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The benefit of horizontal decentralization in durable good procurement☆

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ABSTRACT

A conventional wisdom in industry and academia is that firms suffer from decentralized procurement. In this paper, we demonstrate an important and counter-intuitive benefit of procurement decentralization in a common setting where a firm with multiple divisions procures a durable good from a supplier. We start with a two-period model and obtain analytic equilibrium results on the supplier's wholesale prices, and the firm's procurement quantities and profits under procurement centralization and decentralization. These results show that the firm's profit will benefit from decentralization if and only if the product is durable. We further show that the profit improvement always increases in durability and the number of divisions. To generalize the basic model with two periods, we design an iterative algorithm to compute the equilibrium results for any number of periods. Our extensive numerical simulations show the robustness of our analytic results and managerial insights.

1. Introduction

According to a latest KPMG survey, procurement amounts to 40%–80% of the total cost for most firms, and it continues to be a critical function in firms' strategic management [28]. In particular, the firms are oftentimes faced with the strategic choice between centralization versus decentralization for the procurement function. With procurement centralization, a firm's central planner (e.g., the headquarters) makes procurement decisions to maximize the performance of the whole firm. In decentralization, the firm's divisions (or subsidiaries) are allowed to make their procurement decisions to maximize their own interests. Although more and more firms have given priority to centralized procurement in recent years, a KPMG/Economist Intelligence Unit survey [29] suggested that nearly half of the firms still adopted decentralized procurement.

Conventional wisdom indicates that centralized procurement is more efficient due to its ability to establish a unified front and enhance firm's bargaining power with suppliers. In this paper, we prove a novel view that when procuring durable goods, a firm can actually improve profitability through decentralization. To be more specific, a horizontally decentralized firm where each of its divisions seeks to maximize its own profit can help mitigate the classic time-inconsistency problem in durable goods procurement [15]. This time-inconsistency problem arises from a durable goods seller's incentive for lowering price and selling additional units after the initial quantities have been sold. Such a drop in price will reduce consumers' hold-up value. In other words, the value of the product purchased by early consumers will decrease over time. Thus, consumers' willingness to pay for durable goods is affected adversely because of the seller's inherent incentive to lower prices in the future. The time-inconsistency problem is first recognized by Coase [15], and later formalized by Bulow [13], where they conjectured that a monopolist's changing pricing incentives over time would force it to lower prices and finally lose the monopoly power. Surprisingly, this research shows that this time-inconsistency problem can be addressed when a firm with multiple horizontal divisions engages in decentralized procurement.

To elaborate, we consider a supply chain consisting of an upstream supplier (she) and a downstream firm (he) and examine the firm's strategic choice between centralized and decentralized procurement. The firm procures durable goods as inputs from the supplier and then sells them as outputs. Our question is what will happen if it's the firm's individual divisions rather than its central planner (e.g., the headquarters) that make the procurement decisions. The conventional concern is that decentralized procurement results in discord behavior, which is harmful to achieve economies of scale. However, this usual argument ignores that durable goods

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come with the time-inconsistency problem, which may lead to over procurement for the firm or the divisions. As a result, certain internal decentralization can be useful and play an important role in alleviating this problem.

In particular, we demonstrate that decentralization leads to more sales quantities in early periods and less in later periods, which in turn will lead to lower wholesale prices in each period. To convince one that the benefit of decentralized procurement is not committing to excessively restricting sales quantities (thus keeping prices high), we also demonstrate that moderate sales quantities in each period can be beneficial to solve the time-inconsistency problem in durable goods procurement. Interestingly, such moderation is exactly what decentralized procurement can bring about naturally.

It is worthwhile noting that our research focus on the procurement of durable goods is of practical importance. This is because durable goods, often large-ticket items such as automobiles, electronics and appliances, are important to our everyday lives and national economies. For example, in the U.S., expenditure on durables accounted for 7.3% of the national GDP in the first quarter of 2016 and procurement orders for durable goods rose 3.4% in April 2016 [27]. Furthermore, the growing middle classes in countries such as China and India have shown continuously growing willingness to buy them [19].

Many durable-goods firms have faced the strategic choice between centralized and decentralized decision making. For example, as one of the world's leading automobile manufacturers, Toyota had a strong centralized strategy in the past that was more like a spoke-and-wheel structure. The top headquarters in Japan made all the major decisions. Individual divisions could not communicate with each other but had to go through the headquarters. However, this organizational structure was widely criticized for the slow response to safety issues and consequent product recalls that started in 2009. As a result, Toyota has undertaken significant changes since 2013. In the current less centralized organizational structure, the company has increased the decision-making power of regional and divisional heads [24]. Another case is Harley-Davidson Inc., the fifth biggest motorcycle manufacturer in the world. Harley-Davidson's global expansion has been relatively slow, and most of the revenues are still generated in the United States. To address different markets and achieve global expansion better, the company has recently begun to decentralize by promoting higher autonomy to regional or local operations [41]. Finally, durable-good firms with decentralized divisional decision-making also include Ford Motor Company [36] and Home Depot [23]. Note that these big firms commonly have independent divisions serving different countries or regions, which will be a feature in our models in this paper.

Our research makes the following major contributions in this paper. First, unlike most exiting research on vertical structure of a supply chain, this research focuses on the horizontal centralization or decentralization of a firm with multiple divisions and such firms, like Toyota and Harley-Davidson mentioned above, are widespread in business practice. Second, unlike most extant research showing the benefit of procurement centralization, our research proves the counter-intuitive benefit of decentralization when a firm with multiple divisions procures a durable good from a supplier. Third, in a two-period model, our results analytically show that the firm can benefit from decentralization when procuring durable goods. Furthermore, the benefit is greater when the good involved in more durable. Fourth, we design an iterative algorithm and numerically show the robustness of our analytic results in a multi-period setting.

The rest of the paper is organized as follows. In Section 2, the most related literature is reviewed. In Section 3, we develop a basic two-period model for durable goods procurement under centralization and decentralization. In Section 4, we examine the equilibrium results under centralization and decentralization using backward induction. By comparing decentralization with centralization and some other alternatives, we demonstrate that decentralized procurement is better for the firm. In Section 5, we extend our basic model to multiple periods where we design an iterative numerical algorithm to calculate the equilibrium results. We show that the main managerial insights from the two-period model are robust in the multi-period model. Finally in Section 6, our results and their implications for future research are discussed.

2. Literature review

Our study relates to the strategic choice of procurement centralization and decentralization in the literature. A large body of literature has demonstrated some potential reasons in favor of centralization, such as permitting diversification of stockout risks [20], fortifying bargaining power, obtaining quantity discounts [34], improving the efficiency of resource allocation [22] and reducing internal resource waste [2]. In line with this case, there is also a stream of work in the literature that studies how to reach centralized outcomes if decentralization is a given reality [1,3,8].

The literature has also investigated potential benefits of decentralization. Vagstad [39] shows that decentralization can help exploit localized private information. Snyder et al. [37] and Schmitt et al. [35] posit that decentralizaiton of inventories can permit diversification of supply risks and control the overall risks caused by supply disruptions. Gupta et al. [26] show that decentralization of organizational structure has positive complementary to the implementation of advanced manufacturing technology. Arya et al. [4] model procurement and strategic inventory management for a firm serving mutiple markets and demonstate that decentralized procurement can help moderate inventory levels. Liu et al. [32] investigate the effects of negotiated and administered transfer pricing on profits of each center and the firm. They suggest the decentralized departments and the firm can benefit from the coordination by a committed dynamic transfer price. Meijboom and Obel [33] aslo show that centralization is a good choice for IT-based firms and a more decentralization organization is better when using transfer prices as the coordination device.

Additionally, vertical decentralization in a supply chain has also been demonstrated to be helpful. Belavina and Girotra [6] bulid a continuing trade model and show that the benefit of decentralization can be realized by coordinating inteactions and reducing opportunistic behavior. Belavina and Girotra [7] find that channel conflict can be mitigated by introducing an intermediary if buyers and suppliers are matched well based on pooling buyers' demands. Yang [40] considers strategic customers and finds that a decentralized channel can reap higher profit than that of a centralized channel. This is because of the driving factors of discounting and competition in addition to the double marginalization effect. Su and Zhang [38] analyze the impact of strategic customer behavior on supply chain performance. They show that disparate interests in a supply chain with a wholesale price contract can actually improve overall supply chain performance.

