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Decentralized Procurement in Light of Strategic Inventories

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The centralization versus decentralization choice is perhaps the quintessential organizational structure decision. In the operations realm, this choice is particularly critical when it comes to the procurement function. Why firms may opt to decentralize procurement has been often studied and confirmed to be a multifaceted choice. This paper complements existing studies by detailing the trade-offs in the centralization versus decentralization decision in light of firms' strategic use of inventories to influence supplier pricing. In particular, we demonstrate that a firm's decision to cede procurement choices to its individual divisions can help moderate inventory levels and provide a natural salve on supply chain frictions.

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1. Introduction

Firms face several competing priorities when evaluating whether to centralize decisions or rely on the often disparate choices of decentralized decision makers. The centralization versus decentralization issue is particularly pressing for the procurement function, where firms have frequently oscillated between the two extremes. A recent KPMG/Economist Intelligence Unit (2008) survey demonstrated that although centralized procurement has seen a rise in recent years, decentralized procurement still represents roughly half of firms' organizational structures. Despite the split among the preferred choice of firms, the importance of the procurement function is clear, with 75% of respondents indicating that it is a high strategic priority.

The KPMG/Economist Intelligence Unit report stresses that a critical factor in determining organizational structure is how it influences pricing from and relationships with suppliers. For this reason, some believe centralization, and its ability to fortify buyer bargaining power, represents the future. This paper adds a level of nuance to the choice, demonstrating how organizational structure influences accumulation of strategic inventories, which, in turn, impacts pricing along the supply chain.

To elaborate, we extend the strategic inventory model of Anand et al. (2008) to examine the choice of centralized versus decentralized procurement. A firm initially purchases inputs from a supplier to offer them for sale as outputs. Unsold units from among these initial purchases are carried forward in inventory to the subsequent period. Inventory plays an important strategic role, leading to lower long-term supplier prices but also higher near-term pricing. Given these offsetting pricing consequences, we ask what happens if procurement choices are made not by a central planner but by the firm's individual divisions. The usual concern is that decentralization of procurement creates divergent incentives among the divisions, undercutting economies of scale. What this usual thinking misses is that the firm's penchant for building inventory for strategic reasons comes at a cost in terms of near-term pricing, so some level of internal discord can be useful.

In particular, we demonstrate that the benefit of raising inventory in any one division is much greater from the firm's perspective than from the division manager's perspective, and thus, decentralization leads to lower strategic inventory levels. This, in turn, creates a détente of sorts between the supplier and the firm with both input prices and inventory levels kept in check. Lest one think the benefit of decentralization is minimizing an evil the firm would prefer to entirely eliminate, we demonstrate that strategic inventories can be beneficial provided they are used in moderation, and such moderation is precisely what decentralization can provide.

The result that decentralized procurement can be preferred as a result of the strategic posture it conveys to suppliers is in line with the broader literature on strategic delegation. Though this literature has ostensibly focused on delegation as a means of posturing to competitors (Alles and Datar 1998, Fershtman and Judd 1987, McGuire and Staelin 1983, Sklivas 1987), it certainly also has applicability to supply chains. In effect, a strategic delegation view of the present problem would advocate endowing a centralized planner with decision-making power but altering his incentive structure—say, by providing additional charges for inventory holding—to convince the supplier that the firm will take a softer inventory posture. In an extension, we demonstrate that such strategic delegation can indeed be preferred to centralization but is not necessarily preferable to decentralized procurement.

Our results add to the substantial literature on the centralization versus decentralization choice as it pertains to procurement. Practitioners stress and existing research confirms that several features can favor centralized procurement. For one, centralization permits diversification of stockout risks (Eppen 1979). Having a central planner in charge of procurement also enhances bargaining power and permits quantity discounts (e.g., Munson and Hu 2010). In line with such thinking, much of the literature takes decentralization as given and then asks how firms can improve coordination to get close to centralized outcomes (e.g., Andersson and Marklund 2000, Anupindi et al. 2001, Bernstein and Federgruen 2005).

