Comparison of Two Outsourcing Structures under Push, Pull and Two-Wholesale-Price Contracts

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Abstract

In this paper, we study the performance of a multi-tier supply chain consisting of an original equipment manufacturer (OEM), a contract manufacturer (CM) and a supplier under push, pull and two-wholesale-price contracts. For each contract, two vertical outsourcing structures are considered: Control and delegation. We derive the equilibrium ordering quantities and capacities for all the combinations of the outsourcing structures and contracts.

Due to the space constraint, we only present our results on push and pull contracts here. Our analysis shows that under the push contract, the OEM prefers delegation to control if the wholesale price it pays to the CM under delegation is no more than the sum that it pays to the CM and the supplier under control. As to the pull contract, we find that the OEM is more likely to prefer delegation if the wholesale price under delegation is in a moderate range and the customer demand has low uncertainty. Lastly, we compare the performance of push and pull contracts under the two outsourcing structures. We show that pull contract is more likely to be preferred over push contract by the OEM if the prebook wholesale prices are high or at-once wholesale prices are in a moderate range.

Keywords: Pull, Push, Outsourcing, Control, Delegation

1. Introduction

Nowadays, there are unprecedented opportunities for original equipment manufacturers (OEMs) to outsource all of the assembling function to contract manufacturers (CMs). However, outsourcing activities enlarge the distance between the supply chain parties and lengthen the lead time. This gives rise to greater risk in production planning and capacity decisions for those CMs and suppliers, as such decisions need to be made well before demand is observed. It is therefore interesting to consider risk-sharing mechanisms among the supply chain parties such that the supply chain capacity can be increased. In particular, it is interesting to explore whether the OEM can be better off by bearing some inventory/capacity risks. The sharing of inventory/capacity risks can be affected by multiple factors, which, can be summarized into three questions: Who will order? When to order? And how much to order?

Who will order? Consider a serial three-tier supply chain consisting of an OEM, a CM and a supplier. Compared with the two-tier supply chain, this multi-tier supply chain provides one more layer of flexibility to the OEM by allowing the OEM not only deciding how to share the inventory/capacity with the upstream parties but also choosing the way how it outsources the manufacturing: the OEM can either outsource just the product manufacturing function to the CM and continue procuring the component from the supplier, or it can outsource both the product manufacturing and component procurement functions to the CM and let the CM handle the component procurement with the supplier. We call these two outsourcing structures *control* (C for the superscript) and *delegation* (D for the superscript), respectively, and they are depicted in Figure 1.

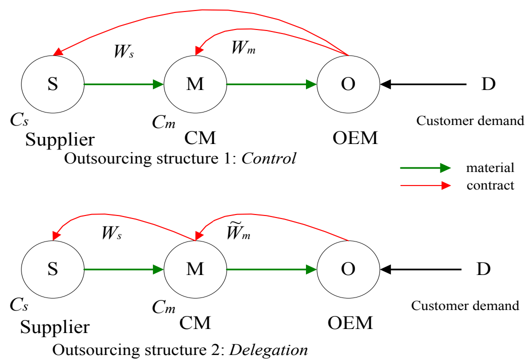


Figure 1: Control and Delegation

When to order? The sharing of inventory/capacity risks is also affected by the timing of orders. In practice, some OEMs ease the uncertainty of their CMs and suppliers by adopting *push* contract; that is, they place the order before the selling season and hence bear all the inventory risk. In contrast, there exists another *pull* contract, under which OEMs place the order in the selling season, and the CMs and the suppliers have to bear all the inventory risk.

How much to order? The inventory responsibility of the supply chain parties is also affected by the quantity of orders. Ordering too much or too little may both bring big cost for the OEM. Hence, the questions here we are interested in are the supply chain parties' *optimal* decisions on quantity:

- What are the OEM's optimal ordering quantities under the different combinations of the outsourcing structures and contracts?
- What are best responses for the CM and the supplier in capacity decision?

We consider four scenarios according to the combinations of two vertical outsourcing structures (control and delegation) and two contracts (push and pull). Under each scenario, we analyse the performance of three supply chain parties, the OEM, the CM and the supplier. To draw some managerial insights, we conduct two types of comparison among the results in different scenarios: For each contract, which outsourcing structure is more beneficial to the OEM and under which conditions? For each outsourcing structure, what is the best timing of ordering for the OEM and under which conditions? Section 2 reviews the related literature. Section 3 introduces the model and preliminaries. Sections 4 and 5 study performance of push and pull contracts, respectively. In each section, we consider the supply chain parties' quantity ordering and capacity building decisions under both control and delegation. Sections 6 compares the supply chain capacities and the OEM's profits under push and pull contracts. Section 7 summarizes and concludes the paper. All the proofs are omitted.

