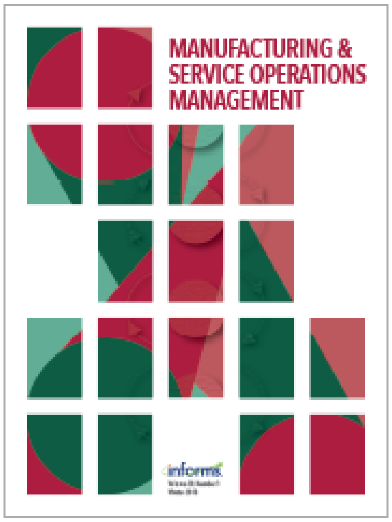

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The Effect of Probabilistic Selling on Channel Dynamics in Supply Chains

Scott Fay,[a,*] **Shahryar Gheibi**[b]

[a] Whitman School of Management, Syracuse University, Syracuse, New York 13244; [b] School of Business, Siena College, Loudonville, New York 12211

*Corresponding author

Contact: scfay@syr.edu, https://orcid.org/0000-0002-6694-9169 (SF); sgheibi@siena.edu, https://orcid.org/0000-0002-1067-4442 (SG)

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Abstract. ***Problem definition*:** Probabilistic selling (PS) is a business model whereby, in addition to selling transparent products, a firm sells an opaque good, which is unknown to buyers until after purchase. We examine how PS affects retailer-manufacturer interactions in markets for physical goods and how upstream competition impacts channel members' incentives to facilitate PS. ***Methodology/results*:** Using a Hotelling-based model of a multiproduct retailer, we find that a retailer maximizes its profit by assigning equal probability to each product even when the products have different wholesale prices. We also find that PS mitigates the inefficiencies caused by the double-marginalization problem. Although the potential benefit from PS is greater for a decentralized channel than for a centralized one, the market conditions for which PS arises are narrower for a decentralized channel. Furthermore, PS shifts channel power toward the manufacturer. However, it is possible for a win-win-win outcome to arise in which the manufacturer, retailer, and consumers benefit from PS. As expected, upstream competition shifts channel profit toward the retailer. However, competition also has surprising effects: It shrinks, rather than expands, the viability of PS and makes it possible for each manufacturer to benefit from its rival's cost reduction. ***Managerial implications*:** A manufacturer should induce the retailer to offer an opaque good if its production costs are sufficiently low and the products are sufficiently close substitutes. It is optimal for the manufacturer to increase (decrease) its wholesale prices in response to the retailer's ability to offer opaque goods if product differentiation is low (modest). Setting a wholesale price below cost sometimes maximizes a manufacturer's profit. Furthermore, a retailer can achieve a strategic advantage by using products from multiple manufacturers to construct opaque goods. However, the retailer's ability to leverage this advantage is curtailed because its use of equal-probability assignments relaxes competition between manufacturers.

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1. Introduction

Probabilistic selling (PS) occurs when, in addition to offering transparent products, a seller offers an opaque good, the identity of which is hidden until the buyer pays for the product (Fay and Xie 2008). While the most prominent early applications of PS occurred in service industries (by travel companies such as Priceline and Hotwire), our focus is upon markets for physical products because of the growing prevalence of PS in such markets. In many current applications for physical products, a retailer sells items obtained from an independent manufacturer. For example, SwimOutlet.com offers numerous "grab bag" options for which the customer selects the desired brand, size, and swimsuit type (e.g., brief, jammer, or one-piece), but does not specify the exact color or print. One such option is a Sporti jammer youth swimsuit, size 22Y, for $17.96. SwimOutlet.com offers the same suits at a higher price, namely, $18.86, if the customer chooses the color and print.