Despite the theoretical allure of centralized decision making, there are several extant justifications for decentralized procurement. The ability to exploit localized private information represents a key case for decentralization (e.g., Vagstad 2000). Snyder and Shen (2007) posit that diversification of supply risks can favor decentralization of inventories, since unforeseen supply disruptions would only affect a fraction of divisions, thereby mitigating overall risks. Further, Hu et al. (2013) show that even when the desire to pool demand risks points to centralization, it can be detrimental for privately informed buyers. This is because a pooled order can enhance the supplier's ability to construct contracts that limit buyer information rents.

Decentralization that introduces an additional vertical layer has also proven useful. Arya and Mittendorf (2006) demonstrate that vertical disintegration and the channel conflict it engenders can help alleviate the time inconsistency problem of a durable goods monopolist. Belavina and Girotra (2012b) show that adding an intermediary can also reduce channel discord by pooling sourcing needs of different buyers and achieving more appropriate fit between buyers and suppliers. Belavina and Girotra (2012a) show that the mindset that decentralization is detrimental hinges critically on the assumption of one-off trade. Utilizing a model of continuing trade, their paper shows that decentralization can reap benefits by improving coordination among participants and limiting their scope for opportunistic behavior.

Our model intentionally excludes the above considerations in the centralization versus decentralization decision to highlight an additional factor: strategic inventories. The strategic role of inventory in supply chains was formally demonstrated in Anand et al. (2008). Subsequently, Arya and Mittendorf (2013) studied the role of strategic inventory in the design of consumer rebates, and Hartwig et al. (2013) experimentally demonstrated the importance of strategic inventories. The notion that inventory can act as a hedge against supplier pricing has been well recognized for some time at the macro level, with countries developing strategic reserves of petroleum and other key commodities for which price risks are prominent. Interestingly, Dudine et al. (2006) make a complementary point at the consumer level, which they label the storable goods monopoly problem, demonstrating an incentive to store purchases for future consumption in light of deterministic increases in future demand (and pricing). They show that such a propensity to store goods to protect against future price increases can have detrimental welfare effects in the long-run since it leads to short-term price increases. This suggests that our results may be even more pronounced when excess use of strategic inventory is intensified by predictable future demand increases.

2. Model

We study a basic formulation of procurement and strategic inventory management for a firm serving multiple markets. In each of two periods, the firm purchases inputs from a supplier and sells final products to end consumers. The firm consists of n, $n \geq 2$, segments (divisions), each of which serves a distinct market. The markets correspond to different geographical territories and/or distinct product offerings. The (common knowledge) demand for the retail product in market i, $i = 1, \ldots, n$, in period t, $t = 1, 2$, is given by $p_t^i = a - q_t^i$, where p_t^i is the price paid by consumers and q_t^i is the quantity sold in the retail market. The supplier's production costs and the firm's conversion costs are each normalized to zero.

At the start of each period, the supplier sets its (per-unit) wholesale price, w_t, for the firm. Subsequent to the supplier setting its terms, the firm procures Q_t^i units of the product and sells q_t^i units (equivalently, sets the retail price p_t^i) in retail market i. At the end of period 1, the firm carries forward any excess purchases as inventory; denote the inventory level for market i by I^i, $I^i = Q_1^i - q_1^i$. For each unit it carries in its inventory, the firm incurs a holding cost of h, $h \geq 0$.

The focus herein is on whether procurement/inventory decisions (i.e., Q_t^i and q_t^i) should be made centrally for all n markets or whether the firm should decentralize and leave these decisions to respective division managers who each seek to maximize their own divisional profit.

To formally compare the outcomes under centralization versus decentralization, we first characterize the unique (subgame-perfect) equilibrium of the game under each regime using backward induction. As is customary, we assume the regularity condition that the demand intercept a is sufficiently large: the condition $a > 8h$ is necessary and sufficient for inventory levels to be positive under both organizational structures for at least some n.