2. Literature Review

Our work is closely related to the literature on quantity commitment and advance purchase. Push, pull and advance-purchase contracts are first studied in Cachon (2004). Later Dong and Zhu (2007) consider a unified two-wholesale-price (TWP) contract. Both Cachon (2004) and Dong and Zhu (2007) consider a two-tier supply chain while we consider a three-tier supply chain. Besides these two work, Lariviere and Porteus (2001), Ferguson (2003), Ferguson et al. (2005), Ozer and Wei (2006), Netessine and Rudi (2006), Taylor (2006), Bernstein et al. (2006) and Chen (2007) are also related. See the reviews by Cachon (2003) and Lariviere (1998) for a more detailed discussion.

Our work is also closely related to the research on the decentralized capacity decisions in multiple-tier supply chains. Bernstein and DeCroix (2004) investigate a modular assembly system in which the final assembler oursources some of the assembly tasks to subassemblers, and the subassembler buys the components from suppliers. Bernstein et al. (2007) consider the equilibrium price and capacity decisions in an assembly system with multiple-type products and different types of suppliers.

The study on delegation and control is also related with our work. Mookherjee (2006) provides a comprehensive review. Kayis et al. (2009) consider delegation and control in a three-tier supply chain under the Newsvendor setting. They compare the optimal menu contract with the price-only contract and find that either delegation or control may be preferable, depending on the degree of manufacturer's prior information on the suppliers' costs. Guo et al. (2010) study the impact of information distortion induced by different outsourcing structures. They show that, with a long-term contract, delegation performs better than control even with information distortion. Chen et al. (2010) consider a situation in which a manufacturer either decides how to allocate its capacity among multiple retailers or delegates this decision to its distributor.

3. Model Setting and Preliminaries

We use subscript *o*, *m* and *s* to label the OEM, the CM and the supplier, respectively. Customer demand for the end product is random and denoted by a random variable *X* with a density function *f* and a cumulative distribution function (cdf) *F*. Define $\bar{F}(x)=1-F(x)$. Besides, we assume that the demand distribution has increasing generalized failure rate (IGFR) property, see Lariviere and Porteus (2001), Cachon (2004), Dong and Zhu (2007) and the reference therein for further information. The market price for the end product is exogenously given and denoted by *p*. And one unit of the end product the CM produces requires one unit of the supplier component. Assume the CM and the supplier incur a cost of c_m and c_s for building one unit of their capacities, respectively. The production costs of the OEM, the CM and the supplier are normalized to zero. We also assume that the related fixed costs are sunk. To guarantee a positive profit margin, $p>c_m+c_s$ is assumed. The demand distribution and capacity installing costs are all common knowledge (see Plarmbeck and Taylor (2007) and Nagarajan and Bassok (2008) for the discussion on this assumption).

Consider that a long lead-time is required for production and there exist two ordering opportunities, i.e. an early order before production and a late order just before or during the selling season. Denote the pre-selling period as period 1 and the selling season as period 2. Similar to Cachon (2004) and Dong and Zhu (2007), we assume the wholesale prices are set before orders and production take place. Then a downstream party can prebook in period 1, or it can place at-once orders in period 2. Specifically, for the control structure, we denote the wholesale price offered to player *i* in period *t* by w_{it}, $i=m,s$, $t=1,2$. For the delegation structure, we assume the wholesale price offered to the supplier by the CM is still w_{st}, $t=1,2$, the same as that offered by the OEM under control. However, the wholesale price offered to the CM by the OEM in this case needs to cover both the CM's manufacturing cost and its component procurement cost. We denote the wholesale price paid to the CM under delegation as $\tilde{w}_{mt}$, $t=1,2$ ($\tilde{w}_{mt} \geq c_m+w_{st}$, $t=1,2$). To avoid the trivial case, we focus on the wholesale price region $\{w_{m1}, w_{m2}, w_{s1}, w_{s2}\} \in [c_m, p]\ X\ [c_m, p]\ X\ [c_s, p]\ X\ [c_s, p]$. We also assume that $p-w_{mt}-w_{st}>0$ and $p-\tilde{w}_{mt}>0$, $t=1,2$.

