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Retailer or e-tailer? Strategic pricing and economic-lot-size decisions in a competitive supply chain with drop-shipping

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Drop-shipping is an arrangement whereby an e-tailer, who does not hold inventories, processes orders and requests a manufacturer to ship products directly to the end customers. To explore the economic benefits of adopting drop-shipping distribution strategy in a competitive environment, we investigate the profitability and the efficiency of the drop-shipping channel as compared to the traditional channel. Specifically, we develop Economic Order Quantity (EOQ) games with pricing and lot-sizing decisions to examine the strategic interactions between a manufacturer and its retailer/e-tailer in the traditional/drop-shipping distribution channels. We identify conditions under which the drop-shipping channel profitably outperforms the traditional one. It is found that the economic interests of adopting drop-shipping distribution for the channel members may not always be consistent. There are cases where only the manufacture would favour drop-shipping. In this study, we also reveal that the inefficiency caused by lack of coordination in the traditional channel can be alleviated in the drop-shipping channel where the lot-sizing decision is made by the manufacturer.

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1. Introduction

The Internet has opened new opportunities for supply chain management, meanwhile posing challenges to the practice of traditional logistics strategies. Many new business initiatives have emerged to take advantages of the Internet by substituting or complementing the traditional channel of distribution with an innovative logistics strategy called the drop-shipping distribution. Drop-shipping distribution is an arrangement whereby an online retailer (henceforth, we call it an e-tailer for brevity) takes customer orders and requests a manufacturer/distributor to ship products directly to the end customers. Obviously, one distinguishing feature of such a distribution strategy is that an e-tailer, by shifting the inventory management burden to its manufacturers or suppliers, does not hold any inventory. A recent survey indicates that more than 30% of online-only retailers use drop-shipping as the primary way to fulfill orders (eRetailing World, 2000). It has also been reported that many companies in the information-technology hardware industry use drop-shipping to keep costs down (Fuscaldo, 2003). Could adopting the drop-shipping distribution indeed enhance channel profitability and distribution efficiency in a supply chain? If so, is such a logistics arrangement always desired by all channel members?

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Although adopting the drop-shipping distribution can result in a lower inventory-related cost, it may possibly discourage some potential demands as customers might find it too inconvenient to buy from an e-tailer due to, for example, the additional waiting time for product delivery. Moreover, as most supply chains operate as a collection of independent channel members whose respective profits are in conjunction with each individual firm's price and/or inventory decisions, the impact of adopting the drop-shipping distribution on the strategic interactions among channel members is ambiguous. Thus, it is not clear immediately whether the gain from a more effective inventory control can outweigh the loss caused by vertical channel competition in a supply chain. To enhance our understanding on the economic values of the drop-shipping strategy, the objective of this study is to develop analytical models that provide justifications on the circumstances when adopting drop-shipping distribution that could lead to significant business values in a competitive supply chain.

2. Related literature

Past studies have provided various valuable insights into the issues related to the implementation of drop-shipping distribution. In particular, based on the news-vendor type of inventory model, Netessine and Rudi (2006) examine the competition between a traditional channel and a drop-shipping channel and show that, in most cases, drop-shipping channel is more attractive than the traditional retail channel. Zhao and Cao (2004) investigate the competition between a zero-inventory e-tailer and a positive-inventory one, and they find that the former charges lower prices, though the price differential decreases if the market expands rapidly. Based on consumer heterogeneity, Pan *et al* (2002) study the channel competition and argue that the traditional retailer may provide better service, charge a higher price and earn greater profit than the pure-play e-tailer. Within a single-period framework, Khouja (2001) examines the mixed strategy in which e-tailers can use local inventory as a primary source and use drop-shipping for backup. Under different sources of uncertainty (eg demand variability and lead-time variability), Ayanso *et al* (2006) develop a simulation model to provide the implications for Internet retailers to leverage the drop-shipping fulfillment choice with an inventory rationing policy.

One of the key issues differentiating this work from the previous studies reviewed above is the lot-size decision. From this point of view, our study is related to the EOQ literature on joint pricing and production decisions. The EOQ model has been widely studied in single-firm optimization but not in a competitive environment. Whitin's paper (1955) is one of the earliest works considering the joint pricing and production decisions in an EOQ framework. Kunreuther and Richard (1971) investigate the interrelationship between the pricing and inventory decisions for a retailer who orders products from an outside distributor. Abad (1988) extends the work of Kunreuther and Richard (1971) on considering the case when the supplier offers all-unit quantity discounts. Lee (1993) presents a geometric programming (GP) approach to finding a profit-maximizing selling price and ordering quantity for a retailer. In the multi-period, discrete-time model, constant price through the whole planning horizon has been shown optimal under some conditions (Kunreuther and Schrage, 1973; Gilbert, 2000; Van den Heuvel and Wagelmans, 2006). With different model assumptions, dynamic prices during different periods have also been widely studied (Thomas, 1970; Kim and Lee, 1998; Zhao and Wang, 2002). Deng and Yano (2006) give a comprehensive review on joint decisions about price and production quantity.