The PS strategy has been utilized by both small and large retailers, and in a wide range of product categories. For instance, the University of Southern California (USC) bookstore offers a USC Trojans Women's Nike Mystery Tee for which customers specify a size and then receive a "random Women's Nike top," which could be a short-sleeve, long-sleeve, or tank top in either a cotton or Dri-Fit material (USC Bookstore 2022). Fox Airsoft offers various mystery boxes, which consist of a single item or a bundle of items, with bundles ranging in price from $25 to $1,000 (Fox Airsoft 2022). Buyers receive random airsoft or tactical items from the store's product assortment, such as BBs, patches, optics, cool gear, accessories, and swag, where the retail value of these items is guaranteed to meet or exceed the price of the mystery box. An example of Target using the PS strategy is its offering of a Toynk Fallout mystery box for $69.99, which consists of a Vault-Box themed gift box that contains a bundle of $100 worth of Fallout collectibles (Target 2022). In addition to offering opaque goods in the category of toys, Amazon implements PS in many other categories such as cosmetics, hardware, and collectibles, referring to them as blind bags, mystery bags, grab bags, or surprise bags. For instance, one can buy a random-colored small Meiyuuo cosmetic bag for $7.99, where the bag received will be blue, pink, navy blue, white marble, or leopard print (Amazon 2022). If customers want a specific color, they must pay a higher price (either $8.99 or $9.99 depending on one's preferred color). In each of these examples, the sets of items from which the opaque good is drawn have similar quality but differ on a taste dimension such as color or style. Thus, we focus our attention in this paper on products that are differentiated horizontally rather than vertically.

While the extant literature has shown PS to be a potentially profitable strategy for coordinated channels, this paper examines PS's impact on decentralized channel interactions between a retailer and its supplier(s). Specifically, we examine the following research questions:

1. Is the advantage of PS larger in a decentralized channel or a centralized one? Does channel conflict expand or diminish the market conditions for which an opaque good is viable?

2. How does the retailer's ability to offer an opaque good alter its channel power relative to that of the manufacturer?

3. How does upstream competition between manufacturers influence the impact of PS on the allocation of profit across channel members and on the retailer's incentive to adopt PS?

In addressing these research questions, we uncover several new important findings that contribute to the understanding of PS. First, we discover that PS can improve channel performance by mitigating the demand distortion caused by double marginalization, but that PS is less likely to arise in decentralized channels relative to centralized ones despite this additional potential benefit. For transparent goods, it is well known that, when the retailer acquires products from outside suppliers, double marginalization can create channel conflict: When each channel member chooses its markup to maximize its own profit, inefficiently high prices lead to suboptimally low unit sales and total channel profit. In this paper, we find that the availability of an opaque good incentivizes the retailer to serve more customers. As a result, the profit increase from introducing an opaque good is greater for a decentralized than for a centralized channel, thus suggesting PS has the potential to be a more useful strategy in decentralized channels. However, to induce the retailer to offer an opaque good, the manufacturer must ensure that the retailer also gains from PS. The manufacturer's inability to retain the entire benefit of PS implies that the conditions under which PS arises in a decentralized channel are stricter than those in a coordinated channel. Thus, even though PS can improve channel performance (if it were to be adopted), we discover that channel conflict can prevent the introduction of opaque goods.

Second, we show that a retailer's capability to offer an opaque good may work to the benefit of the manufacturer and enable it to obtain a larger share of channel profit. When its products are sufficiently similar to each other, the manufacturer uses its enhanced channel power to charge higher wholesale prices. Interestingly, the manufacturer is able to obtain higher unit sales even at higher wholesale prices because, under PS, the retailer has an incentive to expand market coverage by targeting the opaque good to price-sensitive consumers. The higher wholesale prices can negatively impact the retailer's profit so severely that the retailer may be strictly worse off when PS becomes feasible. Specifically, if the products are sufficiently close substitutes, the retailer earns less profit when it is able, rather than unable, to offer an opaque good.

Although the preceding finding suggests that PS-facilitating technology can be detrimental to a retailer, our analysis indicates that, when the products that comprise the opaque good are sufficiently differentiated, the manufacturer lowers its wholesale prices (relative to the wholesale prices it would set if an opaque good were not feasible) in order to induce the retailer to offer an opaque good. In fact, when the products have substantially different production costs, the manufacturer may even sell one of its products for less than it costs to produce. Even when the availability of PS does not lead to negative margins, smaller markups on the wholesale prices lead to lower retail prices, which increase total sales and create a win-win-win outcome in which the introduction of an opaque good simultaneously increases each channel member's profit and also enhances consumer surplus.

Third, we find, surprisingly, that competition between manufacturers shrinks the market settings for which PS is viable. Upstream competition typically leads to lower wholesale prices, and a prerequisite for the retailer to offer an opaque good is that wholesale prices are sufficiently low. As a result, one would expect the retailer to be more likely to adopt PS when there are competing manufacturers. Thus, our finding that competition reduces the set of market conditions under which PS arises is particularly interesting and unexpected.

