to the buyers') because, in that case, the supplier wants the buyers to reserve large capacity quantities. When they do so, it is more likely that they will profit by reserving one fewer capacity unit and receiving excess capacity from the other buyer (i.e., $Pr(D_i > Q, D_t < 2Q)$) than by reserving one more capacity unit and transferring excess capacity (i.e., $Pr(D_i < Q, D_t > 2Q)$). Hence, the buyers are incentivized to increase θ.

We also investigate how optimal decisions regarding θ_s, r, and θ depend on the demand pa-

[6] When $\theta_s = 1$, the value of θ is irrelevant.

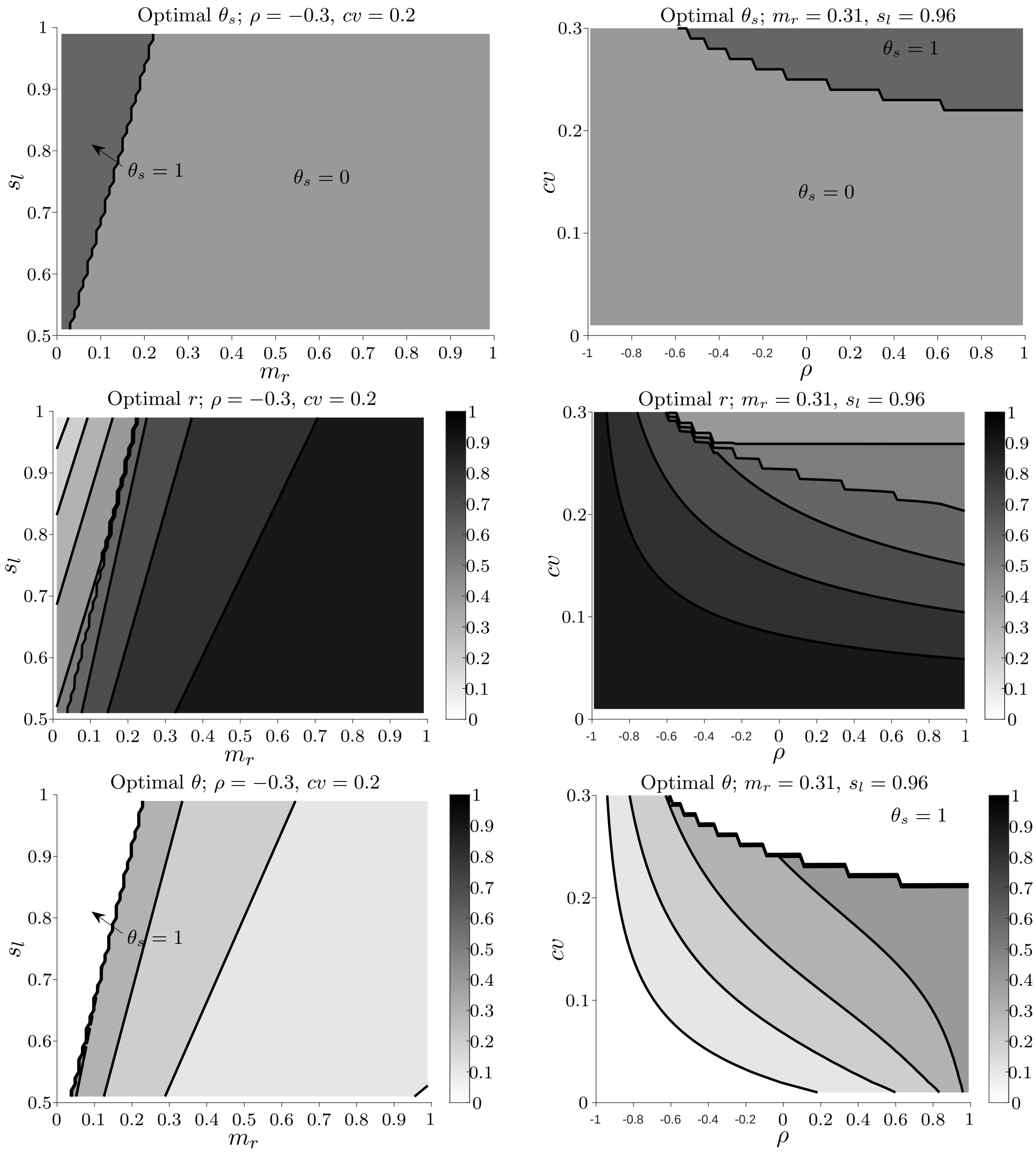

Figure 8: Shown is how the optimal θ_s, θ, and r values depend on the cost parameters s_l and m_r or demand parameters cv and s_l. In the model, symmetric buyers decide θ. In the left panels, m_r is represented on the X-axis and s_l is on the Y-axis. In the right panels, ρ is on the X-axis and cv is on the Y-axis. The upper plots show optimal θ_s, the center plots show the corresponding optimal r, and the lower plots show the corresponding optimal θ. In the region where $\theta_s = 1$, the θ value is irrelevant.

rameters cv and ρ. The right panels of Figure 8 show an example of how optimal θ_s, r, and θ values depend on demand parameters cv and ρ. Similar to our main model, optimal r is relatively small when cv and ρ are relatively large (see middle right panel of Figure 8), and $\theta_s = 1$ is optimal when

Policy	Count optimal	Optimality gap (if not optimal) Mean	Median	Max
$\theta_s = 0$	87.92%	0.4%	0.23%	2.69%
$\theta_s = 1$	12.08%	5.36%	3.45%	42.52%

Table 3: Shown is the optimality gap for the two symmetric buyer model when the buyers decide θ and the supplier sets r optimally after θ_s is decided. The "Count optimal" column specifies the percentage of 1,735,134 instances considered, depending on whether $\theta_s = 0$ or $\theta_s = 1$ is optimal.

the coefficient of variation cv is relatively large (see top right panel of Figure 8). Contrary to our main model, the impact of ρ on optimal θ_s is monotone in all cases considered (see middle right panel of Figure 8); specifically, with a relatively large ρ, it is more likely that $\theta_s = 1$ is optimal. As discussed, lowering θ_s has a different impact on profit when the buyers determine θ, leading to a different impact of ρ on optimal θ_s.