In contrast to these studies, our examination of centralization versus decentralization focuses on durable goods procurement. The literature has largely ignored the issue of how product durability impacts the choice of centralization versus decentralization. We seek to fill this gap by considering durable goods procurement. Durable good procurement exposes a firm to the time-inconsistency problem. As previously mentioned, this issue is first formulated by Coase [15], who shows that monopolists have the temptation to lower price and end up losing the monopoly power, because consumers will anticipate this tendency and wait for price reduction. Bulow [13] proposes an important insight that a durable

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good manufacturer can solve this problem by leasing rather than selling. Other studies also find that some level of leasing is optimal depending on several factors, such as competition in the durables market, potential entrants, interactions with strategic intermediary, depreciation of durable products, the presence of complementary products and exporting used products to an international secondary market [9,10,12,17,18,30]. Li and Xu [31] show that trade-in and/or leasing can be adopted to shorten consumers' upgrade cycle and gain control over secondary markets. The preference between trade-in and leasing is determined by the interplay between product reuse profitability and new product price. Once leasing durable products is impossible, several papers address the time-inconsistency problem by choosing to provide money-back guarantees, reduce the production capabilities, and commit to shut down production after an initial one-time sale under a lock-in strategy [14,25]. In addition, some studies find that a firm can consider contingent services or consumables as the primary source of profitability, and examine the compatibility of durable goods with contingent generic consumables [21,25].

Several extant studies closely related to this paper explore the interactions between channel structure and durable goods time-inconsistency problem. Desai et al. [16] recognize that introducing an intermediary within the distribution channel can benefit the manufacturer by making public commitment to future wholesale prices with the intermediary. Arya and Mittendorf [5] show that vertical disintegration can keep price high and improve channel performance even when there is no pre-commitment to wholesale prices. Bhaskaran and Gilbert [11] find that decentralized channel can strengthen the manufacturer's willingness to invest in durability if she changes the operation mode from leasing to selling. All these studies compare centralization and decentralization in a vertical distribution channel for durable goods and seek to improve manufacturer's or channel's performance. Our paper is different in that we examine the choice of centralization versus decentralization in a setting where a firm may be decentralized with multiple horizontal divisions. In contrast to prior work on durable goods, our contribution lies in explicitly recognizing that the time-inconsistency problem of durable good procurement can be alleviated effectively by horizontal decentralization in a natural way.

3. Model

In our basic model, a firm (he) procures durable goods from a supplier (she) and, in turn, sells to customers. The firm owns $n (n \geq 2)$ intendent divisions (or subsidiaries) each serving a distinct market. This is realistic when each division serves a different geographical region and/or offer a distinct product. For example, Toyota Motor Corporation has two horizontally independent divisions: Toyota Canada and Toyota Motor North America, which serves the U.S. market. To sharpen our focus on product durability, we further assume those divisions serve identical markets. Note that such an assumption is not uncommon in stylized models (e.g., [4]). Of course, future research can be done by assuming competing divisions with different market demands.

The firm has a strategic choice: centralized procurement where the firm's headquarters makes procurement quantity decisions, or decentralized procurement where each division makes its own procurement quantity decisions. As our focus is on durable goods, multiple periods need to be modelled. For simplicity, $t = 2$ periods are assumed in our basic model, as commonly done in the literature (e.g., [4,16]). In each of t periods, the supplier first sets a uniform per-unit wholesale price w_t. Note that this assumption of uniform pricing can be quite realistic because of the Robinson–Patman Act in the U.S., which prohibits a supplier from charging different prices for the same product to different customers. Then the firm or its divisions decide how many units to procure at that price. Similar to the Desai et al. [16] setup, we assume the durability of the product from one period to the next is $\delta (0 \leq \delta \leq 1)$, which reflects the extent of product deterioration due to usage. That is, a unit durable product sold in period t deteriorates and becomes the equivalent of δ unit in period $t+1$ after one period usage. In particular, if $\delta = 1$, the product is perfectly durable and there is no difference between new units and used units. If $\delta = 0$, the product has no durability and new products completely exit the market after one period. Needless to say, the greater the value of product durability, the more substitution of used goods for new goods.

As in most stylized models of durable goods [5,16], the consumption demand for the durable goods in market $i (i = 1, \cdots, n)$ in period $t = 1, 2$ is: $r_1^i = a - q_1^i$, $r_2^i = a - (\delta q_1^i + q_2^i)$, where r_t^i is the valuation of durable goods paid by consumers, q_t^i is the sales quantity in the retail market, and a is a positive constant intercept parameter. Note that q_1^i is the units of new products in period 1, and $\delta q_1^i + q_2^i$ is the equivalent units of new products in period 2 because of the deterioration of the q_1^i units from period 1. The selling price of the new durable goods produced in any period t,p_t^i, should reflect the service benefits provided both in present and future periods. Therefore, under the two-period model, $p_1^i = r_1^i + r_2^i$, $p_2^i = r_2^i$. For simplicity, we also normalize the supplier's production costs, the firm's conversion costs, the supplier's and the firm's discount rates to zero. Prices and quantities can be defined similarly when extended to more periods.

In each period, the supplier and the firm or its divisions make pricing and/or procurement decisions to maximize profit. Our focus is whether the firm, with a central planner like the headquarters, should make procurement decisions centrally for all n markets or decentralize and leave these decisions to each division manager who seek his/her own optimal profit. As usual, we use backward induction throughout this paper to derive subgame-perfect equilibrium outcomes for both cases of centralization and decentralization.

4. Analysis and results

To consider how centralization or decentralization can influence the pricing and procurement decisions of durable goods, we begin with a product with zero durability. As a result, a one-period model is sufficient. Under centralized procurement, sales quantities, q^i, $i = 1, \cdots, n$, are chosen by a firm to maximize its profit: $\max_{q^i, i=1,\cdots,n} \sum_{i=1}^n [(a - q^i)q^i - wq^i]$. For a given w from the supplier, the equilibrium quantities are $\widehat{q}^i(w) = (a - w)/2$, where "$\frown$" denotes the outcomes of centralized procurement. Working backwards, the supplier sets its wholesale price w to solve $\max_w \sum_{i=1}^n w\widehat{q}^i(w)$. The first-order condition of this problem yields the equilibrium, $\widehat{w} = a/2$. We next examine the outcome under decentralized procurement. Using backward induction again, each division i chooses output market quantities to focus only on its own profit: $\max_{q^i, i=1,\cdots,n} [(a - q^i)q^i - wq^i]$. This yields the sales quantities, $\breve{q}^i(w) = (a - w)/2$, where "$\smile$" denotes the decentralization outcome. It is identical to that obtained in the centralized case. Thus, the supplier's wholesale price equals the one under centralization as well. Therefore, in a one-period setting, centralization and decentralization yield the equivalent outcomes just as a product with zero durability.

We now move to our focus on a product with durability $0 < \delta \leq 1$. We start with the basic setting with two periods. It's worthy to note that in this two-period setting, a product produced in period 1 becomes a used product in period 2.

4.1. Equilibrium

4.1.1. Centralized procurement

We first consider the outcomes under centralized procurement where the firm makes all procurement decisions to maximize his profit. As we use backward induction, we examine the decisions and outcomes in the 2nd period in the beginning. Given q_1^i, $i = 1, \cdots, n$, and the period 2 wholesale price, w_2, the firm chooses period 2 sales quantity in market i, q_2^i to maximize his total profit:

$$\max_{q_2^i, i=1,\cdots,n} \left\{ \sum_{i=1}^{n} \left[\left(a - \delta q_1^i - q_2^i\right) q_2^i - w_2 q_2^i \right] \right\}. \tag{1}$$

In (1), the first term is the retail revenue, the second term denotes the input market wholesale costs, and the summation reflects the firm's period 2 profit compositions. Solving (1) yields period 2 sales quantities of $q_2^i(q_1^i, w_2) = (a - \delta q_1^i - w_2)/2$. Anticipating this response from the firm, the supplier maximizes its second-period profit, solving

$$\max_{w_2} \sum_{i=1}^{n} w_2 q_2^i\left(q_1^i, w_2\right). \tag{2}$$

Plugging $q_2^i(q_1^i, w_2)$ and solving the first-order condition of (2) reveal the period 2 wholesale price,

$$w_2(\mathbf{q_1}) = \frac{a}{2} - \sum_{i=1}^{n} \frac{\delta q_1^i}{2n}. \tag{3}$$

where $\mathbf{q_1}$ is the vector of first-period retail quantities sold in each market. Eq. (3) shows that the period 2 wholesale price is as in the one-period setting (i.e., $a/2$), less an adjustment for sales quantities used in period 1. Intuitively, the more products sold by the firm in the first period, the less his willingness to procure units from the supplier in the second period (since first-period durable goods still exist in the second-period market). Lower willingness by procure then translates into a lower wholesale price. Moreover, as the product durability δ increases, the wholesale price becomes lower.