3. Results

As the key novelty of the present analysis is to consider how strategic inventories can influence the desirability of decentralized procurement, consider a one-period version of the model wherein inventories are moot. Under centralized procurement, a firm chooses sales quantities, q^i, $i = 1, \ldots, n$, to solve $\max_{q^i,\, i=1,\ldots,n} \sum_{i=1}^n [(a - q^i)q^i - wq^i]$. This yields equilibrium quantities of $q^i(w) = [a - w]/2$. The supplier, in turn, sets its input price to maximize its profit, taking into account all output markets. In particular, it solves $\max_w \sum_{i=1}^n wq^i(w)$. Solving this problem yields the equilibrium input price of $w = a/2$. Under decentralization, output market quantities are chosen by individual divisions, each of which is focused only on its own profit. Again working backward in the game, division i solves $\max_{q^i}[(a - q^i)q^i - wq^i]$. The first-order condition of this problem yields $q^i(w) = [a - w]/2$, precisely as in the centralized case; thus, the supplier price is unchanged as well. In other words, in a one-period (no inventory) setting, decentralization and centralization are equivalent. Thus, the model is one where the usual reasons for centralization or decentralization are absent, providing an opportunity to isolate how strategic inventories can alter the procurement choice. Given this, we now consider the equilibrium in the two-period setting for each organizational structure.

3.1. Equilibrium

Consider the outcome under centralized procurement, as analyzed in Anand et al. (2008). Working backward in the game, the firm's period 2 choices potentially depend not only on the prevailing wholesale price, w_2, but also the inventory it has retained in each market, I^i. To be precise, the firm's period 2 retail sales quantity in market i, q_2^i, solves

$$\max_{q_2^i,\, i=1,\ldots,n} \left\{ \sum_{i=1}^n \left[(a - q_2^i)q_2^i - w_2(q_2^i - I^i) \right] \right\}. \tag{1}$$

In (1), the first term for each market reflects retail revenue, whereas the second reflects input market outlays; the summation indicates the firm cares about revenues and outlays only in the aggregate. Solving (1) yields retail quantities in market i of $q_2^i(w_2) = [a - w_2]/2$ (and associated input purchases of $q_2^i(w_2) - I^i$). Given this, the supplier's period 2 pricing problem is

$$\max_{w_2} \left\{ \sum_{i=1}^n w_2 \left[q_2^i(w_2) - I^i \right] \right\}. \tag{2}$$

Solving (2) reveals the supplier's second-period input price, $w_2(\mathbf{I}) = a/2 - (1/n)\sum_{i=1}^n I^i$, where $\mathbf{I}$ denotes the vector of inventories held in each market. Note that the chosen input price is as in the one-period case (i.e., $a/2$), less an adjustment for inventory levels. Intuitively, the greater the inventory carried forward by the firm, the less its willingness to pay for more units (since its inventory can service the high-demand consumers). This lower willingness to pay translates into leverage and thus a lower prevailing wholesale price. Since the input price reflects the average position of each market, the lower price as a result of inventory reflects the average inventory level held in the n markets.

Given this period 2 outcome, the game unfolds in period 1 as follows. The firm's chosen retail sales and inventory levels in period 1 solve

$$\begin{aligned} \max_{q_1^i,\, I^i,\, i=1,\ldots,n} \Bigg\{ & \sum_{i=1}^n \left[(a - q_1^i)q_1^i - w_1(q_1^i + I^i) - hI^i \right] \\ & + \sum_{i=1}^n \big[[a - q_2^i(w_2(\mathbf{I}))] q_2^i(w_2(\mathbf{I})) \\ & \qquad - w_2(\mathbf{I})[q_2^i(w_2(\mathbf{I})) - I^i] \big] \Bigg\}. \end{aligned} \tag{3}$$

First-order conditions of (3) reveal first-period retail sales and inventory levels for market i equal to $q_1^i(w_1) = [a - w_1]/2$ and $\hat{I}^i(w_1) = [3a - 4(h + w_1)]/6$, respectively; the "ˆ" reflects the centralization outcome. Denoting the vector of inventory levels $(\hat{I}^i(w_1))$ by $\hat{\mathbf{I}}(w_1)$, the supplier's first-period input price, taking into account the subsequent behavior of all parties, solves (4):

$$\begin{aligned} \max_{w_1} \Bigg\{ & \sum_{i=1}^n w_1 \left[q_1^i(w_1) + \hat{I}^i(w_1) \right] \\ & + \sum_{i=1}^n w_2(\hat{\mathbf{I}}(w_1)) \left[q_2^i(w_2(\hat{\mathbf{I}}(w_1))) - \hat{I}^i(w_1) \right] \Bigg\}. \end{aligned} \tag{4}$$

In (4), the first term reflects aggregate period 1 profit, and the second reflects the ensuing aggregate period 2 profit. Solving (4) yields period 1 wholesale price of $\hat{w}_1 = [9a - 2h]/17$. Using this equilibrium price and back substituting yields the equilibrium outcome under centralization.