Next, we show that when optimal $\theta_s = 1$, setting $\theta_s = 0$ is still close to optimal. We examine the optimality gap between setting $\theta_s = 0$ and $\theta_s = 1$ when buyers determine θ (see Table 3) using the same parameters set described for our main model. We find $\theta_s = 0$ is optimal in 87.92% of $1,735,134$ cases. In the 12.08% of cases in which $\theta_s = 0$ is not optimal, the average optimality gap is 0.4%, with a maximum of 2.69%. When $\theta_s = 1$ is not optimal, we find an average optimality gap of 5.36%, with a maximum of 42.52%. As in our main model, setting $\theta_s = 1$ and charging buyers transfer fees can hurt supplier profits more than simply never charging transfer fees. This is because whenever the supplier's optimal $\theta_s = 1$, the likelihood of capacity transfers is small, making profit division less impactful.

How does a change in the decision maker of θ influence the supplier's θ_s policy? To examine the situation, we generate plots to simultaneously find the lines separating optimal $\theta_s = 1$ and $\theta_s = 0$ regions when θ is decided by the supplier versus the buyers. Figure 9 shows an example. We generate figures for all parameter sets used in the numerical study. In all figures, the region in which $\theta_s = 1$ is optimal when the supplier chooses θ is smaller and contained in the region in which $\theta_s = 1$ is optimal when the buyers choose θ. That is, the parameter set for which $\theta_s = 1$ is optimal expands when the buyers decide θ. As this parameter set grows, suppliers should be less willing to grant capacity transfer rights to buyers if they control how the benefits are divided.

Suppliers are likely to set θ to zero. Buyers are likely to make it larger than zero. Previously, on Page 25, we explained that with large θ, the supplier has more incentive to set θ_s to 1. As a result, the parameter set in which $\theta_s = 1$ is optimal is larger when buyers decide it than when the