Continuing with backward induction, the firm and the supplier make the decisions in the 1st period taking into account the outcomes from the 2nd period. Specifically, the firm chooses sales quantities in period 1 to maximize his two-period total profit:

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

Solving (4) yields first-period retail sales for market i as follows.

$$\widehat{q}_1^i(w_1) = \frac{(14 - \delta)a - 8w_1}{12\delta - \delta^2 + 16}. \tag{5}$$

Here, we use $\widehat{\mathbf{q}}_\mathbf{1}(w_1)$ to denote the vector of $\widehat{q}_1^i(w_1)$. Again, anticipating this response, the supplier chooses first-period wholesale price to maximize her total profit over the two periods, solving

$$\max_{w_1} \left\{ \sum_{i=1}^{n} w_1 \widehat{q}_1^i(w_1) + \sum_{i=1}^{n} w_2(\widehat{\mathbf{q}}_\mathbf{1}(w_1)) q_2^i(\widehat{q}_1^i(w_1), w_2(\widehat{\mathbf{q}}_\mathbf{1}(w_1))) \right\}. \tag{6}$$

In (6), the first term denotes the total first-period profit, and the second one is the ensuing total second-period profit. First-order conditions of (6) reveal the first-period wholesale price:

$$\widehat{w}_1 = \frac{(\delta^3 - 30\delta^2 + 184\delta + 224)a}{32(6\delta - \delta^2 + 8)}. \tag{7}$$

With this equilibrium wholesale price, we can easily obtain other equilibrium outcomes under centralization, which will be summarized in the next proposition.

4.1.2. Decentralized procurement

Under centralized procurement, the firm makes decisions to maximize his total profit. In contrast, under decentralized procurement, each division makes decisions to maximize its divisional profit only. Given period 2 wholesale price w_2, division i chooses its second-period sales quantities, q_2^i, to solve

$$\max_{q_2^i} \left[\left(a - \delta q_1^i - q_2^i\right) q_2^i - w_2 q_2^i \right]. \tag{8}$$

First-order conditions of (8) yield the second-period retail sales in market i, $q_2^i(q_1^i, w_2) = (a - \delta q_1^i - w_2)/2$, which is identical to that under the centralization case. Taking this into account, the supplier's second-period pricing problem is also equivalent to (2), thus revealing a period 2 wholesale prices of $w_2(\mathbf{q_1}) = a/2 - \sum_{i=1}^{n} \delta q_1^i/(2n)$. Given the period 2 outcomes, division i in the first period chooses retail sales, q_1^i, to solve

$$\begin{aligned}\max_{q_1^i} &\left\{ \left[a - q_1^i + a - \delta q_1^i - q_2^i\left(q_1^i, w_2(\mathbf{q_1})\right)\right] q_1^i - w_1 q_1^i \right. \\ &+ \left[a - \delta q_1^i - q_2^i\left(q_1^i, w_2(\mathbf{q_1})\right)\right] q_2^i\left(q_1^i, w_2(\mathbf{q_1})\right) \\ &\left. - w_2(\mathbf{q_1}) q_2^i\left(q_1^i, w_2(\mathbf{q_1})\right) \right\}. \end{aligned} \tag{9}$$

In (9), the first term represents division i's first-period profit and the second one denotes the division's ensuing second-period profit. Solving (9) yields period 1 retail sales in market i as follows:

$$\breve{q}_1^i(w_1) = \frac{[(14 - 2\delta)n + \delta]a - 8nw_1}{2(5\delta - \delta^2 + 8)n + 2\delta + \delta^2}. \tag{10}$$

The period 1 retail sales, $\breve{q}_1^i(w_1)$, in the decentralized setting is not only related to the period 1 wholesale price, w_1, but also to the number of divisions which reflects the degree of decentralization. Using the notation $\breve{\mathbf{q}}_\mathbf{1}(w_1)$ to denote the vector of first-period retail sales, $\breve{q}_1^i(w_1)$, the supplier chooses first-period wholesale price, w_1, to maximize her profit, solving

$$\max_{w_1} \left\{ \sum_{i=1}^{n} w_1 \breve{q}_1^i(w_1) + \sum_{i=1}^{n} w_2(\breve{\mathbf{q}}_\mathbf{1}(w_1)) q_2^i(\breve{q}_1^i(w_1), w_2(\breve{\mathbf{q}}_\mathbf{1}(w_1))) \right\}. \tag{11}$$

Maximizing (11) reveals period 1 wholesale price:

$$\breve{w}_1 = \frac{4(\delta^3 - 14\delta^2 + 35\delta + 56)n^2 + 4\delta(6\delta - \delta^2 + 11)n + (\delta + 2)\delta^2}{16n[(10\delta - 3\delta^2 + 16)n + \delta(\delta + 2)]} a. \tag{12}$$

Using this equilibrium period 1 wholesale price, we can obtain the equilibrium outcomes for procurement decentralization. Those results obtained so far are summarized in the following proposition.

Proposition 1. *The two-period equilibrium outcomes under centralized procurement and decentralized procurement for durable goods* $(0 < \delta \le 1)$ *are given in Table 1, where we have* $\breve{w}_1 < \widehat{w}_1$, $\breve{w}_2 < \widehat{w}_2$, $\breve{q}_1^i > \widehat{q}_1^i$, $\breve{q}_2^i < \widehat{q}_2^i$.

Table 1
Equilibrium outcomes under centralization and decentralization.

	Centralized procurement	Decentralized procurement
w_1	$\frac{(\delta^3-30\delta^2+184\delta+224)a}{32(6\delta-\delta^2+8)}$	$\frac{[4(\delta^3-14\delta^2+35\delta+56)n^2+4\delta(6\delta-\delta^2+11)n+(\delta+2)\delta^2]a}{16n[(10\delta-3\delta^2+16)n+\delta(\delta+2)]}$
w_2	$\frac{[10\delta-\delta^2+32]a}{8(6\delta-\delta^2+8)}$	$\frac{[2(3\delta-\delta^2+16)n+\delta(\delta+4)]a}{4[(10\delta-3\delta^2+16)n+\delta(\delta+2)]}$
q_1^i	$\frac{(14-3\delta)a}{4(6\delta-\delta^2+8)}$	$\frac{[2(7-2\delta)n+\delta]a}{2[(10\delta-3\delta^2+16)n+\delta(\delta+2)]}$
q_2^i	$\frac{[10\delta-\delta^2+32]a}{16(6\delta-\delta^2+8)}$	$\frac{[2(3\delta-\delta^2+16)n+\delta(\delta+4)]a}{8[(10\delta-3\delta^2+16)n+\delta(\delta+2)]}$

Proof. Using equilibrium first-period wholesale price and back substitution, the solution under either centralized or decentralized procurement can be obtained. For $0<\delta\leq 1$, we can verify that $\overset{\smile}{w}_1-\overset{\frown}{w}_1<0$, $\overset{\smile}{w}_2-\overset{\frown}{w}_2<0$, $\overset{\smile}{q}{}_1^i-\overset{\frown}{q}{}_1^i>0$ and $\overset{\smile}{q}{}_2^i-\overset{\frown}{q}{}_2^i<0$. ■

4.2. Centralization vs. Decentralization

With the equilibrium results in hand, a strategic question is whether centralization or decentralization is better for a firm when procuring durable goods ($0<\delta\leq 1$). By comparing the firm's profit under centralization versus decentralization, denoted by $\overset{\frown}{F}$ and $\overset{\smile}{F}$, respectively, we have the following proposition.