To the best of our knowledge, the economic benefits of drop-shipping distribution in an EOQ framework have not yet been explored in the literature. This study aims to fill the gap in the literature by developing stylized models to enhance our understanding of this essential subject. Specifically, we develop EOQ games with pricing and lot-sizing decisions to investigate the strategic interactions between upstream and downstream supply chain members in the traditional and drop-shipping distribution channels.

3. Model development

Consider a two-echelon supply chain where a contract manufacturer (henceforth, we will call this a manufacturer for brevity) distributes a standard product either through an independent retailer (traditional channel) or an independent e-tailer (drop-shipping channel). Like conventional EOQ models in the literature, we assume that the supply chain faces constant customer demands generated by a non-increasing price-dependent function. The retailer holds inventory to fulfill the customer demands at the retail store (see Figure 1(a)), whereas the e-tailer, who takes customer orders and initiates the delivery request, does not hold any inventory (see Figure 1(b)). When the e-tailer is adopted as the sales channel, all inventories are stored at the manufacturer and the product is shipped directly from the manufacturer to the end customer.

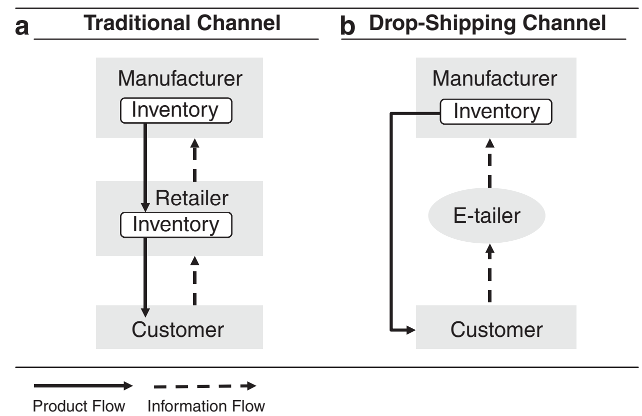

Figure 1 Channel structure. (a) Traditional channel; (b) Drop-shipping channel.

The basic notation used in our analysis is defined below:

- l: Manufacturer's production rate, measured by the amount manufactured in a unit time.
- G: Time span of the demand. It may contain multiple periods.
- d: The customer demand rate. It can be obtained by $d = D(p)/G$, where $D(p)$ is the customer demand over the time span G. $D(p)$ is a function of the retail price p. To assure all customer demand can be filled on time, we assume $l > d$.
- K: Manufacturer's production setup cost. It is a one-time cost during each production cycle, and it is independent of the production quantity.
- S: Retailer's ordering cost. Ordering cost occurs when the retailer orders products from the manufacturer. This cost is constant and is not related to the order quantity.
- h: Retailer's inventory holding cost rate. This cost rate is the retailer's cost of holding one unit value of the stock. It is usually calculated based on the interest rate.
- H: Manufacturer's inventory holding cost rate. This rate is similar to retailer's inventory holding cost rate.
- c: Manufacturer's unit cost of production. It includes the material purchasing cost, the assembling cost, etc.

Note that although the framework of model, which consists of a single manufacturer and a single retailer (e-tailer), is quite basic, it serves as a reasonable approximation for some real business context. For example, many contract manufacturers sell standard products exclusively through a brand-name retailer (eg, Osim does not produce massage chairs, but it distributes the products for the manufacturer with its own brand name). Although an exclusive retailer may operate multiple retail stores, in practice it may establish a regional warehouse to fill the demands from local stores. In such a context, the single manufacturer–retailer setup is considered applicable. In the case of drop-shipping, the single e-tailer assumption is less restrictive since e-tailers do not hold any inventory. As long as the manufacturer's standard product is distributed exclusively through a single e-tailer (or multiple e-tailers with product differentiations), the applicability of our model is justifiable.

3.1. The traditional channel

We start our analysis by formalizing the traditional manufacture–retailer channel. Following a common approach in the related EOQ literature (eg Whitin, 1955; Pekelman, 1974; Eliashberg and Steinberg, 1987; Abad, 1988), assume that the product demand in the traditional channel is a linear function of the retail price expressed by $D(p) = N - \beta p$, which reduces to

$$D(p) = N - p, \tag{1}$$

when the parameter β is normalized to 1 without loss of generality (the unit of measurement of quantity being arbitrary). The parameter N is a given constant which reflect the size of the market. Similar to the studies in the supply chain literature (eg, Monahan, 1984; Lal and Staelin, 1984; Li *et al*, 1996), suppose that the manufacturer adopts a lot-for-lot policy to fulfill the retailer's orders and the delivery lead-time is assumed to be negligible or constant without loss of generality. Past studies generally assume that, with the receipt of an order from the retailer, the manufacturer produces the required quantity of the product with an infinite production rate, so that the manufacturer does not hold any inventory as the product is immediately transferred to the retailer. However, this assumption is relaxed in our analysis. In particular, we assume that the manufacturer's production rate is a fixed constant larger than the demand rate, and thus the manufacturer also holds inventories and incurs the inventory holding cost. Figure 2 shows the relationships among the ordering, production and the inventory status of the manufacturer and the retailer.