This counterintuitive result arises because, when the products have different production costs, a monopolist manufacturer uses its two wholesale prices to maximize the combined profit of both products, whereas, with competition, each manufacturer has only one lever, that is, the wholesale price of its own product, to maximize its profit. As a result, a monopolist manufacturer may set a low (or even negative) margin for the high-cost product in order to induce the retailer to offer an opaque good because PS boosts sales of the low-cost (high-margin) product; that is, the retailer now procures additional units of the low-cost product to meet demand for the opaque good. In contrast, with competition, the high-cost manufacturer is not willing to provide the profit-reducing subsidy that would be needed to induce the retailer to adopt PS. As a result, when the products are moderately differentiated and differ in their costs of production, an opaque good is not offered in the presence of upstream competition while it is offered in its absence. For example, while SwimOutlet.com could conceivably offer a grab bag that includes either a Sporti- or a TYR-branded swimsuit instead of using only swimsuits from the brand Sporti, the retailer may not profit from creating an opaque good from such combinations.

Despite upstream competition shifting channel power toward the retailer, we discover that manufacturers strictly benefit from a retailer's addition of an opaque good to its product mix whenever it is an equilibrium for the opaque good to be offered. This finding is driven by the fact that a retailer has an incentive to maximize opacity of the opaque good in order to price-discriminate most effectively on the basis of consumers' strength of preferences. As a result, the retailer splits demand for the opaque product equally across the two products even when the products have different wholesale prices. Making such balanced assignments dampens the intensity of competition between manufacturers, thus enabling them to share in the profit gains and generating a win-win outcome for all channel members. Furthermore, the mutual benefit manufacturers obtain from sales of the opaque good creates a form of coopetition in which, interestingly, a manufacturer's profit can increase when its rival's production cost decreases.

The remainder of the paper is organized as follows. Section 2 provides a literature review. Section 3 describes our model; Section 4 contains our core analysis of a centralized channel and a decentralized channel. Section 5 examines upstream competition; Section 6 concludes by discussing managerial implications and identifying areas for future research.

2. Literature Review

Our research contributes to several strands of the literature. Previous research identifies facilitation of price discrimination on the basis of heterogeneity in consumers' strengths of preferences as the fundamental source of the profit advantage of PS (Jiang 2007, Fay and Xie 2008, Anderson and Xie 2014). Improved capacity utilization and inventory management have been identified as another potential source of the profit advantage of PS (Gallego and Phillips 2004, Jerath et al. 2010, Chen et al. 2014, Wu and Wu 2015, Zhang et al. 2015, Wu and Jin 2022). In addition, PS can capitalize upon consumers' bounded rationality, for example, when consumers use anecdotal reasoning (Huang and Yin 2021) or are subject to a decoy effect (Zheng et al. 2019). Interestingly, PS can be a profitable mechanism both when consumers are overly optimistic (Huang and Yu 2014) and when they are pessimistic (Elmachtoub and Hamilton 2021) about their probability of receiving their less preferred product.

The key distinction of our paper from past research is that, although our model captures the PS ability to enhance price discrimination, we examine PS in a decentralized, uncoordinated channel. In contrast, previous research either assumes there is no intermediary (that is, all products are sold directly to consumers by the manufacturer (Jiang 2007, Fay and Xie 2008, Huang and Yu 2014, Zhang et al. 2015) or abstracts away any potential for channel conflict, for example, by assuming lump-sum transfer payments between channel members (Fay 2008) or that the manufacturer controls the retail price of the opaque good (Anderson and Xie 2014). By examining a decentralized channel, we uncover a new potential benefit of PS—mitigating channel inefficiencies that arise due to double marginalization. Furthermore, we find that channel conflict can prevent the adoption of PS even though the entire channel's benefits from PS are heightened.

In order to maintain focus on channel coordination issues, our model assumes that there are not any capacity constraints, consumers know the a priori probability of assignment of each product, and the distribution of consumers' valuations is known. Therefore, we can attribute our finding of heightened gains from PS solely to more efficient channel interactions rather than to improved capacity utilization, capitalization on consumers' bounded rationality, or mitigation of demand uncertainty.

The paper most closely related to ours is Jerath et al. (2010), which also incorporates a retailer (intermediary) into its model. Jerath et al. identify conditions whereby selling distressed inventory via an intermediary can be advantageous to last-minute selling through a direct channel. In contrast to our focus on physical products, their model applies to service markets, such as the travel industry, in which capacity constraints play a crucial role and profit sharing is a frequently employed tool for mitigating channel conflict. In addition, in their model, the intermediary sells only opaque goods and only after the manufacturer has used a direct channel to fulfill the demand for transparent products.