In contrast to the centralized firm, each division is concerned with just its divisional profits, not firmwide profits. Thus, under decentralized procurement, each division's period 2 choice, q_2^i, solves

$$\max_{q_2^i}\{[a-q_2^i]q_2^i - w_2[q_2^i - I^i]\}. \tag{5}$$

Solving (5) indicates, for a given w_2, the retail quantities in market i are equivalent to those obtained in the centralization case: $q_2^i(w_2)=[a-w_2]/2$ (so input purchases are $q_2^i(w_2)-I^i$). Given this, the supplier's period 2 pricing problem is again as in (2), yielding a second-period input price of $w_2(\mathbf{I}) = a/2-(1/n)\sum_{i=1}^n I^i$. In period 1, division i's chosen sales and inventory levels solve

$$\max_{q_1^i,\,I^i}\{[a-q_1^i]q_1^i - w_1[q_1^i+I^i] - hI^i + [a-q_2^i(w_2(\mathbf{I}))]q_2^i(w_2(\mathbf{I})) - w_2(\mathbf{I})[q_2^i(w_2(\mathbf{I}))-I^i]\}. \tag{6}$$

In (6), the first term reflects the division's period 1 profit and the second term reflects the ensuing period 2 divisional profit. Maximizing (6) reveals first-period retail sales and inventory levels for market i of $q_1^i(w_1) = [a - w_1]/2$ and $\tilde{I}^i(w_1) = \max\{[(2n+1)a-4n(h+w_1)]/[2(2n+1)], 0\}$ (the "~" reflects the decentralization outcome). Whereas, for a given w_1, period 1 retail sales are the same as under centralized procurement, inventory levels (and thus procurement levels) are not. In particular, $\tilde{I}^i(w_1)$ and $\hat{I}^i(w_1)$ are equivalent for the limiting case of $n=1$ (as expected), but $\tilde{I}^i(w_1) < \hat{I}^i(w_1)$ for $n>1$. This reflects that the chosen inventory level balances the costs (paying for inputs at the higher w_1 rate and holding costs h) and the benefits (securing a lower w_2). Whereas division i incurs the cost of carrying its inventory, the benefit of a reduction in w_2 is shared with other divisions. As a result, each division is more reluctant to carry inventory. In effect, decentralization engenders a free rider problem, one for which it is often criticized. In this case, however, the free rider problem also conveys a certain posture to the supplier that influences its initial pricing (w_1). Denoting the vector of inventory levels ($\tilde{I}^i(w_1)$) by $\tilde{\mathbf{I}}(w_1)$, the supplier's first-period input price solves

$$\max_{w_1}\left\{\sum_{i=1}^n w_1[q_1^i(w_1)+\tilde{I}^i(w_1)] + \sum_{i=1}^n w_2(\tilde{\mathbf{I}}(w_1))\big[q_2^i(w_2(\tilde{\mathbf{I}}(w_1)))-\tilde{I}^i(w_1)\big]\right\}. \tag{7}$$

Solving (7) yields a period 1 wholesale price of $\tilde{w}_1 = \max\{[(2n+1)^2a-2nh]/[8n(n+1)+1], a/2\}$. Using this equilibrium wholesale price and back substituting yields the equilibrium outcome under decentralization. The following proposition summarizes the results in this section. (All proofs are provided in the appendix.)

Proposition 1. *The equilibrium outcomes under centralized and decentralized procurement are as indicated in the table below.*

		Decentralized procurement	
	Centralized procurement	$h/a < 1/(4n)$	$h/a \geq 1/(4n)$
w_1	$\frac{9a-2h}{17}$	$\frac{[2n+1]^2a-2nh}{8n[n+1]+1}$	$\frac{a}{2}$
w_2	$\frac{2[3a+5h]}{17}$	$\frac{2n[a(2n+1)+h(4n+1)]}{8n[n+1]+1}$	$\frac{a}{2}$
q_1	$\frac{4a+h}{17}$	$\frac{n[2a(n+1)+h]}{8n[n+1]+1}$	$\frac{a}{4}$
q_2	$\frac{11a-10h}{34}$	$\frac{a[2n(2n+3)+1]-2nh[4n+1]}{2[8n(n+1)+1]}$	$\frac{a}{4}$
I	$\frac{5[a-4h]}{34}$	$\frac{[4n+1][a-4nh]}{2[8n(n+1)+1]}$	0