In the traditional channel, both the manufacturer and the retailer bear inventory setup/ordering and holding costs. Since the channel is uncoordinated, the manufacturer and the retailer are independent decision makers, and each looks at its own profit when making decisions, ignoring the collective impact of their decisions on the channel as a whole. Following the conventional setting for a dyadic channel, we assume that the manufacturer is the Stackelberg game leader. Specifically, anticipating the retailer's choices, the manufacturer moves first in determining the wholesale price w. Given the manufacturer's decision in w, the retailer, as the follower,

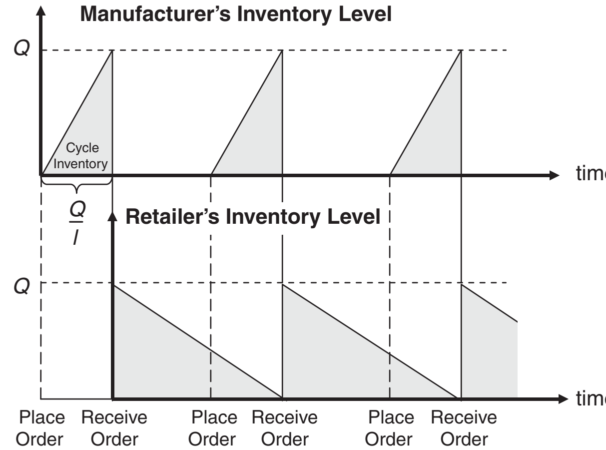

Figure 2 Inventory levels in the traditional channel.

decides the retail price p and the order quantity Q to maximize its profit given by

$$\pi_r(p, Q) = \underbrace{p(N-p)}_{\text{revenue}} - \underbrace{w(N-p)}_{\text{purchase cost}} - \underbrace{\frac{(N-p)}{Q}S}_{\text{ordering cost}} - \underbrace{\frac{Q}{2}hw}_{\text{holding cost}}. \tag{2}$$

The first-order conditions of (2) with respect to p and Q are

$$\begin{cases} N - 2p + w + \dfrac{S}{Q} = 0, \\ \dfrac{S(N-p)}{Q^2} - \dfrac{hw}{2} = 0. \end{cases} \tag{3}$$

The two equations in (3) characterize the retailer's best reaction to the manufacturer's wholesale price decision. Subject to (3), the problem for the manufacturer is to choose the wholesale price w which maximizes its profit given by

$$\pi_m(w) = \underbrace{w(N-p)}_{\text{revenue}} - \underbrace{c(N-p)}_{\text{production cost}} - \underbrace{\frac{(N-p)}{Q}K}_{\text{setup cost}} - \underbrace{\frac{Q(N-p)}{2Gl}Hc}_{\text{holding cost}}. \tag{4}$$

Note that unlike the retailer's holding cost (which resembles that in the traditional EOQ model), the manufacturer's holding cost depends on the total customer demand specified in (1) over the time span G. The detailed formulation of the holding cost item in (4) is given below:

$$\text{Holding Cost} = \text{Average Inventory} \times \text{Unit Holding Cost}$$
$$= \frac{\overbrace{Q^2/2l}^{\text{Cycle Inventory}} \times \overbrace{(N-p)/Q}^{\text{No. of Cycle}}}{\underbrace{G}_{\text{Time Span}}} \times Hc, \tag{5}$$

where the cycle inventory is the shaded area illustrated in Figure 2.

The equilibrium of the game corresponds to the solution of the manufacturer's problem, which is a non-linear optimization problem with non-linear constraints. To solve the problem, we first specify p and w as functions of Q based on (3):

$$\begin{cases} p(Q) = \dfrac{2NS + NQ^2h + SQh}{2(S + Q^2h)}, \\ w(Q) = \dfrac{NSQ - S^2}{hQ^3 + SQ}. \end{cases} \quad (6)$$

Plugging (6) into (4), we can then convert the manufacturer's profit function into the following single-variable function of Q:

$$\text{Maximize } \pi(w(Q)) = \frac{1}{2}\left(N - \frac{NQS - S^2}{QS + Q^3h} - \frac{S}{Q}\right) \times \left(\frac{NQS - S^2}{QS + Q^3h} - \frac{K}{Q} - \frac{cHQ}{2Gl} - c\right). \quad (7)$$

The problem now becomes an unconstrained optimization problem. It can be verified that the optimality condition of (7) is a six-degree polynomial equation of Q with the following 6×6 companion matrix:

$$\begin{bmatrix} & & & & & 2S^2Gl(cS/N - 2S - K)/Hch^2 \\ 1 & & & & & 4S^2(N^2lG - 2SGlh + SHc/2 - NGlc - KGlh)/NHch^2 \\ & 1 & & & & 3S^2(4Glh - Hc)/Hch^2 \\ & & 1 & & & 2SG(HcS/G - 2Klh - 2lN^2 - 2cNl)/NHch \\ & & & 1 & & 2(SGl/N + 2SH/h - KGl/c)H \\ & & & & 1 & \end{bmatrix} \quad (8)$$

The six roots of the polynomial equation, which are the local maximizers for the optimization problem, are the eigenvalues of the companion matrix in (8). Since there are at most six local rational maximizers, the global optimal solution can be easily identified after the local maximizers are found by any eigenvalue algorithm.