Therefore, since the retailer would not make any sales if opaque goods were not available, their model is not designed to address the impact of introduction of an opaque good on channel interactions. In contrast, our paper demonstrates that introducing an opaque good can improve channel coordination. Furthermore, by assuming the proportion of profit earned by each channel member is exogenous and immutable, Jerath et al. (2010) do not examine how an opaque good affects channel power, whereas a major contribution of our paper is that we demonstrate how PS alters channel power, specifically that it shifts it toward the manufacturer. We also show that although upstream competition shifts channel profit back toward the retailer, it has the surprising effect of shrinking, rather than expanding, the viability of PS.

In addition, our paper contributes to the literature regarding the optimal design of an opaque product. Previous research has explored how utilizing PS impacts the optimal quality levels (Zhang et al. 2015) and the extent of horizontal differentiation (Fay et al. 2015) of the transparent products. In contrast, we show that a retailer, in order to maximize its own profit, should construct the opaque good by using products from different manufacturers rather than multiple products from the same manufacturer. Furthermore, we find that a retailer should combine the products in equal proportions even if the products have different procurement costs.

Our paper also contributes to the extant literature regarding the pricing decisions. More specifically, previous papers have identified several situations in which a firm may strategically set a price below cost: dumping to liquidate inventory, using loss-leaders, predatory pricing, and protecting oneself against uncertainty in exchange rates (Rosenthal 1981, Cabral and Riordan 1994, Lal and Matutes 1994, Vogler et al. 2013, Park et al. 2016). We add to this literature by identifying another rationale for pricing below cost, namely, to induce retailers to offer an opaque good, which enables the manufacturers to benefit from the rise in the sales of their other products which do have positive profit margins.

3. Model

We develop a stylized model to represent market settings, such as those described in the Introduction, in which the retailer is a channel intermediary. We simplify the analysis by assuming that there are two products that can be used to construct the opaque good. Let v_{ji} be the value of product j (j = A, B) to consumer i. Valuations for the two products follow a Hotelling model in which the value for a consumer's ideal product is normalized to one, the fit-cost-loss coefficient equals t, where $0 < t \leq 1$, and the consumer's location on the Hotelling line is x_i.

Product A is located at 0, while product B is located at 1. The parameter t captures the extent of product differentiation, with smaller t representing products that are closer substitutes. When there is competition between manufacturers (discussed in Section 5), t serves as a proxy for the intensity of competition. Given these assumptions, consumer valuations for the two products are

$$v_{Ai} = 1 - tx_i, v_{Bi} = 1 - t(1 - x_i) \text{ where } x_i \sim U[0, 1]. \quad (1)$$

We assume each consumer purchases at most one unit of one good; that is, there is no value from consuming more than one product.

The cost of production of product j is c_j per unit, where $0 \leq c_B \leq c_A < c_B + t$ and the upper bound on c_A ensures that both products are profitable to sell. Under PS, the retailer (R) gives consumers the option to purchase product A at price P_A, product B at price P_B, or an opaque good at a price of P_o. The retailer decides whether a particular buyer of the opaque good will receive product A or product B. Let ϕ be the probability the retailer assigns product A as the opaque good. We assume that, although consumers who buy the opaque good do not know whether they will receive product A or product B, they do know the value of ϕ. Thus, they expect to receive product A with a probability of ϕ and product B with a probability of $1 - \phi$.

The assumption that ϕ is known by consumers at the time of purchase follows the literature, for example, Fay and Xie (2008), Zhang et al. (2015), Li and Ma (2016), Wang et al. (2017), Huang and Li (2018), and Anderson and Celik (2020). The motivation for this assumption is that consumers can learn about past assignments of the opaque good to others via online forums, social networks, and third-party websites. Thus, consumer expectations about assignments of the opaque good are likely to converge over time to the actual probability they will receive a specific product. This assumption ensures that a retailer's business strategy does not rely on consumers having biased expectations of true assignment probabilities.