3.2. Preferred Organizational Structure

As noted in the previous section, decentralization creates a free rider problem in procurement. Although this certainly has coordination downsides, an interesting question is whether decentralization is ever preferred to centralization. The sagacious reader will probably have guessed the answer is affirmative. The reason decentralization can be preferred is that the free rider problem also alters the supplier's period 1 pricing choice. Whereas under centralization the supplier is forced to charge an excessive price to dissuade excessive inventory holding, the uncoordinated behavior of separate divisions partially accomplishes this task for the supplier, permitting a lower initial wholesale price. To see this effect most clearly, note that the more disjoint the behavior under decentralization, the lower the period 1 wholesale price; i.e., $\tilde{w}_1$ is decreasing in n.

This effect suggests that some of the dangers of excessive inventory are naturally curbed when the firm employs decentralization. That said, it remains unclear whether this can go too far and, importantly, whether the firm can benefit from such curbs on its own behavior. A comparison of the firm's profit under centralization and decentralization confirms the following proposition. (The closed-form expression for $f(n)$ is provided in the appendix.)

Proposition 2. *Decentralized procurement is strictly preferred if and only if $h/a < f(n)$, where $f(n)$ is decreasing in n.*

Following the above logic, low values of h/a indicate a particularly disconcerting inventory problem—inventories held for strategic reasons excessively bump up period 1 input price. In such cases, decentralization is useful as it helps the firm precommit to not carrying excessive inventory, which, in turn, ensures a more moderate period 1 wholesale price. The flip side of the equation is that the diffuse priorities of many divisions can create an excessively uncoordinated procurement policy, one in which the firm's inventory level is too low. Hence, provided discord is sufficiently small (i.e., n is sufficiently low), the downsides of decentralization are not too severe. This is reflected by the fact that the right-hand side of the condition in Proposition 2 is decreasing in n.

Importantly, the upside of decentralized procurement here is not simply to reduce inventories. A better interpretation is that when decentralization is preferred, it is because it helps moderate inventory levels. This is crisply seen by comparing the outcome to the case where inventory is not permitted (say, a precommitment to just-in-time purchases) or when it is not needed (say, the supplier can make a long-term commitment to wholesale prices). If inventory were just an evil to be eradicated, and decentralization was imperfect at such eradication, a precommitment to wholesale prices or no inventory would be preferable. As it turns out, decentralization is also preferred to those alternatives, pointing to its potential for creating the right mix of inventories and sales.

Following the theme of moderation, it is also worth pointing out that just because a move toward decentralized procurement (where the divisions choose their own quantities) can be optimal does not mean a move toward full decentralization (where the divisions choose their quantities and negotiate their own separate supplier pricing) is more desirable. By moving toward full decentralization, the firm actually undermines any benefits of decentralized procurement. With full decentralization, the inventory free rider effect disappears and each division's inventory solely benefits its own wholesale price. As such, in the setting full decentralization yields the same outcomes as under centralization. Thus, the moderation inherent in decentralized procurement makes it a particularly appealing firm structure, as formalized in the next proposition.

Proposition 3. *For $h/a < f(n)$, decentralized procurement is preferred to* (i) *precommitment to wholesale prices by the supplier,* (ii) *a zero-inventory policy by the firm, and* (iii) *full decentralization.*

We next conclude our results with a comparison of decentralized procurement to strategic delegation.

3.3. Strategic Delegation

Since decentralized procurement serves the role of presenting a particular posture to the supplier to influence its subsequent pricing, our result is related to the notion of strategic delegation. The noteworthy contrast to strategic delegation here is that we focus on organizational structure rather than a particular compensation structure to enact a strategic posture. To see the importance of the contrast, consider a simple strategic delegation alternative: keep decisions with a single (central) procurement agent but include an additional charge for carrying inventory in the agent's compensation. In particular, say the procurement agent's compensation is proportional to firm profit less an additional charge for holding inventory, denoted ψI. This way, the firm can increase the inventory charge by increasing ψ as a means of incentivizing the agent to accumulate less inventory. With such a strategic delegation scheme, the firm's optimal inventory charge and a resulting comparison of outcomes to decentralized procurement are presented in the following proposition.