Let $D(q)=E[min(X, q)]$ be the expected demand that can be satisfied by production quantity q. Then, given q_m and q_s, the customer demand that can be satisfied by the supply chain is $D(q_m \wedge q_s)$, where $a \wedge b= min(a, b)$. In the following sections, we are going to use superscript $j = C, D$ to represent the optimal solutions under control and delegation, respectively.

4. Push Contract

4.1. Push and Control

Under push and control, the game sequence is defined as follows:

- Given the unit wholesale prices w_{m1} and w_{s1} in period 1, the OEM announces its prebook quantity q to the CM and supplier. (It is never in the best interest of the OEM to prebook different quantities to the CM and supplier as the components are compliments.)

- The CM and supplier then install their capacities according to the OEM's prebook order.

In period 2, demand is realized and all revenues and costs are incurred. As a result, the profit functions of the three parties are, respectively:

$$\pi_o = pD(q) - (w_{m1}+w_{s1})q,\ \pi_m = (w_{m1}-c_m)q,\ \pi_s = (w_{s1}-c_s)q. \quad (1)$$

So the decision problem for the OEM is a newsvendor-type problem, and the optimal ordering decision of the OEM can be summarized below.

Proposition 1: *Under push and control, the OEM's optimal prebook* $q^C = \bar{F}^{-1}\left(\frac{w_{m1}+w_{s1}}{p}\right)$.

Here, q^C is also the system capacity.

4.2. Push and Delegation

Under push and delegation, the game sequence is thus as follows:

- Given the unit wholesale price $\tilde{w}_{m1}$, the OEM announces its prebook quantity q to the CM. The CM then announces the OEM's prebook quantity q to the supplier. (It is never in the best interest of the CM to prebook a different quantity to the supplier because of complementarity between the CM and supplier's products.)
- The CM and supplier install their capacities according to their prebook order.

In period 2, demand is realized and all revenues and costs are incurred. Similarly, we can write the profit functions of the supply chain parties as

$$\pi_o = pD(q) - \tilde{w}_{m1} q,\ \pi_m = (\tilde{w}_{m1} - w_{s1} - c_m)q,\ \pi_s = (w_{s1}-c_s)q. \quad (2)$$

Again, the OEM's optimization problem is a newsvendor-type problem. Then we have the following proposition.

Proposition 2: *Under push and delegation, the OEM's optimal prebook* $q^D = \bar{F}^{-1}\left(\frac{\tilde{w}_{m1}}{p}\right)$.

Note that q^D is also the system capacity.

4.3. Comparison of Control and Delegation under Push

Similar to Kayis et al. (2009), here we also focus on studying the preference of the OEM over control and delegation. Then we have

Proposition 3: *Under push contract , if* $\tilde{w}_{m1} \geq (w_{m1}+w_{s1})$, $q^D \geq q^C$ *and* $\pi_o^D \geq \pi_o^C$ *; otherwise,* $q^D < q^C$ *and* $\pi_o^D < \pi_o^C$.

So if $\tilde{w}_{m1} \geq (w_{m1}+w_{s1})$, delegating the component procurement function to the CM is more beneficial to the OEM; otherwise, the OEM shall keep this function in-house. The reason is that $\tilde{w}_{m1} < (w_{m1}+w_{s1})$, on the one hand, implies that the OEM can obtain a lower unit wholesale price and achieve cost saving by delegating the procurement function to the CM, and on the other hand, also implies that the OEM is willing to bear more inventory risk since $q^D \geq q^C$. This joint cost saving and higher system capacity leads to a higher expected profit for the OEM under delegation than that under control.

5. Pull Contract

5.1. Pull and Control

Under pull and control, the game sequence is defined as follows:

- In period 1, given the unit wholesale prices w_{m2} and w_{s2} in period 2, the CM and supplier install their capacities q_m and q_s in anticipation of the OEM's at-once order. The CM and supplier then install their capacities according to the OEM's prebook order.
- In period 2, the market demand is observed. The OEM makes the at-once orders to the CM and the supplier to satisfy the observed demand.

We are going to solve this game by backward induction. First in period 2, the OEM makes the at-once order $x \wedge q_m \wedge q_s$, where x is the realized demand. Actually $x \wedge q_m \wedge q_s$ represents the effective demand that the whole supply chain can satisfy by using the available capacities of the CM and the supplier.