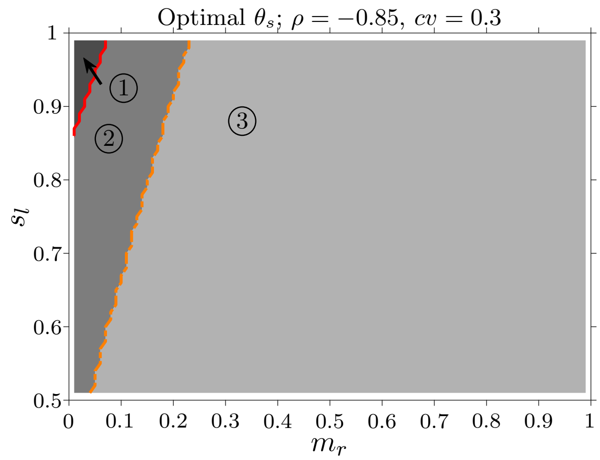

Figure 9: The line separating optimal $\theta_s = 1$ and $\theta_s = 0$ regions depends on the decision maker of θ. The solid red line separates the region in which $\theta_s = 1$ is optimal from that in which $\theta_s = 0$ is optimal when the supplier decides θ. The dashed orange line separates the regions for the model in which the buyers agree on θ. In region 1, $\theta_s = 1$ is optimal regardless of which party decides θ. In region 3, $\theta_s = 0$ is also optimal regardless of decision maker. However, in region 2, $\theta_s = 1$ is optimal when the buyers decide θ, while $\theta_s = 0$ is optimal when the supplier makes the decision.

supplier decides it.

7 Conclusions

Researchers have studied inventory transshipment and its impact on the supply chain extensively. However, much less is known about capacity reservation and whether its transfer among buyers benefits suppliers. Unlike inventory problems, where buyers own the manufactured product after purchase, capacity reservation gives buyers and suppliers multiple contractual options regarding unused reserved capacity.

Our capacity reservation examination consistently shows that supplier profit is maximized when either (i) the supplier collects all transfer benefits via a fee (i.e., $\theta_s = 1$) or (ii) the supplier charges no capacity transfer fee (i.e., $\theta_s = 0$) and all retail-level benefits accrue to the buyer releasing excess capacity. Not charging buyers for transfers allows the supplier to set a higher capacity reservation fee r. The drivers of this result are the assumptions that: (i) the transfer fee and the capacity reservation fee r is charged *per unit*; and (ii) the supplier *decides* the capacity reservation fee r.

We demonstrate that the supplier can perform close to optimal by not charging a transfer fee in all cases, even when $\theta_s = 1$ is optimal. However, the reverse statement is not true: If not charging a transfer fee is optimal, the supplier's profit can substantially decrease when charging a transfer fee in error.

In our hard drive suspension assembly example, the supplier informed buyers they would lose any unused capacity after a given time, allowing the supplier to regain control. In our model, the decision corresponds to $\theta_s = 1$, in which the supplier, not the buyers, benefits from excess reserved capacity. We find $\theta_s = 1$ can be optimal in some cases; however, the hard drive suspension assembly supplier was not exactly sure they actually should be following this policy, and asked us what in fact the optimal policy should be.

Taiwan Semiconductor Manufacturing Corporation grants its buyers capacity transfer rights and does not charge fees. In our model, the decision corresponds to $\theta_s = 0$. Our results suggest that $\theta_s = 0$ is a simple policy that is either optimal or close to optimal in all situations, and Taiwan Semiconductor has become a pioneer in "tradable capacity options" (LaPedus, 1995; Economist, 1996) as a result of its approach.

Amazon Web Services allow its users to transfer capacity but charges a fee of 12% of the trading price. The approach is fairly consistent with $\theta_s = 0$ in our model. Amazon charges only a small capacity transfer fee and also incurs direct costs to set up an excess capacity marketplace and collect and transfer payments among parties. We do not model such transactional costs in our paper but can assume the 12% fee is an attempt to recoup them.

We believe our results both explain why we see liberal capacity transfer policies in the field and provide guidance to managers making decisions about capacity transfer fees. Specifically, we suggest a simple policy of not charging capacity transfer fees is either optimal or performs close to optimal in all cases. Although our model is stylized using two or three buyers, we believe the insights generalize to other situations. However, further research verifying our results and intuitions in cases with more buyers would be of interest.

References

Anupindi, R. and Y. Bassok (1999). Centralization of stocks: Retailers vs. manufacturer. *Management Science 45*, 178–191.

Anupindi, R., Y. Bassok, and E. Zemel (2001). A general framework for the study of decentralized distribution systems. *Manufacturing & Service Operations Management 3*, 349–368.

Archibald, T. W., S. Sassen, and L.C.Thomas (1997). An optimal policy for a two depot inventory problem with stock transfer. *Management Science 43*, 278–295.