Proposition 4. (i) *Under the strategic delegation scheme, the firm optimally imposes a surcharge on the procurement agent of $\psi = [13a - 18h]/188$ per-unit of inventory. The ensuing equilibrium wholesale prices, inventory, and sales are then as under centralization in Proposition* 1 *with h replaced by $h + \psi$.*

(ii) *Decentralized procurement is strictly preferred to strategic delegation* (*and centralized procurement*) *if and only if $h/a < g(n)$, $g(n) < f(n)$.*

Proposition 4(i) confirms that the flexible compensation structure inherent in strategic delegation yields an outcome that improves upon centralization. Though the firm benefits from carrying strategic inventories, it can gain by committing to carry less than under centralization; strategic delegation with $\psi > 0$ provides this opportunity. In fact, since equilibrium inventory levels are monotonically decreasing in ψ, strategic delegation provides a lever to guarantee any level of inventory to which the firm wishes to commit.

Proposition 4(ii) confirms that there is more to the story, however. Despite the flexibility provided by strategic delegation, decentralized procurement can still be preferred—the condition for this is similar to that in Proposition 2, only more stringent. Although strategic delegation permits a firm to effectively commit to any inventory level, the importance of inventory is not entirely on the equilibrium path. Although the level of inventory is important to the outcome, so is the sensitivity of that level to changes in supplier prices. After all, the firm's ultimate goal is both to lower inventory levels and to convince the supplier to lower its first-period wholesale price in the process.

Formally, under decentralized procurement, the inventory-to-wholesale price sensitivity is $|d\tilde{I}_i/dw_1| = 4n/[2(2n+1)]$. The corresponding sensitivity under strategic delegation is lower and equals $|dI_i/dw_1| = 2/3$. The increased sensitivity in the former case implies that the supplier recognizes that under decentralized procurement even a slight increase in its first-period wholesale price will lead to a significant lowering of the buyer's inventory level. Thus, the supplier's need to boost first-period wholesale price to curb inventory buildup is dampened.

Before concluding this section, it is worth stressing that we only considered one, albeit natural, strategic delegation scheme for the sake of comparison. There are, of course, many permutations, some of which could yield preferable outcomes. For example, delegating procurement decisions to division managers and fine-tuning their compensation contracts so they maximize a weighted average of firm profits and division profits makes use of elements of both decentralization and strategic delegation. Not surprisingly, such an arrangement can be preferred to either option alone.

It is also worth noting that one appealing feature of the form of decentralized procurement examined here relative to a more detailed strategic delegation scheme is that it only requires the supplier to observe the basic structure of its customer's organization, whereas strategic delegation requires observability of the actual compensation contracts. To the degree that organizational forms are more readily observed and credibly conveyed than compensation arrangements, decentralized procurement may be a more practical means of the firm posturing to the supplier than strategic delegation. The broader point, however, is not that the particular (simple) decentralized procurement scheme studied herein is the best, but rather that a desire to soften strategic inventory accumulation can favor a move away from centralization.

4. Conclusion

Textbook discussions of organizational structure typically view centralized decision making as an ideal. Practicalities such as limited resources and time coupled with diffuse information typically form the basis for decentralization as an imperfect substitute. This paper demonstrates that the seemingly imperfect nature of decentralization may actually prove to be desirable when a firm relies on external suppliers and strategically manages inventory.

In particular, when a firm procures inputs to be sold in a variety of markets, it has incentives to use inventory management as a strategic tool to extract surplus from its supplier. The supplier, in turn, must rely on its own strategic weapons (here, wholesale prices) to dissuade such behavior. A decentralized procurement policy serves as a natural salve on the otherwise strained supply chain relationship. Since individual divisions find large inventory buildup a substantial cost to bear for influencing supplier pricing—the benefit of a price cut is shared by all divisions—the confrontational position between the firm and its supplier is moderated.