The game proceeds in three stages: In Stage I, the manufacturer(s) sets the wholesale prices (w_j). In Stage II, the retailer sets the retail prices (P_j) and ϕ. In Stage III, consumers make their purchase decisions. Note that wholesale pricing is prevalent in many markets, especially for physical goods for which transportation from the production site to the end user is logistically complicated and it is very challenging for a manufacturer to track the revenue generated from each unit of merchandise. For instance, wholesale price contracts are extensively employed in the cosmetics, semiconductor, floriculture, and music industries (Chen et al. 2018, Hwang et al. 2018). More generally, Lariviere and Porteus (2001) assert that "many supply-chain transactions are governed by simple contracts defined only by a per-unit wholesale price" (p. 293) and Cachon (2003) argues that "the wholesale-price contract is worth studying because it is commonly observed in practice" (p. 238).

4. Analysis

4.1. Consumer Demand and the Retailer's Procurement Decision

We solve the game recursively. In Stage III, customers decide which good to purchase, if any, choosing the purchase option that yields the highest expected surplus net of price. A consumer chooses to purchase nothing if all available options yield a negative net surplus. Specifically, based on the product valuations given in Equation (1), consumer i's expected consumer surplus from buying product A is $CS_A = 1 - t\,x_i - P_A$, the expected consumer surplus from buying product B is $CS_B = 1 - t\,(1 - x_i) - P_B$, the expected consumer surplus from buying the opaque good is $CS_O = 1 - \phi\, t\, x_i - (1-\phi)\, t\,(1 - x_i) - P_o$, and the net surplus from purchasing nothing is normalized to zero. Demand from consumers will depend upon both the retail prices and the assignment probability ϕ. For expositional convenience, we focus on the setting where $\phi \le 1/2$ in the text (but analyze the entire range of ϕ in the appendix). As illustrated in Figure 1, consumers with $x_i \le \hat{x}_A$ purchase product A, while those with $x_i \ge \hat{x}_B$ purchase product B. Some, or all, of the consumers between these two marginal consumers purchase the opaque good. If the price of the opaque good is sufficiently low, the market is fully covered; that is, $x_o = \hat{x}_A$. Otherwise, a segment of consumers, with $x_i \in (\hat{x}_A,\ x_o)$, chooses to purchase nothing.

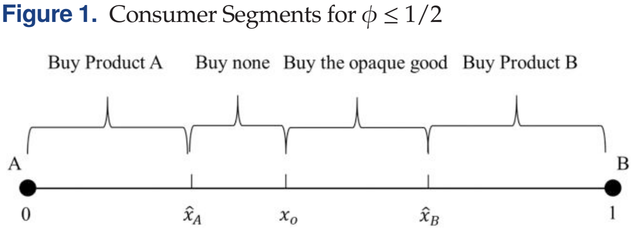
Thus, demand for product A is $\hat{x}_A$, demand for product B is $1 - \hat{x}_B$, and demand for the opaque good is $\hat{x}_B - x_o$, where (the proof of Proposition 1 details the derivations of these expressions)

$$\hat{x}_A = \frac{1 - P_A}{t}, \hat{x}_B = \frac{P_B - P_o + t\phi}{2t\phi}, \text{ and}$$
$$x_o = \frac{-1 + P_o + t(1-\phi)}{t(1-2\phi)}. \tag{2}$$

Taking into account the wholesale prices determined in Stage I, the retailer chooses P_A, P_B, P_O, and ϕ in Stage II to maximize its profit:

$$\begin{aligned}\Pi_R^{PS}(P_A, P_B, P_o, \phi) = (P_A - w_A)\hat{x}_A + (P_B - w_B)(1 - \hat{x}_B)\\ + (P_o - \phi w_A - (1-\phi)w_B)(\hat{x}_B - x_o)\end{aligned} \tag{3}$$
$$\text{s.t. } 0 \le \hat{x}_A \le x_o \le \hat{x}_B \le 1.$$

Figure 1. Consumer Segments for $\phi \le 1/2$



The retailer's profit-maximization problem yields the following result. (Throughout this paper, we mean "positive," "negative," "increase," and "decrease" in their weak sense, unless otherwise specified. The proofs of all propositions are provided in the appendix or the Online Appendix.)