Next, in period 1, anticipating the OEM's at-once order, the CM and the supplier decide how much capacities to build up to maximize their respective expected profits:

$$\pi_m (q_m \mid q_s) = w_{m2} D(q_m \wedge q_s) - c_m q_m, \quad \pi_s (q_s \mid q_m) = w_{s2} D(q_m \wedge q_s) - c_s q_s. \tag{3}$$

Here, the capacity game between the CM and the supplier is a simultaneous one. We first derive the best response function of the CM given the supplier's capacity decision q_s. Since the CM and the supplier's products are complements, it is never optimal for the CM to install a capacity $q_m > q_s$. We can show that given the supplier's capacity q_s, the best response function of the CM is to install

$$q_m^*(q_s) = \min(K_m^C, q_s), \text{ where } K_m^C = \bar{F}^{-1}\left(\frac{c_m}{w_{m2}}\right) \tag{4}$$

and is the CM's optimal newsvendor capacity decision by assuming the supplier's capacity q_s is ample (much larger than q_m). It represents the maximum amount of the capacity that the CM has incentives to build up under control. Similarly, the best response function of the supplier is

$$q_s^*(q_m) = \min(K_s^C, q_m), \text{ where } K_s^C = \bar{F}^{-1}\left(\frac{c_s}{w_{s2}}\right) \tag{5}$$

and also represents the maximum amount of the capacity that the supplier has incentives to build up under control. Solving these two best response functions simultaneously yields the equilibrium capacities of the CM and the supplier under pull and control as $q_m^C = q_s^C = K_m^C \wedge K_s^C$ Consequently, the system capacity is also this value.

Proposition 4: *Under pull and control, the equilibrium capacities of the CM and the supplier are* $q_m^C = q_s^C = K_m^C \wedge K_s^C$.

5.2. Pull and Delegation

Under pull and delegation, the game sequence is defined as follows:

- In period 1, given the unit wholesale prices $\tilde{w}_{m2}$ and w_{s2} in period 2, the CM and the supplier install their capacities q_m and q_s in anticipation of the OEM's at-once order.

- In period 2, the market demand is observed. The OEM makes at-once order to the CM and then the CM makes at-once order to the supplier.

Similarly we solve this game backwards. Again the OEM and the CM make the at-once order $x \wedge q_m \wedge q_s$ in period 2. And in period 1, the CM and the supplier make their respective capacity decisions by maximizing their expected profit functions:

$$\pi_m (q_m \mid q_s) = (\tilde{w}_{m2} - w_{s2})\, D(q_m \wedge q_s) - c_m q_m, \quad \pi_s (q_s \mid q_m) = w_{s2}\, D(q_m \wedge q_s) - c_s q_s. \tag{6}$$

Similar to K_m^C and K_s^C in section 5.1, define

$$K_m^D = \bar{F}^{-1}\left(\frac{c_m}{\tilde{w}_{m2} - w_{s2}}\right) \quad \text{and} \quad K_s^D = \bar{F}^{-1}\left(\frac{c_s}{w_{s2}}\right) \tag{7}$$

Then they are the optimal capacities the CM and the supplier are going to invest in under delegation assuming that the other party has ample capacity. It represents the maximum amount of the capacity that the CM or the supplier has incentives to build up under delegation. Naturally, we observe that the supplier's capacity building incentives remain the same under the two outsourcing structures as it receives the same wholesale price no matter whether paid by the OEM or the CM. Analogously, the equilibrium capacities of the CM and the supplier under pull and delegation and the corresponding system capacity are $q_m^D = q_s^D = K_m^D \wedge K_s^D$.

Proposition 5: *Under pull and delegation, the equilibrium capacities of the CM and the supplier are*
$q_m^D = q_s^D = K_m^D \wedge K_s^D$.

5.3. Comparison of Control and Delegation under Pull

First we compare the supply chain system capacity under the two outsourcing structures and obtain the following corollary.

Corollary 1: *Under pull contract , if* $\tilde{w}_{m2} \le (w_{m2}+w_{s2})$, $K_m^D \le K_m^C$ *and* $(K_m^D \wedge K_s^D) \le (K_m^C \wedge K_s^C)$*; otherwise,* $K_m^D > K_m^C$ *and* $(K_m^D \wedge K_s^D) > (K_m^C \wedge K_s^C)$.

So compared with control structure, if the total unit wholesale price (covering both manufacturing and procurement cost) is lower under delegation structure, then the CM will build up less capacity and as a result, the supply chain capacity under delegation is also lower.