To understand the efficiency loss in the decentralized traditional channel, we also analyse the performance of the centralized traditional channel. The analysis is analogous, and thus the details are relegated to Appendix A for the interest of space.

3.2. The drop-shipping channel

To analyse the performance of the drop-shipping channel, assume that the e-tailer faces the constant demand generated by an analogous non-increasing price-dependent function. Specifically, the demand function for the drop-shipping channel is defined as

$$D(p) = N - \theta p, \quad (9)$$

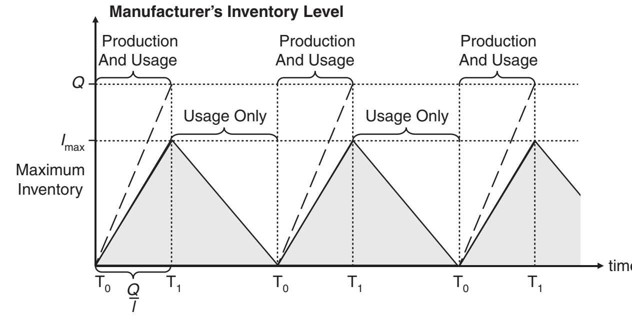

Figure 3 Inventory level in the drop-shipping channel.

where the parameter θ, called the *drop-shipping refusal factor*, represents the relative demand sensitivity to the price as compared to that in the traditional channel (c.f. Chiang *et al*, 2003 for a similar justification of the demand function). When $\theta = 1$, customers are indifferent between the two channels. A higher value of θ implies a lower convenience level of dropping-shipping to customers. With the same price, the demand in the drop-shipping channel is lower [higher] than that in the traditional channel if $\theta > 1$ [$\theta < 1$]. When $\theta = 1$, customers are indifferent between the two channels. Note that Similar to the 'acceptance level' in Chiang *et al* (2003), the 'refusal factor' in this study is used to distinguish customers' attitudes towards the traditional (brick and mortar) retailer and the e-tailer. The rationale behind is that consumers' willingness-to-pay price will be affected by various channel attributes, which include product found is in stock, physical examination of products, immediate possession of products, uncertainty about getting the right item, accepts all forms of payment, helpfulness of salespeople, post-purchase service, exchange-refund policy for returns, ability to compare products, speed of selection and purchase, charges for shipping and handling, etc. Therefore, even if the e-tailer (who does not hold any inventory for immediate possession by customers) can display the product to customers in a physical space, customers' attitudes towards the two shopping channels may not be identical.

When the drop-shipping channel strategy is adopted, inventories are held by the manufacturer only. The e-tailer receives the orders from the customers and requests the manufacturer to ship the product directly to the customers. Figure 3 shows the production and inventory status of the manufacturer. At the beginning of each production cycle T_0, the manufacturer sets the targeted production quantity to be run size Q. During the production and usage period (from T_0 to T_1), the manufacturer produces and delivers the product to customers. Note that if the demand rate were zero, the inventory would accumulate at a rate as shown by the dash line. However, due to the positive demand rate, the actual inventory increase rate, as illustrated by the bold solid line, is lower than that with a zero demand rate. Therefore, at the end of each production cycle T_1, the maximum inventory is smaller than the run size Q. In the usage only period (T_1 to T_0), the manufacturer consumes the remaining inventory to fulfill the customers' orders.

Again, to obtain the equilibrium result in the decentralized channel, we start with solving the retailer's problem. Subsequently, we solve the manufacturer's problem, taking into account the reaction function of the retailer. The manufacturer, as the game leader, decides the wholesale price w and the production quantity Q in the first stage of the game. Given the manufacturer's decisions, the e-tailer sets the retail price p to minimize its profit given by

$$\pi_r(p) = (p - w)(N - \theta p). \tag{10}$$

It is straightforward to verify that the optimal retail price is

$$p = \frac{N + \theta w}{2\theta}. \tag{11}$$

Anticipating the e-tailer's best price response in (11), the manufacturer, by choosing w and Q, maximizes its profit specified by

$$\begin{aligned}\pi_m(w, Q) &= \underbrace{(N - \theta p)w}_{\text{revenue}} - \underbrace{(N - \theta p)c}_{\text{production cost}} - \underbrace{\frac{(N - \theta p)}{Q}K}_{\text{setup cost}} - \underbrace{\frac{I_{\max}}{2}Hc}_{\text{holding cost}} \\ &= \frac{N - \theta w}{2}\left(w - c - \frac{K}{Q}\right) - \frac{(2Gl - N + \theta w)Q}{4Gl}Hc, \end{aligned}\tag{12}$$

where $I_{\max}$ is the maximum inventory illustrated in Figure 3. Specifically,

$$I_{\max} = \frac{Q}{l}(l - d) = \frac{Q}{l}\left(l - \frac{N - \theta_p}{G}\right) = \frac{(2Gl - N + \theta w)Q}{2Gl}.$$