Proposition 2. *For durable goods ($0<\delta\leq 1$), decentralized procurement is strictly preferred to centralized procurement in a two-period setting. In particular, let $\Delta F=\overset{\smile}{F}-\overset{\frown}{F}$ be the benefit of decentralization over centralization, we have:* ***(i)*** *ΔF strictly increases in the number of divisions.* ***(ii)*** *ΔF strictly increases in product durability.*

Proof. Using the outcomes listed in Proposition 1, the firm's profits under centralized and decentralized procurement for durable goods are as follows:

$$\overset{\frown}{F}=\frac{(7\delta^4-740\delta^2+2544\delta+4160)na^2}{256(6\delta-\delta^2+8)^2}, \tag{13}$$

$$\begin{aligned}\overset{\smile}{F}=&\frac{a^2}{64[(10\delta-3\delta^2+16)n+\delta(\delta+2)]^2}\\&\times[4(9\delta^4-26\delta^3-227\delta^2+488\delta+1040)n^3+4\delta(-11\delta^3+29\delta^2\\&+50\delta+148)n^2+\delta^2(17\delta^2-8\delta-32)n-2\delta^3(\delta+2)].\end{aligned} \tag{14}$$

From (13) and (14), given $0<\delta\leq 1$, it is easy to verify that $d\Delta F/dn|_{n=2}>0$ and $d^2\Delta F/dn^2>0$. This proves $d\Delta F/dn>0$. In addition, note that $\Delta F|_{n=1}=0$, it follows that given $0<\delta\leq 1$, $\Delta F>0$ and ΔF strictly increases in n, for $n\geq 2$.

Similarly, given $n\geq 2$, we note that $d\Delta F/d\delta|_{\delta=0}>0$ and $d^2\Delta F/d\delta^2>0$. Hence, $d\Delta F/d\delta>0$, and notice $\Delta F|_{\delta=0}=0$. This proves that given $n\geq 2$, $\Delta F>0$ and ΔF strictly increases in δ, for $0<\delta\leq 1$. ■

Surprisingly, our results show that decentralized procurement achieves higher profit. This is contrary to the conventional view that uncoordinated procurement should be avoided. The reasons are as follows.

First, an essential driving force is that the supplier can set a uniform wholesale price for a firm or its all divisions in each period, which makes the decentralized procurement better off. As shown in Proposition 3 (***i***) and (***ii***), if the supplier sets the wholesale price for each division rather than a uniform wholesale price for all divisions, or the wholesale prices for both periods are fixed (e.g. $w_1=w_2$, or exogenously given), the decentralized and centralized procurements will be identical. Note that uniform wholesale pricing is quite practical as price discrimination is prohibited by laws like the Robinson–Patman Act in the U.S.

Second, from the supplier's period 2 wholesale prices of $w_2(\mathbf{q_1})=a/2-\sum_{i=1}^{n}\delta q_1^i/(2n)$ under decentralization, it means that the period 2 wholesale price decreases in the total order quantities of n divisions in the first period. Thus, the n divisions in the first period are involved in a game under decentralization which makes more profitable quantity and wholesale price decisions than the centralization. To be more specific, it can be seen from Proposition 1 that the usual under-procurement problem still exists for the durable goods. For goods with durability δ, both centralization and decentralization could suffer from under-procurement in period 1 and benefit from committing to less procurement in period 2, i.e., $\overset{\frown}{q}{}_1^i>\overset{\frown}{q}{}_2^i$, $\overset{\smile}{q}{}_1^i>\overset{\smile}{q}{}_2^i$. Thus, the reason decentralized procurement is preferred is that decentralization alters the supplier's first-period pricing, and makes a better balance between the cost of under-procurement in period 1 and the commitment benefit gained in period 2. In fact, under centralized procurement, the firm tends to under-procure in period 1 and over-procure in period 2. In contrast to centralization, decentralization allows a firm to procure more durable goods ($\overset{\smile}{q}{}_1^i>\overset{\frown}{q}{}_1^i$) in period 1 and less ($\overset{\smile}{q}{}_2^i<\overset{\frown}{q}{}_2^i$) in period 2, and to enjoy lower wholesale prices ($\overset{\smile}{w}_1<\overset{\frown}{w}_1$,$\overset{\smile}{w}_2<\overset{\frown}{w}_2$) in both periods. The above analysis suggests that the benefits of employing decentralization for a firm can outweigh the costs.

From Proposition 2 (***i***), we can see that for a given durable product, the firm can benefit from decentralized procurement. Furthermore, firm's profit improvement from decentralization increases as the number of divisions increases. This shows that the more divisional disjoint behavior, the greater the firm can benefit from decentralized procurement. From Proposition 2 (***ii***), we can also see that the upside of decentralized procurement is more prominent as the product durability δ increases.

4.3. Pre-commitment and Full Decentralization Strategies vs. Decentralization

To explore the driving forces that make the decentralization better, we shall study the effects of some changes in the basic assumptions under decentralization on main results and discuss the possible trade-off of centralization and decentralization. Decentralization is compared with two typical strategies: pre-commitment to wholesale prices by the supplier, where the wholesale prices are fixed in both periods, and full decentralization, where the supplier sets the different wholesale price for each division and allows each division to choose its own sales quantities separately.

Pre-commitment to keep a constant wholesale price by the supplier is a common policy in practice to control sales quantities. Similar pricing strategy is also mentioned in Arya et al. [4] to justify the strategic inventory. Previous studies (e.g., [5,16]) emphasize that solving the time-inconsistency problem of durable goods is to curb the product from flooding the market. Even so, the merit of decentralized procurement is not simply to reduce the sales quantities of durable goods in the market. When we prefer decentralized procurement, a better and more important reason is that decentralization can potentially induce the right sales (in terms of both quantities and prices) in accordance with the nature of durable goods. This can be clearly seen by comparing the outcome under decentralization to the wholesale prices pre-commitment policy.

On the other hand, even though we prefer to decentralized procurement for durable goods where each division decides its own sales quantities, this does not mean we expect a full decentralization, where each division chooses its own sales quantities and make pricing negotiation with supplier separately. With full decentralization, the discord behavior disappears and each division's chosen sales quantities just benefits its own wholesale price. In this way, full decentralization is equivalent to centralization in essence, and they have the same solutions. These arguments are formally summarized in the following proposition.

Proposition 3. *For a firm with multiple divisions in a two-period setting, its durable goods procurement under decentralization is preferred to* (***i***) *pre-commitment to wholesale prices by the supplier if and only if* $(9-\sqrt{41})/5 \le \delta \le 1$, (***ii***) *full decentralized procurement.*

Proof. For part (***i***), when the supplier makes a commitment to wholesale prices, the first-period wholesale price equals to the second-period one, i.e., $w_1 = w_2$, which means the sales quantities no longer impact w_2. Returning to the backward induction steps employed in the proof of Proposition 1 under centralized and decentralized procurements, the differences are that the wholesale price in the two periods is fixed and the second-period wholesale price can't be chosen by the supplier. We find that the equilibriums under both centralized and decentralized procurements are the same. The firm's profit when the supplier pre-commits to wholesale prices is:

$$F_w = \begin{cases} \dfrac{(-8\delta^5+35\delta^4+230\delta^3-1240\delta^2+440\delta+2768)na^2}{16[(6-\delta)(2\delta-\delta^2+4)]^2}, & 0<\delta<\dfrac{9-\sqrt{41}}{5} \\ \dfrac{na^2}{4(1+\delta)}, & \dfrac{9-\sqrt{41}}{5} \le \delta \le 1 \end{cases} \tag{15}$$

Here, when $(9-\sqrt{41})/5 \le \delta \le 1$, $q_2^i = 0$, which means the firm has to choose to provide units in period 1 and zero in period 2. Hence, from (14) and (15), we find that $\breve{F} - F_w|_{\delta=0} < 0$ and $d[\breve{F} - F_w]/d\delta < 0$, for $0 < \delta < (9-\sqrt{41})/5$; $\breve{F} - F_w|_{\delta=(9-\sqrt{41})/5} > 0$ and $d[\breve{F} - F_w]/d\delta > 0$, for $(9-\sqrt{41})/5 \le \delta \le 1$. This proves that $\breve{F} - F_w > 0$ if and only if $(9-\sqrt{41})/5 \le \delta \le 1$.

As for part (***ii***), under full decentralized procurement, each division negotiates pricing with the supplier and obtains different wholesale prices, thus solving (1)(2) and (4)(6) at fixing $n = 1$ yields the solution. In other words, the outcome is the same to the one under centralized procurement in Proposition 1. From Proposition 2, part (***ii***) holds as well. ■

From the proof of Proposition 3 (***i***), when $(9-\sqrt{41})/5 \le \delta \le 1$, $q_2^i = 0$. This special case corresponds to an intial one-time supply strategy which is introduced by Gilbert and Jonnalagedda [25] to mitigate cosumer's hold-up problem where the manufacturer commits to shutting down production of her durable goods after an initial one-time sale. In such case, solving the first-order condition of (4) and (6) under centralization or (9) and (11) under decentralization with the added constraint that $q_2^i = 0$ yields identical profit for the firm, $F_I = na^2/[4(1+\delta)]$. Again, we verify that $\breve{F} - F_I|_{\delta=0} > 0$ and $d[\breve{F} - F_I]/d\delta > 0$. Thus, we have $\breve{F} - F_I > 0$. This indicates that decentralized procurement is also preferred to initial one-time supply strategy by the supplier.