Proposition 1 (Optimal Construction of the Opaque Good). *Even if the products have different wholesale prices, the retailer maximizes its profit by assigning equal probability to each product; that is,* $\arg\max_{\phi\in[0,1]} \Pi_R^{PS}\,(P_A, P_B,\ P_o, \phi) = \{1/2\}$ *whenever it chooses to adopt the PS strategy.*

Proposition 1 shows that the retailer constructs the product so that consumers receive product A with the same probability that they receive product B *if* it offers an opaque good. Such a decision mitigates the opaque good's cannibalization of transparent good sales by maximizing the degree of differentiation between the opaque and the transparent goods. Notably, the optimality of assigning equal probability to the products does *not* depend on wholesale prices being identical. Thus, even when one product is more costly for the retailer to acquire, the retailer satisfies demand for the opaque good by obtaining equal amounts of each product. This result is new to the literature. Fay and Xie (2008) show that equal assignments are optimal when both products have the same production cost. In contrast, Proposition 1 demonstrates that, when the products have different procurement costs, equal assignment remains optimal. Furthermore, notice that Proposition 1 does not guarantee that the retailer always offers an opaque good. Specifically, if one (or both) of the wholesale prices is (are) too high, the retailer chooses not to sell any units of the opaque good (which is achieved by setting prices such that$x_o = \hat{x}_B$).

4.2. Benchmark Case: Centralized Channel

Before analyzing the decentralized channel setting, we first consider the case of a centralized channel, that is, a channel in which a single firm produces and sells the two products. This case is solved by substituting $w_A = c_A$ and $w_B = c_B$ into Equation (3). The left section of Table 1 reports the results. If the products are substantially differentiated from each other, that is, $t > \bar{t}$, an opaque good is not offered. For levels of product differentiation below this threshold, the integrated firm offers an opaque good. Note that rearranging the condition $t \le \bar{t}$ can equivalently be stated as $c_A + c_B \le 2 - t$. Thus, for a given level of product differentiation, the integrated firm offers an opaque good as long as production costs are sufficiently low.

4.3. Decentralized Channel (Single Manufacturer)

Now consider the case of a decentralized channel in which a single manufacturer (M) produces both products. In Stage I, the manufacturer chooses its wholesale prices

Table 1. Equilibrium Prices and Profit in Centralized and Decentralized Channels

	Centralized channel		Decentralized channel	
	$t \le \bar{t}$	$t > \bar{t}$	$t \le \hat{t}$	$t > \hat{t}$
Wholesale prices	N/A	N/A	$w_A = 1 - \frac{2t - c_A + c_B}{4}$ $w_B = 1 - \frac{2t + c_A - c_B}{4}$	$w_A = \frac{1+c_A}{2}$ $w_B = \frac{1+c_B}{2}$
Retail prices	$P_A = 1 - \frac{t - c_A + c_B}{4}$ $P_B = 1 - \frac{t + c_A - c_B}{4}$ $P_o = 1 - \frac{t}{2}$	$P_A = \frac{1+c_A}{2}$ $P_B = \frac{1+c_B}{2}$	$P_A = 1 - \frac{2t - c_A + c_B}{8}$ $P_B = 1 - \frac{2t + c_A - c_B}{8}$ $P_o = 1 - \frac{t}{2}$	$P_A = \frac{3+c_A}{4}$ $P_B = \frac{3+c_B}{4}$
Manufacturer's profit	N/A	N/A	$\frac{8t\bar{t} + (c_A - c_B)^2 - 8t^2}{16t}$	$\frac{(1-c_A)^2 + (1-c_B)^2}{8t}$
Retailer's profit	N/A	N/A	$\frac{(c_A - c_B)^2 + 4t^2}{32t}$	$\frac{(1-c_A)^2 + (1-c_B)^2}{16t}$
Total channel profit	$\frac{4t\bar{t} + (c_A - c_B)^2 - 3t^2}{8t}$	$\frac{(1-c_A)^2 + (1-c_B)^2}{4t}$	$\frac{16t\bar{t} + 3(c_A - c_B)^2 - 12t^2}{32t}$	$\frac{3[(1-c_A)^2 + (1-c_B)^2]}{16t}$

Notes. Where $\bar{t} = 2 - c_A - c_B$ and $\hat{t} = \frac{2+\sqrt{2}}{4}\bar{t} < \bar{t}$. N/A, not applicable.

(w_A and w_B) to maximize its profit:

$$\Pi_M^{PS}(w_A, w_B) = (w_A - c_A)\left(\hat{x}_A + \frac{1}{2}(\hat{x}_B - x_o)\right) + (w_B - c_B)\left(1 - \hat{x}_B + \frac{1}{2}(\hat{x}_B - x_o)\right) \quad (4)$$

Table 1 also reports the equilibrium prices and resulting profits for the decentralized channel setting. The results have a similar structure as the case of a centralized channel, specifically that an opaque product is offered only if the degree of product differentiation is not too large. However, the threshold for offering an opaque good differs from that of the centralized channel.