Based on (12), the first-order conditions of the manufacturer's optimization problem are

$$w^*(Q) = \frac{1}{2}\left(\frac{K}{Q} + \frac{N}{\theta} + c - \frac{HQc}{2Gl}\right), \tag{13}$$

$$Q^* = \sqrt{\frac{2GlK(N - \theta w)}{Hc(2Gl - N + \theta w)}}. \tag{14}$$

Substituting (13) into (12) results in the following single-variable profit function of Q:

$$\pi_m(Q) = \frac{N - \theta w^*(Q)}{2}\left(w^*(Q) - c - \frac{K}{Q}\right) - \frac{(2Gl - N + \theta w^*(Q))Q}{4Gl}Hc. \tag{15}$$

It can be verified that (15) is convex-concave, and thus we develop below a similar line-search algorithm proposed by Abad (1988) to obtain the global optimal solution.

Step 1: Let $k = 0$ and $Q^0 = \infty$.
Step 2: Compute $w^*(Q^k)$ using Equation (13).
Step 3: Compute Q^{k+1} using Equation (14).
Step 4: If $|Q^{k+1} - Q^k| < \varepsilon$, stop. Otherwise let $k = k + 1$ and go to Step 2.

The analysis of the centralized drop-shipping channel is detailed in Appendix B.

4. Numerical experiments

Based on the models developed, we conduct numerical experiments to gain more insights into the difference between the traditional and drop-shipping channels. To better generalize the results, we study 2400 cases formed by the combinations of the following parametric values: $h = H \in \{0.02, 0.04, 0.06, 0.08, 0.1\}$, $G \in \{30, 40, 50, 60\}$, $S \in \{10\,000, 13\,000, 16\,000, 19\,000\}$, $K \in \{30\,000, 60\,000, 90\,000, 120\,000, 150\,000, 180\,000\}$, $l \in 60, 90, 120, 150, 180\}$. The study first focuses on the case when the two alternative distribution channels are equally convenient to customers, that is, the drop-shipping refusal factor $\theta = 1$. Table 1 summarizes the results of equilibrium decisions and the subsequent profits for each member.

The results indicate that the discrepancy of retail prices between the two channels is not very considerable, but the

Table 1 Equilibrium decisions and profits

	Minimum	*Maximum*	*Average*
Traditional channel			
Wholesale price	1610	1657	1633
Ordering quantity	281	886	494
Retail price	2326	2346	2332
Profit: Retailer	6724	14 752	10 094
Profit: Manufacturer	7790	29 122	17 427
Profit: Total	14 588	43 780	27 521
Drop-shipping channel			
Wholesale price	1652	1679	1663
Production quantity	1194	8028	3291
Retail price	2326	2340	2332
Profit: Retailer	7272	15 146	10 617
Profit: Manufacturer	13 817	29 964	20 622
Profit: Total	21 088	45 111	31 239

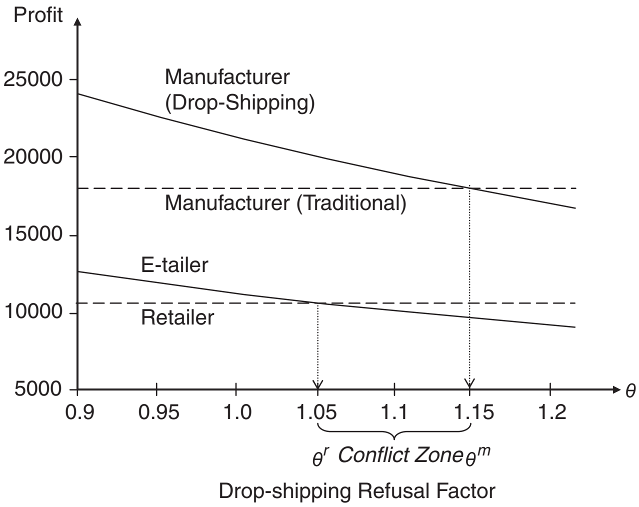

Figure 4 Impact of drop-shipping refusal factor on channel profitability.

average wholesale price in the drop-shipping channel is significantly higher than that in the traditional channel. Although the e-tailer is charged a higher wholesale price than the retailer, with the advantage of holding no inventory, the average profit of the e-tailer is 5.18% higher than that in the traditional retailer. We also find that the average profit of the manufacturer in the drop-shipping channel is 18.33% higher than that in the traditional channel. This is mainly because that the manufacturer in the drop-shipping channel enjoys the advantage of controlling the production quantity. We conclude that both channel members are better off with the drop-shipping strategy when the customers are indifferent between the drop-shipping and the traditional channels ($\theta = 1$).