We can see that if preventing durable goods from flowing to the market is the only concern, decentralization is not as good as pre-commitment to wholesale prices or initial one-time supply strategy. As it turns out, decentralized procurement is still preferred to these alternatives, because of its ability to maintain moderate sales quantities in each period.

Proposition 3 also indicates the conditions for decentralized procurement to outperform centralized procurement. First of all, the supplier should have the right to make the wholesale price decision for profit maximization. Otherwise, if the supplier pre-commits on a constant wholesale price for both periods, centralization and decentralization will have no difference as shown in Proposition 3 (***i***). Secondly, under decentralization, the supplier should set a uniform wholesale price for all divisions and allow each division to choose their own quantity independently. However, if the supplier can set a different wholesale price for each division and the divisions choose their quantities, then this means a move toward full decentralization. As such, decentralization will yield the same outcomes as under centralization as indicated in Proposition 3 (***ii***).

As confirmed above, decentralized procurement for durable goods is indeed better in a two-period setting. Based on these results, the intuition suggests that procurement decentralization is also better than centralization in three or more periods. One may even guess that benefits of decentralized procurement increase when the firm's decision horizon is longer. We next analyze the setting of three or more periods using numerical simulations.

5. Numerical simulations for multiple periods

5.1. Iterative procedure

Our goal here is to compare procurement centralization and decentralization of the firm taking into account any number of periods. To this end, one approach is to extend the backward induction processes to multiple periods. Specifically, an iterative procedure is designed to solve the general T period problem, $T \ge 2$. In the last period T, the selling price p_T^i of durable good just reflects the consumer's valuation as a new product. As for any $t = T-1, T-2, \cdots, 1$ period, the selling price p_t^i of durable good reflects not only present valuation as a new good but also future benefits as a used good. Thus, by working backwards in the sequence, we first determine the equilibrium in period T and then that in the $t = T-1, T-2, \cdots, 1$ period.

Under the $T \ge 2$ period setting, the consumer's valuation of durable goods in period $t = 1, 2, \cdots, T$ for division i is $r_t^i = a - \delta^{t-1}q_1^i - \delta^{t-2}q_2^i - \cdots - q_t^i = a - \sum_{k=1}^{t}\delta^{t-k}q_k^i$. Hence, the selling price of durable goods in period t for division i is $p_t^i = r_t^i + r_{t+1}^i + r_{t+2}^i + \cdots + r_T^i = \sum_{j=t}^{T} r_j^i = (T-t+1)a - \sum_{j=t}^{T}\sum_{k=1}^{j}\delta^{j-k}q_k^i$. The following notations are also defined: division i's profit is D_t^i; the supplier's profit is S_t and the firm's profit is $F_t = nD_t^i$.

5.1.1. Iterative procedure for centralized procurement

Step 1. *Equilibrium game in Period T.*

Step 1.1: Solving $\max_{q_T^i, i=1,\cdots,n} F_T = \sum_{i=1}^{n}(p_T^i - w_T)q_T^i$ reveals period T sales quantities of $q_T^i(\mathbf{q_{T-1}}, w_T)$, where $\mathbf{q_{T-1}}$ is the vector of retail quantities in period $1, 2, \cdots, T-1$ for each market.

Step 1.2: Using $q_T^i(\mathbf{q_{T-1}}, w_T)$ and solving $\max_{w_T} S_T = \sum_{i=1}^{n} w_T q_T^i(\mathbf{q_{T-1}}, w_T)$ yields the supplier's period T wholesale price, $w_T = w_T(\mathbf{q_{T-1}})$.

Step 1.3: Plugging $w_T(\mathbf{q_{T-1}})$ and back substituting, the firm's and supplier's profit functions become $F_T(\mathbf{q_{T-1}})$, $S_T(\mathbf{q_{T-1}})$.

Step 2. *Iterative steps from* $t = T-1$ to 1.

Table 2
Centralized procurement vs. decentralized procurement.

T	δ	Centralized procurement $\widehat{q}_1^i(\times a)$	$\widehat{q}_L^i(\times a)$	$\widehat{w}_1(\times a)$	$\widehat{w}_L(\times a)$	$\widehat{F}(\times a^2)$	Decentralized procurement $\breve{q}_1^i(\times a)$	$\breve{q}_L^i(\times a)$	$\breve{w}_1(\times a)$	$\breve{w}_L(\times a)$	$\breve{F}(\times a^2)$
3	0.1	0.5229	0.2388	1.1630	0.4776	3.2096	0.5230	0.2387	1.1601	0.4775	3.2255
	0.5	0.3331	0.1959	1.2115	0.3918	2.1135	0.3366	0.1952	1.1668	0.3903	2.2306
	0.9	0.2085	0.1658	1.261	0.3316	1.4159	0.2137	0.1641	1.1376	0.3281	1.6095
5	0.1	0.6883	0.2386	1.5297	0.4772	8.9069	0.6880	0.2386	1.5289	0.4771	8.9183
	0.5	0.4064	0.1820	1.6236	0.3640	5.3528	0.4069	0.1813	1.5803	0.3626	5.6065
	0.9	0.1907	0.1241	1.8469	0.2482	2.6411	0.1916	0.1224	1.5413	0.2448	3.2577
7	0.1	0.7810	0.2386	1.7355	0.4772	16.6359	0.7808	0.2386	1.7350	0.4771	16.6429
	0.5	0.4534	0.1783	1.8283	0.3565	9.8606	0.4526	0.1776	1.8029	0.3552	10.1874
	0.9	0.1809	0.0999	2.3072	0.1999	4.0073	0.1773	0.0988	1.8349	0.1977	5.2323
Ave.	–	0.4184	0.1847	1.6119	0.3693	6.0160	0.4189	0.1839	1.4986	0.3678	6.3234

Step 2.1: Given the period $t+1$ outcome, solving $\max_{q_t^i, i=1,\cdots,n} F_t = \sum_{i=1}^n (p_t^i - w_t) q_t^i + F_{t+1}(\mathbf{q_t})$ reveals period t sales quantities of $q_t^i(\mathbf{q_{t-1}}, w_t)$.

Step 2.2: Plugging $q_t^i(\mathbf{q_{t-1}}, w_t)$ in the supplier's profit function and solving $\max_{w_t} \quad S_t = \sum_{i=1}^n w_t q_t^i(\mathbf{q_{t-1}}, w_t) + S_{t+1}(\mathbf{q_{t-1}}, q_t^i(\mathbf{q_{t-1}}, w_t))$ yields the supplier's period t wholesale price, $w_t = w_t(\mathbf{q_{t-1}})$.

Step 2.3: Using $w_t(\mathbf{q_{t-1}})$ and back substituting, the firm's and supplier's profit functions become $F_t(\mathbf{q_{t-1}})$,$S_t(\mathbf{q_{t-1}})$.

Step 3. *Output the results*. Working backward to period 1, the supplier's first-period wholesale price $\widehat{w}_1$ is obtained. Using this equilibrium wholesale price and back substituting yields the equilibrium outcomes under centralized procurement.

5.1.2. Iterative procedure for decentralized procurement

Step 1. *Equilibrium game in Period T:*

Step 1.1: Solving $\max_{q_T^i} D_T^i = (p_T^i - w_T) q_T^i$ reveals period T sales quantities of $q_T^i(\mathbf{q_{T-1}}, w_T)$.

Step 1.2: Using $q_T^i(\mathbf{q_{T-1}}, w_T)$ and solving $\max_{w_T} \quad S_T = \sum_{i=1}^n w_T q_T^i(\mathbf{q_{T-1}}, w_T)$ yields the supplier's period T wholesale price, $w_T = w_T(\mathbf{q_{T-1}})$.

Step 1.3: Plugging $w_T(\mathbf{q_{T-1}})$ and back substituting, division i's and supplier's profit functions become $D_T^i(\mathbf{q_{T-1}})$,$S_T(\mathbf{q_{T-1}})$.

Step 2. *Iterative steps from* $t = T-1$ to 1

Step 2.1: Given the period $t+1$ outcome, solving $\max_{q_t^i} D_t^i = (p_t^i - w_t) q_t^i + D_{t+1}^i(\mathbf{q_t})$ reveals period t sales quantities of $q_t^i(\mathbf{q_{t-1}}, w_t)$.