Next in order to compare the performance of the OEM under control and delegation, we define the relative gain of the OEM by switching from control to delegation as

$$\gamma = \frac{\pi_o^D - \pi_o^C}{\pi_o^C} = \frac{(p - \tilde{w}_{m2}) D(K_m^D \wedge K_s^D)}{(p - w_{m2} - w_{s2}) D(K_m^C \wedge K_s^C)} - 1 \tag{8}$$

Lemma 1: *γ is quasi-concave in $\tilde{w}_{m2}$.*

By the quasi-concavity of γ function, it must crosses 0 at most twice. Note that when

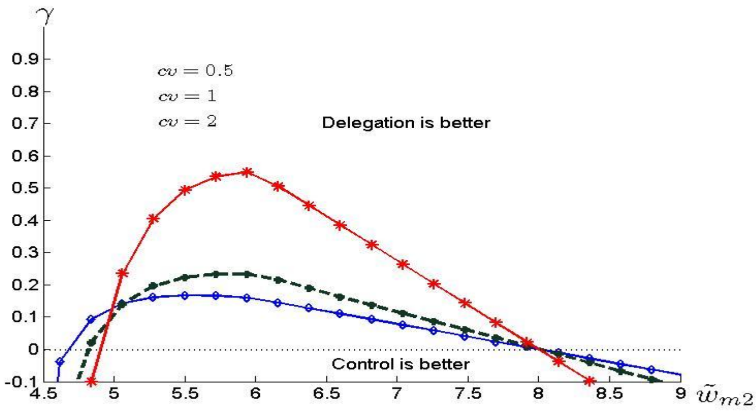
$\tilde{w}_{m2} = w_{m2} + w_{s2}$,

$\pi_o^D = \pi_o^C$. So γ crosses 0 at $\tilde{w}_{m2} = w_{m2} + w_{s2}$. Denote the other possible point that γ crosses 0 as $\underline{\tilde{w}}_{m2}$. Then we have the following proposition.

Proposition 6:
If $\tilde{w}_{m2} \in [\underline{\tilde{w}}_{m2} \wedge (w_{m2} + w_{s2}), \max(\underline{\tilde{w}}_{m2}, (w_{m2} + w_{s2}))]$, *then* $\gamma \geq 0$*; otherwise,* $\gamma < 0$.

Proposition 6 shows that compared with the total wholesale price the OEM pays under control, $w_{m2}+w_{s2}$, when the wholesale price paid to the CM under delegation is moderate, falling in a medium range, then delegation is more beneficial to the OEM, but if the wholesale price paid to the CM under delegation is either too high or too low, then control is more beneficial to the OEM. The possible driving force behind this is the tradeoff between the cost saving of the unit wholesale price and the potential loss of the high demand. Under delegation, when $\tilde{w}_{m2}$ is too high, then the OEM has a small profit margin and when the realized demand is small, it may hurt the OEM's profits. Similarly, when $\tilde{w}_{m2}$ is too low, the CM is not willing to build up a large capacity and as a result, the system capacity is small, and the OEM will lose the sales when the realized demand is high. That may explain why the OEM prefers control over delegation when $\tilde{w}_{m2}$ is either too high or too low.

Assume the customer demand follows truncated normal distribution with a mean μ and the standard deviation σ. Then the coefficient of variation CV is $CV = \frac{\sigma}{\mu}$. Let p=20, w_{m2}=4, w_{s2}=4, c_m=0.4 and c_s=0.8, by varying $\tilde{w}_{m2}$ and CV, we numerically examine how the customer demand and the wholesale price paid to the CM under delegation affect γ, a measurement of the OEM's preference over the two outsourcing structures under pull contract, see Figure 2. We observe from Figure 2 that delegation is more likely to be preferred by the OEM if the customer demand has small CV. That is, it is better for the OEM to control the procurement function instead of delegating to the CM when facing high demand uncertainty. Next, Figure 2 also confirms our Proposition 6 that delegation is preferred by the OEM when $\tilde{w}_{m2}$ is in a moderate range.



$p = 20,\ w_{m2} = 4,\ w_{s2} = 4,\ c_m = 0.4,\ c_s = 0.8$

Figure 2: Impact of $\tilde{w}_{m2}$ and CV on γ

6. Comparison of Push and Pull Contracts

In this section, we compare the supply chain's performance across the three contracts.