Intuitively, the gains from adopting the drop-shipping strategy will be offset when the drop-shipping refusal factor θ is too high. Now we investigate the impact of the drop-shipping refusal factor θ on channel performance. Different values of θ, ranging from 0.9 to 1.2 with step value 0.05, are used in the analysis. Figure 4 illustrates the profits for the retailers and the manufacturers in the two different distribution channels. Not surprisingly, the results show that the corresponding profits for the manufacturer and the e-tailer both decrease with the drop-shipping refusal factor θ in the drop-shipping channel. Note that, in Figure 4, θ^m and θ^r represent the average threshold values of adopting the drop-shipping distribution for the manufacturer and the e-tailer, respectively. When $\theta > \theta^m$ [$\theta > \theta^r$], the manufacture [e-tailer] would prefer the traditional distribution strategy as the drop-shipping distribution is too inconvenient for customers. Our analysis indicates that $1 < \theta^r < \theta^m$, and thus both channel members are better off with drop-shipping distribution if $\theta < \theta^r$. When 12 the customers' drop-shipping refusal factor falls between θ^r and θ^m (identified as the conflict zone in Figure 4), the economic interests of adopting drop-shipping distribution for the channel members is conflicting.

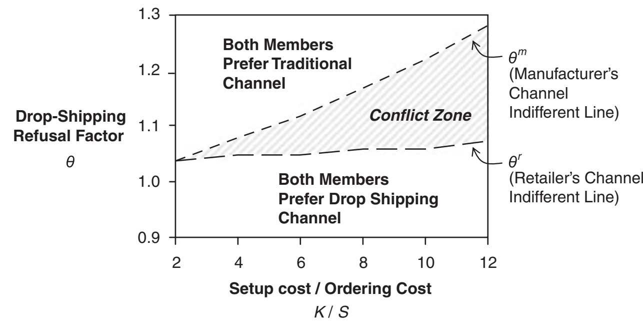

Figure 5 Impact of setup/ordering cost on channel choice.

5. Sensitivity analysis of channel choice

To generate more insights into how the interplays of various parameters in the model affect the channel preferences for the manufacturer and the retailer, in this section, we conduct sensitivity analyses to illustrate the impacts of setup/ordering cost and inventory holding cost rate on the threshold values of adopting the drop-shipping distribution. Note that unless otherwise noted, the same parametric values in section 3 are used for the analysis.

5.1. Effect of setup/ordering cost

In this part of the analysis, we identify the threshold values of adopting the drop-shipping distribution with respect to different ratios of the setup cost to the ordering cost (K/S ratio). The result, illustrated in Figure 5, indicates that while the *K/S* ratio does not appear to significantly affect the retailer's channel preference, the manufacturer's threshold values of adopting the drop-shipping distribution θ^m increases with the *K/S* ratio. It implies that the manufacturer could benefit more from adopting drop-shipping distribution when the setup cost is high. This is to be expected since the inventory-related cost reduction is more considerable with a higher unit setup cost K in the drop-shipping channel in which the manufacture has full control over the lot-size decision.

In Figure 5, the manufacturer's and the retailer's channel indifferent lines divide the $K/S - \theta$ plane into three regions. The shaded area depicts the conflict zone where the manufacturer prefers the drop-shipping channel whereas the retailer, on the contrary, prefers the traditional channel. Obviously, the likelihood for the manufacturer to favour the drop-shipping distribution is higher.

5.2. Effect of holding cost rate

Recall that one of the main differences between the traditional channel and the drop-shipping channel is that the e-tailer in the drop-shipping channel does not hold any inventory. When

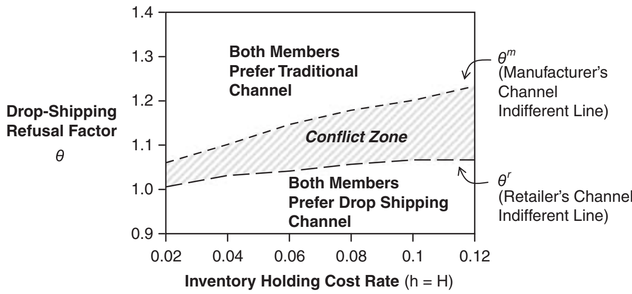

Figure 6 Impact of inventory holding cost rate on channel choice.

Table 2 Competition penalty

	Centralized	*Decentralized*	*Competition penalty*
Traditional channel			
Ordering quantity	5658	494	
Retail price	1667	2332	
Channel profit	41 146	27 521	33.25%
Drop-shipping channel			
Production quantity	5308	3291	
Retail price	1655	2332	
Channel profit	42 002	31 239	25.62%

would it be more profitable for the channel members to have the manufacturer carry all the burden of holding inventory? Now we answer this question by examining the impact of inventory holding cost rate on the channel preference for the manufacturer and the retailer.