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Appendix

Proof of Proposition 1. Under centralized procurement, the backward induction process that solves (1)–(3) yields $q_2^i(w_2)=[a-w_2]/2$, $w_2(\mathbf{I})=a/2-\sum_{i=1}^n I^i/n$, $q_1^i(w_1)=[a-w_1]/2$, and $\hat{I}^i(w_1)=[3a-4(h+w_1)]/6$ if $w_1<3a/4-h$; $\hat{I}^i(w_1)=0$ otherwise. Using these in (4), and solving the first-order condition, yields $\hat{w}_1=[9a-2h]/17$. The condition $a>8h$ confirms $\hat{w}_1<3a/4-h$. Using back substitution, the solution equals $\hat{I}^i=[3a-4(h+\hat{w}_1)]/6$, $\hat{q}_1^i=[a-\hat{w}_1]/2$, $\hat{w}_2=a/2-\sum_{i=1}^n \hat{I}^i/n$, and $\hat{q}_2^i=[a-\hat{w}_2]/2$. These values are presented in the table in Proposition 1. Given $a>8h$, the equilibrium inventory level, purchases, and sales are each nonnegative.

Turning to decentralized procurement, from (5), (2), and (6), $q_2^i(w_2)=[a-w_2]/2$, $w_2(\mathbf{I})=a/2-\sum_{i=1}^n I^i/n$, $q_1^i(w_1)=[a-w_1]/2$, and $\tilde{I}^i(w_1)=[(2n+1)a-4n(h+w_1)]/[2(2n+1)]$ if $w_1<[(2n+1)a]/(4n)-h$; $\tilde{I}^i(w_1)=0$ otherwise. Using these in (7), and solving the first-order condition of the problem corresponding to the two $\tilde{I}^i(w_1)$ values, yields $\tilde{w}_1=[(2n+1)^2a-2nh]/[8n(n+1)+1]$ if $a>4nh$ (equivalently, $h/a<1/(4n)$) and $\tilde{w}_1=a/2$ otherwise. Thus, for $h/a<1/(4n)$, employing the first $\tilde{w}_1$-value and using back substitution, the two-period solution equals $\tilde{I}^i=[(2n+1)a-4n(h+\tilde{w}_1)]/[2(2n+1)]$, $\tilde{q}_1^i=[a-\tilde{w}_1]/2$, $\tilde{w}_2=a/2-\sum_{i=1}^n \tilde{I}^i/n$, and $\tilde{q}_2^i=[a-\tilde{w}_2]/2$. Since $h/a<1/(4n)$ here, the equilibrium inventory level, purchases, and sales are each nonnegative, and these are the values presented in the associated column in the table. For $h/a\geq 1/(4n)$, $\tilde{I}^i=0$. Hence, for these values the decentralized procurement solution is simply the twofold repetition of the one-period solution noted at the beginning of §3. These values are presented in the last column of the table. □

Proof of Proposition 2. Using the solution presented in the table in Proposition 1, the firm's profits under centralized and decentralized procurement are as follows:

$$\hat{\Pi}=\frac{n[155a^2-118ah+304h^2]}{1{,}156},$$

$$\begin{aligned}\tilde{\Pi}=\frac{n}{4[8n(n+1)+1]^2}\big[&a^2(32n^4+80n^3+44n^2-1)\\&-2ah(32n^4+16n^3+4n^2+6n+1)\\&+8nh^2(8n^3+20n^2+9n+1)\big],\end{aligned} \tag{8}$$

if $h/a<1/(4n)$, and $\tilde{\Pi}=na^2/8$ otherwise.

Notice $\hat{\Pi} > na^2/8$ for $h/a < 1/8$. Hence, from (8), $\tilde{\Pi} - \hat{\Pi} > 0$ if and only if $h/a < 1/(4n)$ and $T(h/a) > 0$, where

$$T(h/a) = \left[\frac{h}{a}\right]^2 [76 + 714n + 1{,}592n^2 - 240n^3] + \frac{h}{a}[115 + 510n - 1{,}272n^2 - 2{,}736n^3] + [111 + 731n + 652n^2 - 168n^3]. \tag{9}$$