Step 2.2: Plugging $q_t^i(\mathbf{q_{t-1}}, w_t)$ in the supplier's profit function and solving $\max_{w_t} \quad S_t = \sum_{i=1}^n w_t q_t^i(\mathbf{q_{t-1}}, w_t) + S_{t+1}(\mathbf{q_{t-1}}, q_t^i(\mathbf{q_{t-1}}, w_t))$ yields the supplier's t period wholesale price, $w_t = w_t(\mathbf{q_{t-1}})$.

Step 2.3: Using $w_t(\mathbf{q_{t-1}})$ and back substituting, division i's and supplier's profit functions become $D_t^i(\mathbf{q_{t-1}})$,$S_t(\mathbf{q_{t-1}})$.

Step 3. *Output the results*. Working backward to period 1, the supplier's first-period wholesale price $\breve{w}_1$ is obtained. Using this equilibrium wholesale price and back substituting yields the equilibrium outcomes under decentralized procurement.

5.2. Numerical results

The iterative procedure is coded in Matlab 2015 to conduct numerical simulations. A series of numerical examples are designed below to illustrate the analytical results in Sections 4.2 and 4.3 and obtain more managerial insights.

5.2.1. Comparison of centralization versus decentralization

In this subsection, the results of numerical simulations are presented to compare the centralized procurement and decentralized procurement and check the robustness of Proposition 2 for settings of any number of periods. We choose δ =0.1, 0.5 and 0.9 to represent low, medium and high durability, respectively. Under this setting, the instances are generated with periods of T =3, 5 and 7. Fixing the number of firm's divisions to be 6, i.e., $n = 6$, the numerical results are summarized in Table 2, which lists first-period sales quantities (q_1^i), last-period sales quantities (q_L^i), first-period wholesale price (w_1), last-period wholesale price (w_L), and firm's profit (F).

Table 2 indicates that in settings with three periods or more, compared with centralized procurement, decentralized procurement usually leads to more sales quantities in first period and less sales quantities in last period. Simultaneously, it also brings with wholesale price reductions in all periods, achieving average reductions of up to 7.03% in first-period wholesale price and 0.41% in last-period wholesale price. As a result, decentralized procurement contributes to a substantial improvement of the firm's profit. As a matter of fact, an average of 5.11% profit growth can be achieved. These results show that as in two-period setup, decentralized procurement under longer periods can still make a better tradeoff between the cost of under-procurement in earlier periods and the commitment benefits gained in later periods.

Table 2 also implies that the benefit of decentralized procurement will increase as the product durability increases. To elaborate, we define the firm's relative profit improvement of decentralization versus centralization as $\Delta Fc = (\breve{F} - \widehat{F})/\widehat{F}$. Fig. 1 examines the effect of product durability on the firm's profits under centralized and decentralized procurements. Not surprisingly, it shows that the firm's profit itself will decrease in product durability. However, the firm's relative profit improvement will increase in product durability, especially in longer periods. For example, in the seven-period setting, the relative profit improvement will increase significantly from 0.04% to 44.26% when the product durability varies from 0.1 to 1. These results in the multi-period settings serve to show the robustness of the result in Proposition 2 (***ii***).

Fig. 2 shows the effect of the number of divisions on the firm's profits under centralized and decentralized procurements in a setting of seven periods. It indicates that as n increases, the relative profit improvement will increase, especially for higher level of product durability. For example, when $\delta = 0.9$, the relative profit improvement ranges from about 17% (for two divisions) to about 36% (for twenty divisions). This part verifies that the results of Proposition (***i***) can be generalized to longer period settings.

Fig. 3 exhibits the effect of decision horizon on the firm's profit under centralized and decentralized procurements. Fig. 3 indicates that the firm's profit will steadily increase with increasing decision horizon. However, the relative profit improvement may decrease

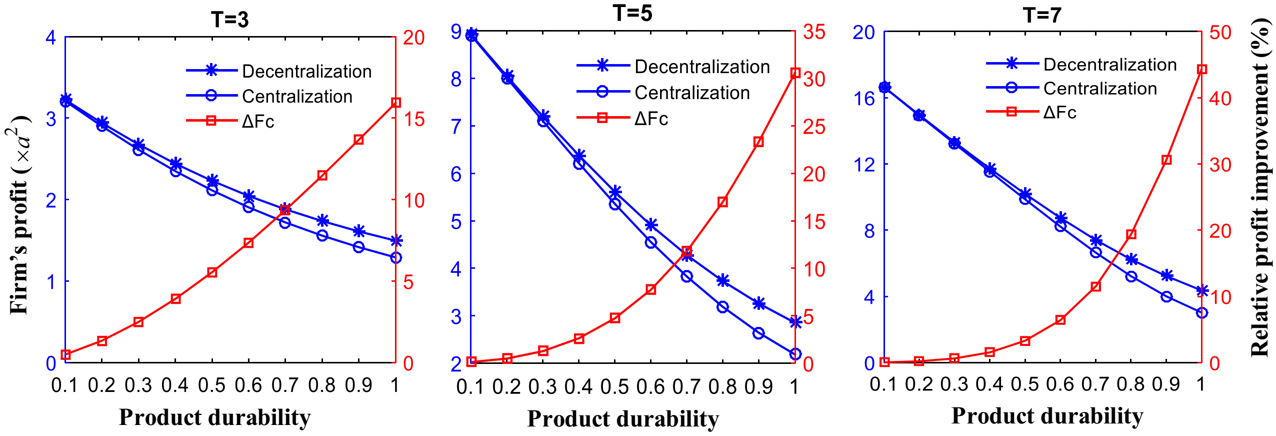

Fig. 1. Effect of product durability on the firm's profit under centralization vs. decentralization.

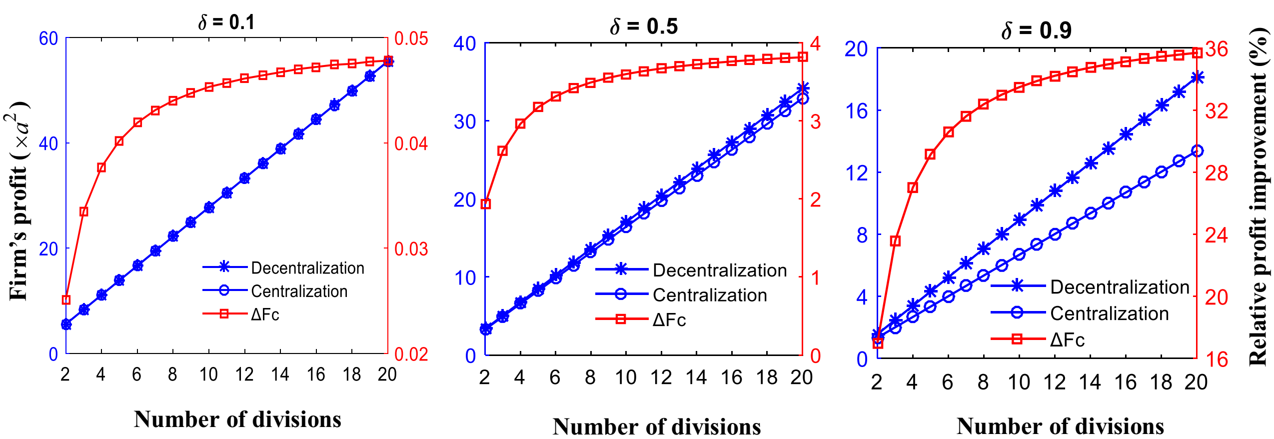

Fig. 2. Effect of the number of divisions on the firm's profit under centralization vs. decentralization.