Figure 6 illustrates the channel preferences for the manufacturer and the retailer under various inventory holding cost rates. Similar to the effect of the *K/S* ratio, we find that the manufacturer's threshold values of adopting the drop-shipping distribution θ^m are consistently higher than the retailer's threshold values θ^r. A higher inventory holding cost rate generally corresponds to higher values of θ^m and θ^r, though the impact of the inventory holding cost rate on θ^r is relatively insignificant. Again, the result indicates that likelihood for the manufacturer to favour the drop-shipping distribution is higher. The manufacturer's and the retailer's channel indifferent lines divide Figure 6 into three regions and the conflict zone where only the manufacturer prefers the drop-shipping channel is identified in the shaded area.

6. Analysis of channel efficiency

The overall channel profit in a decentralized supply chain, due to the competitive decision-making process, is typically lower than that in a centralized supply chain where the system performs at the optimal level. To measure the channel efficiency of the two decentralized channels proposed in this study, we define the *competition penalty* as the difference in the overall supply chain profits between a decentralized solution and the centralized (system optimal) solution, measured as a percentage of the optimal profit.

With same parametric values specified above, Table 2 reports the competition penalty for the traditional channel and the drop-shipping channel. We find that the total channel profit of the decentralized traditional channel is 33.25% lower than the centralized traditional channel. On the other hand, the total channel profit of the decentralized drop-shipping channel is, on average, 26% lower than the centralized drop-shipping channel. Apparently, the significant discrepancy in the competition penalty implies that the drop-shipping channel is relatively more efficient than the traditional channel given that the customers are indifferent between

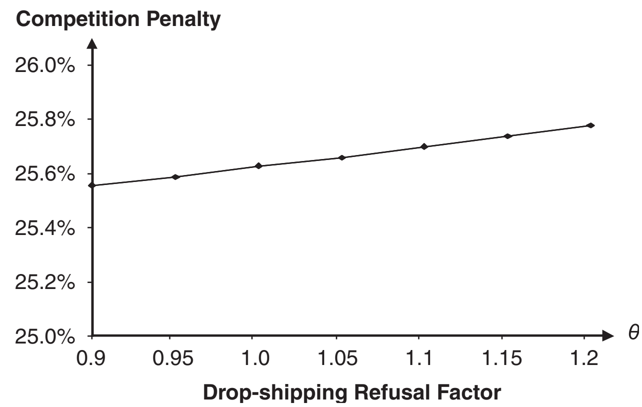

Figure 7 Impact of drop-shipping refusal factor on competition penalty.

the two channels ($\theta = 1$). In other words, the inefficiency caused by vertical channel competition in the traditional channel is alleviated in the drop-shipping channel where the manufacturer takes full control over the lot-sizing decision. Our further analysis indicates that the competition penalty of the drop-shipping channel increases with θ (see Figure 7), though the increase rate is not very substantial.

7. Concluding remarks

The objective of this study is to explore the economic benefits of adopting drop-shipping distribution in a competitive environment. We develop EOQ games with joint pricing and lot-sizing decisions to investigate the strategic interactions between a manufacturer and its retailer/e-tailer in the traditional/drop-shipping distribution channels under various scenarios. From the perspective of each channel member, we identify the conditions under which the drop-shipping channel outperforms the traditional channel in terms of profitability.

Different from that in the traditional channel where the lot-sizing decision is made by the retailer, the manufacturer in the drop-shipping channel takes full control over the lot-sizing decision as the e-tailer does not hold inventory. The result of our analysis indicates that although both channel members could benefit from drop-shipping distribution under some conditions, the manufacturer has a higher likelihood to favour the drop-shipping distribution. Additionally, comparison of the two alternative channels in terms of the difference in the profits between a competitive (decentralized) solution and the system optimal (centralized) solution reveals that the drop-shipping channel is more efficient than the traditional one. This implies that the inefficiency caused by lack of coordination in the traditional channel can be alleviated by adopting drop-shipping distribution. Another implication from our result is that when designing a contract to coordinate a channel with the drop-shipping distribution, the manufacturer has more bargaining power in division of cooperative profit (especially when the scenario occurs in the conflict zone).

Although the game-theoretical model developed in this paper can be viewed as the primitive prototype in examining the pricing and lot-sizing decisions with the drop-shipping distribution, we recognize that it is limited in many respects. Future research topics extending this study are possible in various ways. For example, we consider only one manufacture and one retailer/e-tailer in our model. Although the stylized model is applicable in some situations and the result is justifiable for the insight-oriented investigation, it should be useful to extend the analysis by exploring different channel structures. Another restriction of our model is that it only considers single-product situations. Although such a setting provides a starting point for investigating the problem, studies seeking to tackle multi-product situations will be warranted. In this study, the demand is modelled as a function of the retail price and is deterministic. It should be informative to incorporate other variables, such as the service level or sales effort in to the demand function. The investigation of the impact of demand variability would also be of interest. Finally, because of the change in scale economies, product transportation costs could vary with different distribution arrangements. We ignore such costs due to the complex nature of the problem. Incorporating relevant transportation costs in to the analysis would certainly be valuable.