Table 1: Supply Chain Capacity under Push and Pull Contracts

	Control	Delegation
Push Contract	$\bar{F}^{-1}(\frac{w_{m1}+w_{s1}}{p})$	$\bar{F}^{-1}(\frac{\tilde{w}_{m1}}{p})$
Pull Contract	$K_m^C \wedge K_s^C$	$K_m^D \wedge K_s^D$

First we list the supply chain capacity (the minimum of the capacities of the CM and the supplier) under the various combinations of push, pull contracts and two outsourcing structures in Table 1. As to the system capacities under pull and push contracts, we have the following corollary.

Corollary 2: $\bar{F}^{-1}(\frac{w_{m1}+w_{s1}}{p}) \geq K_m^C \wedge K_s^C$ *if* $\frac{w_{m1}+w_{s1}}{p} \leq \max(\frac{c_m}{w_{m2}}, \frac{c_s}{w_{s2}})$*; otherwise,* $\bar{F}^{-1}(\frac{w_{m1}+w_{s1}}{p}) < K_m^C \wedge K_s^C$*. Similarly,* $\bar{F}^{-1}(\frac{\tilde{w}_{m1}}{p}) \geq K_m^D \wedge K_s^D$ *if* $\frac{\tilde{w}_{m1}}{p} \leq \max(\frac{c_m}{(\tilde{w}_{m2}-w_{s2})}, \frac{c_s}{w_{s2}})$*; otherwise,* $\bar{F}^{-1}(\frac{\tilde{w}_{m1}}{p}) < K_m^D \wedge K_s^D$.

So for both outsourcing structures, whether the supply chain system capacity under push contract is higher or lower than that under pull contract depends solely on the relative magnitude of the market price, the wholesale prices in two periods and the capacity installation costs. It is independent of demand distribution.

Next we investigate the OEM's preference over the pull and push contracts under the two outsourcing structures by comparing the profits of the OEM.

Under control structure, we have

$$\pi_o^C(pull) = \pi_o^C(push) = (p - w_{m2} - w_{s2})D(K_m^C \wedge K_s^C) - [pD(q^C) - (w_{m1} + w_{s1})q^C] \tag{9}$$

Lemma 2: $\pi_o^C(pull) - \pi_o^C(push)$ *is quasi-concave in* w_{m2} *and* w_{s2}*, and increasing in* w_{m1} *and* w_{s1}*.*

Therefore, under control structure, if the at-once wholesale prices w_{m2} and w_{s2} are in a moderate range and/or the prebook wholesale prices w_{m1} and w_{s1} are high, then it is more likely that the OEM prefers pull contract over push contract. The reason is that the wholesale prices affect not only the OEM's profit margin and ordering decisions but also the CM and the supplier's capacity building incentives. Those decisions then jointly affect the supply chain capacity and thus the amount of demand that can be satisfied. If the wholesale prices in periods 1/2 are high, the OEM can only obtain small profit margin. Thus the OEM will not prebook much under push contract. And if the wholesale prices in period 2 are low, then the CM and the supplier have small profit margin and thus would not install much capacity in advance under pull contract. Therefore, under those cases, the system capacity will be low, and the OEM is unable to satisfy all the demands if the realized demand is high, which hurts the OEM's performance.

Similarly, under delegation structure, we have

Lemma 3: $\pi_o^D(pull) - \pi_o^D(push)$ *is quasi-concave in* $\tilde{w}_{m2}$*, and increasing in* $\tilde{w}_{m1}$.

So under delegation structure, the OEM will prefer pull contract over push contract if the at-once wholesale price $\tilde{w}_{m2}$ is in a moderate range and/or the prebook wholesale price $\tilde{w}_{m1}$ is high. And the reason behind is similar to that under Lemma 2.

7. Concluding Remarks

We considered the issue of inventory/capacity risk allocation in a multi-tier supply chain composed of an OEM, a CM and a supplier by allowing the OEM to choose between different outsourcing structures. As to the preference of the outsourcing structures, we showed that under push contract, the OEM prefers delegation to control as long as it can achieve a cost saving of the total procurement price advantage by delegating the component procurement function to the CM. For the pull contract, we showed that the OEM may prefer control over delegation when the wholesale price it pays to the CM under delegation is either too high or too low. Only when the wholesale price under delegation is in a moderate range and the demand for the final product is stable can delegation be more preferable. We also found that control is more beneficial to the OEM if the market has high uncertainty and the pull contract is adopted.

As to the preference over the contract, we showed that the OEM will prefer pull over push if the prebook wholesale prices are high or at-once wholesale prices are in a moderate range.

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