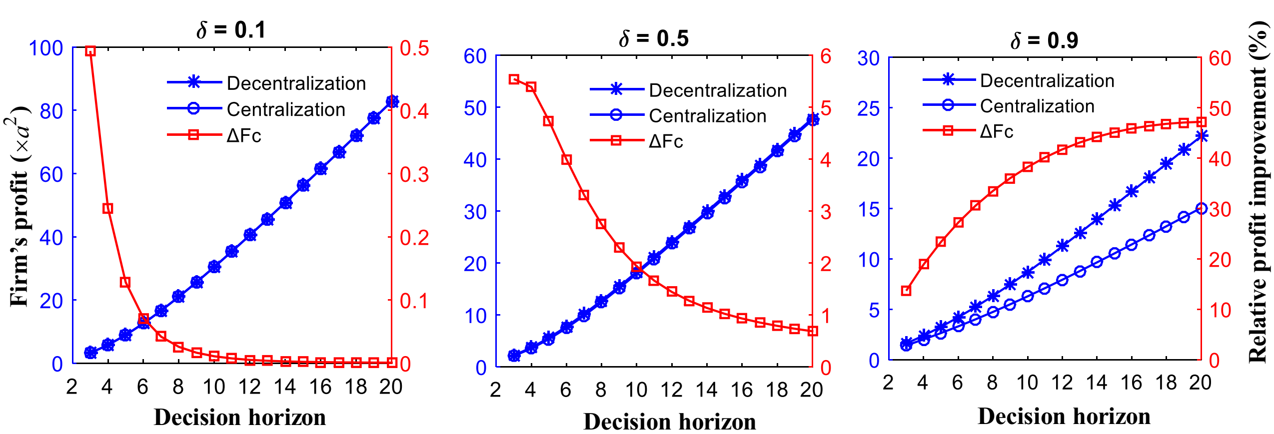

Fig. 3. Effect of decision horizon on the firm's profit under centralization vs. decentralization.

or increase, depending on the product durability. As the decision horizon increases, we note that in low durability level, the relative profit improvement will drop rapidly, and the differences of centralization and decentralization become not substantial; in medium durability level, the relative profit improvement still decrease, but the trend becomes slow; as for high durability level, the relative profit improvement begins to gradual increase. Responding to our previous thinking, these results suggest that whether the benefits of decentralized procurement will increase with the increasing decision horizon is closely related to the level of product durability. In other words, the higher is the product durability, the more the benefits of decentralized procurement can obtain as the decision horizon increases. The underlying reason is that the used products with low-level and medium-level durability become obsolete faster as the number of periods increases, which leads to the decrease in the benefit of decentralized procurement. However, the used products with high-level durability can last longer. Thus, the benefits of decentralized procurement can keep increasing.

Due to the fact that centralized procurement is equivalent to full decentralized procurement as mentioned in Proposition 3 (***ii***), the above results also verify that decentralized procurement is preferred to full decentralized procurement in longer period setting.

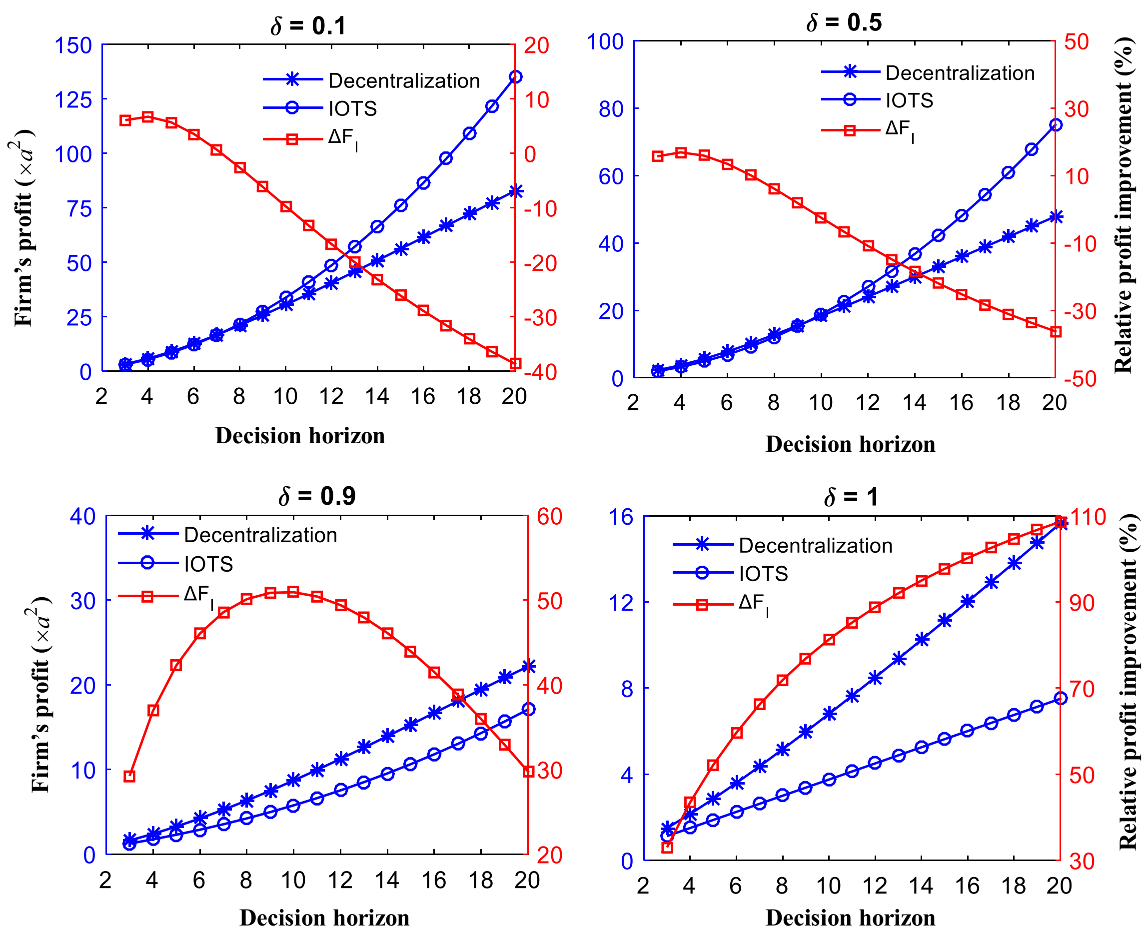

Fig. 4. Effect of decision horizon on firm's profit under IOTS vs. decentralization.

In the same way, as pre-commitment to wholesale prices and initial one-time supply policy in Proposition 3 are identical when the product durability surpasses a threshold, we only need to compare decentralized procurement with initial one-time supply policy (denoted as IOTS) under longer periods.

5.2.2. Comparison of IOTS versus decentralization

Similar to the previous setting, we set the number of divisions to be $n = 6$, and define the firm's relative profit improvement of decentralization versus IOTS as $\Delta F_I = (\breve{F} - F_I)/F_I$. Since the sales quantities from period 2 to period T are zero when employing initial one-time supply policy, a general $T(T \geq 2)$ period problem reduces to solving for the period 1 procurement level. Again, using backward induction, when the supplier carries out the initial one-time supply policy, any T period firm's profits under both centralization and decentralization are the same, that is: $nT^2a^2/(16\sum_{m=1}^{T}\delta^{m-1})$. From the formulation of firm's profit under IOTS, we can see that given division numbers n, firm's profit will increase in decision horizon T but decrease in product durability δ.

Fig. 4 displays the effect of decision horizon on firm's profits under IOTS and decentralization. As decision horizon extends, the firm's profits under both IOTS and decentralization increase. However, the firm's relative profit improvement has different performance with the variation of product durability levels. When the product durability is low ($\delta = 0.1$), the relative profit improvement will decrease with increasing decision horizon. While the decision horizon reaches to the eight periods, the observed relative profit improvement begins to be negative. Similar situation appears in medium product durability ($\delta = 0.5$), even though the negative turning point is delayed to ten-period horizon. It shows that when the product durability is not high, decentralized procurement is preferred to IOTS only in shorter decision horizons. A potential explanation for this observation is that the profit of decentralized procurement increases in product durability, but the profit of IOTS decreases in product durability, and the used product will become obsolete as decision horizon surpasses a threshold for low or medium durability. When the product durability is high ($\delta = 0.9$), decentralized procurement become more significantly preferred to IOTS with longer decision horizon. Moreover, it is interesting to find that the relative profit improvement initially increases and then decreases. The reason is that due to the high durability, the used products can last more periods as almost new ones at the beginning. But they will eventually deteriorate at last. Once the product is perfect durable ($\delta = 1$), we observe that the relative profit improvement is significantly and positively correlated with decision horizon. Hence, we can summarize that decentralized procurement is preferred in short decision horizon and/or in high product durability level. It appears that the benefits of decentralized procurement will increase as decision horizon extends only when the high durability product is considered in short period settings or the product is closely perfect durable.