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Appendix A. The centralized traditional channel

The profit function of the centralized traditional channel is given by

$$\Pi(p,Q) = \underbrace{p(N-p)}_{\text{revenue}} - \underbrace{c(N-p)}_{\text{production cost}} - \underbrace{S\frac{N-p}{Q}}_{\text{ordering cost}} - \underbrace{K\frac{N-p}{Q}}_{\text{setup cost}} - \underbrace{\frac{HQc(N-p)}{2Gl} - \frac{Qhc}{2}}_{\text{holding cost}}$$

$$= \left(p - \frac{S}{Q} - \frac{K}{Q} - c\right)(N-p) - \frac{HQc(N-p)}{2Gl} - \frac{Qhc}{2}. \tag{A.1}$$

The first-order condition with respect to p, Q are:

$$\begin{cases} \dfrac{\partial \Pi}{\partial p} = N - 2p + c + \dfrac{K+S}{Q} + \dfrac{HQc}{2Gl}, \\ \dfrac{\partial \Pi}{\partial Q} = \dfrac{(K+S)(N-p)}{Q^2} - \dfrac{Hc(N-p)}{2Gl} - \dfrac{hc}{2}. \end{cases} \tag{A.2}$$

Then we have the following relationship between the retail price and the ordering quantity:

$$\begin{cases} p^*(Q) = \dfrac{N+c}{2} + \dfrac{K+S}{2Q} + \dfrac{HQc}{4Gl}, \\ Q^* = \sqrt{\dfrac{2Gl(K+S)(N-p)}{(hGl + Hp - HN)c}}. \end{cases} \tag{A.3}$$

The optimal solutions of p, Q are inter-related. Then we have:

$$\Pi_1(Q) = (p^*(Q) - c)(N - p^*(Q)) - (K+S)\frac{N - p^*(Q)}{Q} - \frac{HQc(N - p^*(Q))}{2Gl} - \frac{Qhc}{2}. \tag{A.4}$$

The profit function $\Pi_1(Q)$ is a convex-concave function of Q. A line-search algorithm specified below can be applied to find the optimal solution for the problem:

Step 1: Let $k = 0$ and $Q^0 = \infty$.

Step 2: Compute $p^*(Q^k) = \dfrac{N+c}{2} + \dfrac{K+S}{2Q^k} + \dfrac{HQ^k c}{4Gl}$,

Step 3: Compute $Q^{k+1} = \sqrt{\dfrac{2Gl(K+S)(N - p^*(Q^k))}{(hGl + Hp^*(Q^k) - HN)c}}$.

Step 4: If $|Q^{k+1} - Q^k| < \varepsilon$, stop. Otherwise let $k = k+1$ and go to Step 2.

Appendix B. The centralized drop-shipping channel

The profit function of the centralized drop-shipping channel is given by

$$\Pi(p,Q) = \underbrace{(N - \theta p)}_{\text{revenue}} - \underbrace{(N-\theta p)c}_{\text{production cost}} - \underbrace{\frac{N - \theta p}{Q}K}_{\text{setup cost}} - \underbrace{\frac{HQc(Gl - N + \theta p)}{2Gl}}_{\text{holding cost}}. \tag{B.1}$$

The first-order condition with respect to p, Q are:

$$\begin{cases} \dfrac{\partial \Pi(p,Q)}{\partial p} = N - 2\theta p + \theta c + \dfrac{K\theta}{Q} - \dfrac{HQ\theta c}{2Gl}, \\ \dfrac{\partial \Pi(p,Q)}{\partial Q} = \dfrac{K(N-\theta p)}{Q^2} - \dfrac{H(Gl - N + \theta p)c}{2Gl}. \end{cases} \tag{B.2}$$

Similar to the previous analysis, we have the following relationship between the retail price and the production plan:

$$\begin{cases} p = \left(N + \theta c - \dfrac{HQ\theta c}{2Gl} + \dfrac{K\theta}{Q}\right) \Big/ (2\theta), \\ Hc(Gl - N + \theta p)Q^2 = 2GlK(N - \theta p). \end{cases} \tag{B.3}$$

Then we get:

$$\Pi_1(Q) = (p^*(Q) - c)(N - \theta p^*(Q)) - K\frac{N - \theta p^*(Q)}{Q} - \frac{HQc(Gl - N + \theta p^*(Q))}{2Gl}. \tag{B.4}$$

It can be verified that this objective function is also a convex-concave function. A similar line-search algorithm in Appendix A can be applied to find the optimal solution.

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