Barnes-Schuster, D., Y. Bassok, and R. Anupindi (2002). Coordination and flexibility in supply contracts with options. *Manufacturing & Service Operations Management 4*, 171–207.

Dong, L. and N. Rudi (2004). Who benefits from transshipment? exogenous vs. endogenous wholesale prices. *Management Science 50*, 645–657.

Economist, T. (1996). Asian semiconductors: Saving chips from market dips (january 20). *Electornic Buyers' News (August 28) 63.*

Economist, T. (2009). Invisible but indispensable. *The Economist Group Limited.*

Eppen, G. D. and A. V. Iyer (1997). Backup agreements in fashion buying-the value of upstream flexibility. *Management Science 43*, 1469–1484.

Erkoc, M. and S. D. Wu (2005). Managing high-tech capacity expansion via reservation contracts. *Production and Operations Management 14*(2), 232–251.

Hu, X., I. Duenyas, and R. Kapuscinski (2007). Existence of coordinating transshipment prices in a two-location inventory model. *Management Science 53*, 1289–1302.

Huang, D., Z. Lin, and W. Wei (2018). Optimal production planning with capacity reservation and convex capacity costs. *Advances in Production Engineering & Management 13*(1), 31–43.

Jiang, L. and R. Anupindi (2010). Customer-driven vs. retailer-driven search: Channel performance and implications. *Manufacturing* & *Service Operations Management 12*, 102–119.

Karmarkar, U. S. and N. R. Patel (1977). The one-period n-location distribution problem. *Naval Research Logistics Quarterly 24*, 559–575.

Krishnan, K. and V. Rao (1965). Inventory control in n warehouses. *Journal of Industrial Engineering XVI*, 212–215.

LaPedus, M. A. (1995). Two in taiwan lay new plans. *Electornic Buyers' News (August 28) 10.*

Lee, H. and S. Whang (2002). The impact of the secondary market on the supply chain. *Management Science 48*, 719–731.

Lippman, S. and K. McCardle (1997). The competitive newsboy. *Operations Research 45*, 66–71.

Plambeck, E. L. and T. A. Taylor (2005). Sell the plant? the impact of contract manufacturing on innovation, capacity, and profitability. *Management Science 51*, 133–150.

Plambeck, E. L. and T. A. Taylor (2007a). Implications of breach remedy and renegotiation design for innovation and capacity. *Management Science 53*(12), 1859–1871.

Plambeck, E. L. and T. A. Taylor (2007b). Implications of renegotiation for optimal contract flexibility and investment. *Management Science 53*(12), 1872–1886.

Robinson, L. W. (1989). Optimal and approximate policies in multiperiod, multilocation inventory models with transshipments. *Operations Research 38*, 278–295.

Rudi, N., S. Kapur, and D. F. Pyke (2001). A two-location inventory model with transshipment and local decision making. *Management Science 47*, 1668–1680.

Shao, J., H. Krishnan, and S. T. McCormick (2009). Incentives for transshipment in a supply chain with decentralized retailers. *Working paper, University of British Columbia, Vancouver BC*.

Spinler, S. and A. Huchzermeier (2006). The valuation of options on capacity with cost and demand uncertainty. *European Jounal of Operational Research 171*, 915–934.

Tagaras, G. (1989). Effect of pooling on the optimization and service levels of two-location inventory systems. *IIE Transaction 21*, 250–257.

Tomlin, B. (2003). Capacity investments in supply chains: Sharing the gain rather than sharing the pain. *Manufacturing & Service Operations Management 5*, 317–333.

Van Mieghem, J. A. (1999). Coordinating investment, production, and subcontracting. *Management Science 45*, 954–971.

Wu, S. D., M. Erkoc, and S. Karabuk (2005). Managing capacity in the high-tech industry: A review of literature. *The Engineering Economist 50*, 125–158.

Zhang, J. (2005). Transshipment and its impact on supply chain members' performance. *Management Science 51*, 1534–1539.

Zhao, H., V. Deshpande, and J. K. Ryan (2005). Inventory sharing and rationing in decentralized dealer networks. *Management Science 51*, 531–547.

Zhao, X. and D. Atkins (2009). Transshipment between competing retailers. *IIE Transcations 41*, 665–676.