6. Conclusion and future research

Industry practitioners and academic researches usually hold the convention wisdom that centralized procurement is better for firms. Decentralized procurement is typically viewed as underperforming because of disparate interests and mutual conflicts. This

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paper proves that such convention wisdom may be false. In particular, our study demonstrates that decentralization can actually prove to be useful when a firm with multiple horizontal divisions procures durable goods from an external supplier. With durable goods, there comes with time-inconsistency dilemma, which has been extensively studied in the literature (e.g., [15,30]). In this paper, we show that the dilemma of durable good procurement can be alleviated by seemingly inefficient division conflicts. Specifically, when a firm procures durable goods to sell them in distinct retail markets, it is better off to leave these decisions to respective division managers. Though the supplier generally tries to increase the wholesale prices to fight back, decentralized procurement strategy will encourage each division to purchase more in earlier periods and less in later periods as wholesale prices decrease. As a result, right sales quantities in each period end up with lower pricing between the firm and its supplier.

Our findings have several implications for durable goods procurement. First, our findings suggest that as long as the product is durable, horizontal decentralization can significantly enhance the profit of a firm with multiple divisions. This is a more practical means than contracts and arrangements as organization forms (centralization vs. decentralization) are more readily established and credibly observed. Second, our results highlight that the benefit of decentralization always increases in durability and the number of divisions. To some degree, this may strengthen the firm's willingness to invest in durability and market segmentations, and thereby improving customer services. Third, our results suggest that some mechanisms of restricting sales quantities by pricing or strictly initial one-time supply may not achieve positive effects on firm's profitability. Excessive restrictions on quantities will increase firm's cost. However, although decentralization is appealing from the perspective of durable good procurement, we also stress that full decentralization is not desirable.

Last but not least, our results also have some implications for future research. One important direction is the design of supply chains for green and durable goods. We note that green products are oftentimes durable. It would be interesting to examine the optimal choice of centralization versus decentralization when procuring and selling green products. Another open issue for future research is the incorporation of information asymmetries regarding the durable goods problems. It is not yet clear how the firm can make the optimal procurement decisions without the exact knowledge of durability level. Contracts specifying wholesale prices or sale quantities may be necessary to successfully deal with these information asymmetries for durable good procurement. The third potential direction is to study the effects of strategic inventory on centralized and decentralized supply chain. We consider a fully centralized supply chain, where the supplier and the n divisions are all managed by a single firm. It is worth to investigate the optimal inventory decisions in the decentralized supply chain (under decentralized procurement or centralized procurement) deviate from that in the fully centralized supply chain.

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References

[1] Andersson J, Marklund J. Decentralized inventory control in a two-level distribution system. Eur J Oper Res 2000;127:483–506.
[2] An Q, Yan H, Wu J, Liang L. Internal resource waste and centralization degree in two-stage systems: an efficiency analysis. Omega 2016;61:89–99.
[3] Anupindi R, Bassok Y, Zemel E. A generalized framework for the study of decentralized distribution systems. Manuf Serv Oper Manage 2001;3:349–68.
[4] Arya A, Frimor H, Mittendorf B. Decentralized procurement in light of strategic inventories. Manage Sci 2015;61(3):578–85.
[5] Arya A, Mittendorf B. Benefits of channel discord in the sale of durable goods. Marketing Sci 2006;25:91–6.
[6] Belavina, E., Girotra, K. (2012). The benefits of decentralized decision-making in supply chains. Working Paper, INSEAD, Fontainebleau, France.
[7] Belavina E, Girotra K. The relational advantages of intermediation. Manage Sci 2012;58:1614–31.
[8] Bernstein F, Federgruen A. Decentralized supply chains with competing retailers under demand uncertainty. Manage Sci 2005;51:18–29.
[9] Bhaskaran SR, Gilbert S. Selling and leasing strategies for durable goods with complementary products. Manage Sci 2005;51(8):1278–90.
[10] Bhaskaran SR, Gilbert S. Implications of channel structure for leasing or selling durable goods. Marketing Sci 2009;28(5):918–34.
[11] Bhaskaran SR, Gilbert SM. Implications of channel structure and operational mode upon a manufacturer's durability choice. Prod Oper Manage 2015;24(7):1071–85.
[12] Bucovetsky S, Chilton J. Concurrent renting and selling in a durable goods monopoly under threat of entry. Rand J Econ 1986;17:261–78.
[13] Bulow J. Durable goods monopolists. J Polit Econ 1982;90(2):314–32.
[14] Bulow J. An economic theory of planned obsolescence. Q J Econ 1986;51:729–50.
[15] Coase R. Durability and monopoly. J Law Econ 1972;15:143–9.
[16] Desai P, Koenigsberg O, Purohit D. Strategic decentralization and channel coordination. Quant Marketing Econ 2004;2(1):5–22.
[17] Desai P, Purohit D. Leasing and selling: optimal marketing strategies for a durable goods firm. Manage Sci 1998;44(11):19–34.
[18] Desai P, Purohit D. Competition in durable goods markets: the strategic consequences of leasing and selling. Marketing Sci 1999;18(1):42–58.
[19] Downie R. Global consumer durables: exploring revenue trends and fundamentals; 2016. Report, Investopedia http://www.investopedia.com/articles/markets/052816/global-consumer-durables-exploring-revenue-trends-and-fundamentals.asp.
[20] Eppen GD. Effects of centralization on expected costs in a multi-location newsboy problem. Manage Sci 1979;25:498–501.
[21] Erzurumlu SS. The compatibility of durable goods with contingent generic consumables. Omega 2013;41(3):574–85.
[22] Fang L. Centralized resource allocation based on efficiency analysis for step-by-step improvement paths. Omega 2014;51:24–8.
[23] Greenspan R. Home depot's organizational structure analysis, New York: Panmore Institute; 2017. Report http://panmore.com/home-depot-organizational-structure-analysis.
[24] Gregory L. Toyota's organizational structure: an analysis, New York: Panmore Institute; 2015. Report http://panmore.com/toyota-organizational-structure-analysis.
[25] Gilbert SM, Jonnalagedda S. Durable products, time inconsistency, and lock-in. Manage Sci 2011;57(9):1655–70.
[26] Gupta A, Chen IJ, Chiang D. Determining organizational structure choices in advanced manufacturing technology management. Omega 1997;25(5):511–21.
[27] Investopedia. Durables; 2016. Report, Investopedia http://www.investopedia.com/terms/d/durables.asp.
[28] KPMG. Procurement advisory: next generation procurement, archieving growth and creating sustainable value, Amsterdam: KPMG International; 2016. Report https://home.kpmg.com/content/dam/kpmg/pdf/2016/04/sg-The-Procurement-Journey.pdf.
[29] KPMG/Economist Intelligence Unit. Beyond purchasing: next steps for the procurement profession, Amsterdam: KPMG International; 2008. Report https://www.kpmg.com/US/en/IssuesAndInsights/ArticlesPublications/Documents/beyondpurchasing.pdf.
[30] Lacourbe P. Durable goods leasing in the presence of exporting used products to an international secondary market. Eur J Oper Res 2016;250(2):448–56.
[31] Li KJ, Xu SH. The comparison between trade-in and leasing of a product with technology innovations. Omega 2015;54:134–46.
[32] Liu GW, Zhang JX, Tang WS. Strategic transfer pricing in a marketing–operations interface with quality level and advertising dependent goodwill. Omega 2015;56:1–15.
[33] Meijboom B, Obel B. Tactical coordination in a multi-location and multi-stage operations structure: a model and a pharmaceutical company case. Omega 2007;35(3):258–73.
[34] Munson C, Hu J. Incorporating quantity discounts and their inventory impacts into the centralized purchasing decision. Eur J Oper Res 2010;201:581–92.
[35] Schmitt AJ, Sun SA, Snyder LV, Shen ZJM. Centralization versus decentralization: risk pooling, risk diversification, and supply chain disruptions. Omega 2015;52:201–12.
[36] Smithson N. Ford motor company's organizational structure analysis, New York: Panmore Institute; 2017. Report http://panmore.com/ford-motor-company-organiza-tional-structure-analysis.

[37] Snyder LV, Shen ZJM. Managing disruptions to supply chains. In: Frontiers engrg.: reports on leading-edge engrg. 2006 sympos.. National Academies Press; 2007. p. 139–48.
[38] Su XM, Zhang FQ. Strategic customer behavior, commitment, and supply chain performance. Manage Sci 2008;54(10):1759–73 2008.
[39] Vagstad S. Centralized vs. decentralized procurement: does dispersed information call for decentralized decision-making. Int J Ind Organ 2000;18:949–63.
[40] Yang HJ. Impact of discounting and competition on benefit of decentralization with strategic customers. Oper Res Lett 2012;40(2):123–7.
[41] Yong J. Harley-Davidson's organizational structure analysis, New York: Panmore Institute; 2016. Report http://panmore.com/harley-davidson-organizational-structure-analysis.