Using (9), $T'(h/a) < 0$ for $h/a < 1/8$, and $T(1/(4n)) = -[21n - 38][1 + 8n + 8n^2]^2/[8n^2] < 0$. This proves decentralized procurement is preferred if and only if h/a is sufficiently small, and the cutoff h/a-value is obtained by setting $T(h/a) = 0$. Thus, decentralized procurement is preferred if and only $h/a < f(n)$, where

$$f(n) = \left(115 + 510n - 1{,}272n^2 - 2{,}736n^3 + 17[8n(n+1) + 1]\sqrt{396n^2 - 324n - 71}\right) \cdot \left(4[120n^3 - 796n^2 - 357n - 38]\right)^{-1}. \tag{10}$$

Using (10), $f'(n) < 0$ for $n \geq 2$. □

Proof of Proposition 3. When the supplier precommits to wholesale price, inventory levels no longer impact w_2. Thus, under wholesale price commitment, the inventory level is zero. In other words, the outcomes in parts (i) and (ii) are the same. Moreover, with zero inventory, the solution under either centralized or decentralized procurement is merely a twofold replication of the one-period solution. Formally, this can be verified by repeating the backward induction process employed in the proof of Proposition 1 for both the centralized and decentralized procurement cases with the added constraint that I is not a choice variable but is fixed at $I = 0$. Thus, the two-period firm profit is $na^2/8$ when the supplier precommits to wholesale prices or when the firm commits to zero inventory. Hence, proving parts (i) and (ii) requires showing that $\tilde{\Pi} - na^2/8 > 0$, where $\tilde{\Pi}$ is the first expression in (8) since, from (10), $f(n) < 1/(4n)$. It is easy to verify that

$$\tilde{\Pi} - na^2/8\big|_{h/a=1/(4n)} = 0 \quad \text{and} \quad \frac{d[\tilde{\Pi} - na^2/8]}{dh} < 0, \quad \text{for } \frac{h}{a} < \frac{1}{4n}. \tag{11}$$

From (11), it follows that $\tilde{\Pi} - na^2/8 > 0$ for $h/a < 1/(4n)$. Since $f(n) < 1/(4n)$, $\tilde{\Pi} - na^2/8 > 0$ for $h/a < f(n)$. Turning to part (iii), under full decentralization, the supplier can set a different wholesale price for each division, so the solution is obtained by solving (1)–(4) with $n = 1$. In this case, the solution is as under centralized procurement in Proposition 1. The result in part (iii) then follows from Proposition 2. □

Proof of Proposition 4. Under strategic delegation, the procurement agent's inventory holding cost is effectively $h + \psi$ per unit. Hence, the solution is as under centralized procurement in Proposition 1 with h replaced by $h + \psi$. Substituting this solution in (3) yields firm profits

$$\Pi = \frac{n[155a^2 - 118ah + 304h^2 + 52a\psi - 72h\psi - 376\psi^2]}{1{,}156}. \tag{12}$$

Solving the first-order condition of (12) with respect to ψ yields the ψ-value in part (i). Thus, under strategic delegation, firm value, denoted Π^d, is

$$\Pi^d = \frac{n[51a^2 - 40ah + 100h^2]}{376}. \tag{13}$$

From (8) and (13),

$$\Pi^d - \hat{\Pi} = \frac{n[13a - 18h]^2}{108{,}664} > 0 \quad \text{and} \quad \Pi^d - \frac{na^2}{8} = \frac{n[a - 5h]^2}{94} > 0.$$

Hence, from (8), $\tilde{\Pi} - \Pi^d > 0$ if and only if $h/a < 1/(4n)$ and $M(h/a) > 0$, where

$$M(h/a) = \left[\frac{h}{a}\right]^2 [-100 - 848n - 1{,}232n^2 + 2{,}240n^3 - 384n^4] + \frac{h}{a}[-148 - 488n + 2{,}448n^2 + 2{,}112n^3 - 3{,}456n^4] - 145 - 816n + 56n^2 + 992n^3 - 256n^4. \tag{14}$$

From (10) and (14), $M'(h/a) < 0$ for $h/a < 1/8$, and $M(f(n)) < 0$. This proves that decentralized procurement is preferred to strategic delegation if and only if h/a is sufficiently small, and the cutoff h/a-value, denoted by $g(n)$, $g(n) < f(n)$, solves $M(g(n)) = 0$. The fact that decentralized procurement then is also preferred to centralized procurement follows immediately from $\Pi^d - \hat{\Pi} > 0$. □

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