4.4. Effect of Channel Conflict on the Profitability and Viability of PS

We now compare the viability and the impact of PS in a decentralized channel (*DC*) to that of a centralized channel (*C*). Proposition 2 summarizes the key insights from this comparison. We use superscript *TS* to denote traditional selling, that is, when no opaque good is offered, and subscript *TOT* to denote total profit.

Proposition 2 (Decentralized vs. Centralized Channel). *(a) The range of product differentiation and production costs under which opaque products are offered in a decentralized channel is smaller than in a centralized channel. Specifically, an opaque good is offered in a centralized (decentralized) channel if $t \le \bar{t}$ $(t \le \hat{t})$, or equivalently, if $c_A + c_B \le \bar{\varsigma}$ $(c_A + c_B \le \hat{\varsigma})$ where $\bar{\varsigma} = 2 - t$, $\hat{\varsigma} = 2 - 2(2 - \sqrt{2})t$, $\hat{t}$ and $\bar{t}$ are defined in Table 1, and $\hat{t} \le \bar{t}$ as well as $\hat{\varsigma} \le \bar{\varsigma}$. (b) However, in the range in which PS arises for both market structures, the resulting increase in total channel profit is greater for a decentralized than for a centralized channel; that is, $\Pi_{DC,TOT}^{PS} - \Pi_{DC,TOT}^{TS} \ge \Pi_{C,TOT}^{PS} - \Pi_{C,TOT}^{TS}$ $\forall\, t \le \hat{t}$.*

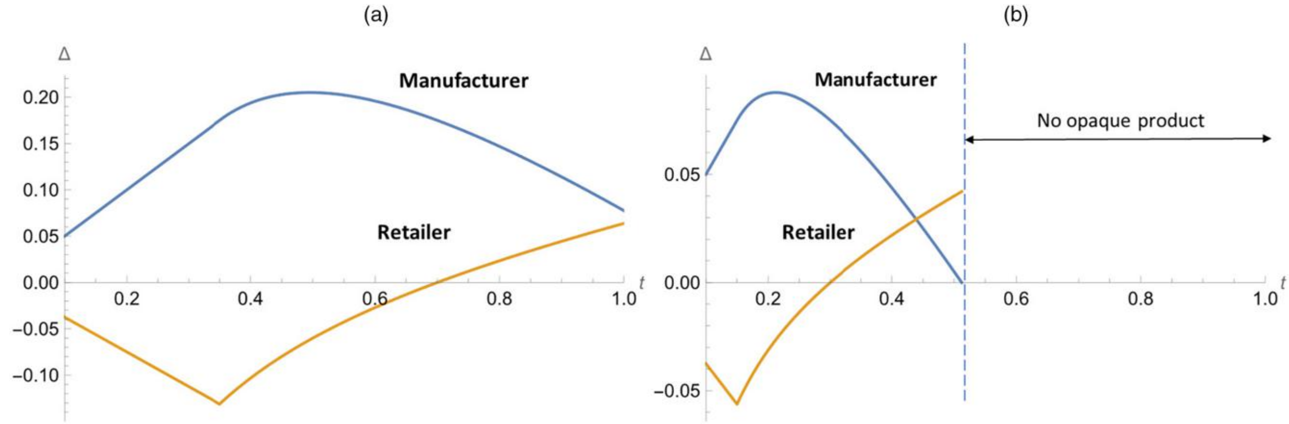
Proposition 2 shows that channel conflict alters the effectiveness of PS in contrastive and nuanced ways. On one hand, channel conflict can undermine the introduction of opaque goods. On the other hand, the increase in total channel profit arising from the introduction of an opaque good is greater for a decentralized than for a centralized channel.

PS is more effective at increasing total channel profit in a decentralized channel because PS reduces the distortion caused by double marginalization. Specifically, in a decentralized channel, double marginalization leads to unit sales being below the channel-wide optimal level. When an opaque good is introduced, it is sold to all consumers who do not purchase a transparent good (i.e., the consumers located in the middle of the Hotelling line). This market expansion is more pronounced for a decentralized channel where unit sales were originally lower, thus generating more total profit in that setting.

Despite this larger potential profit advantage in decentralized channels, Proposition 2(a) indicates that PS is less likely to be adopted in markets with channel conflict. This result arises because, even under PS, the double-marginalization problem is present for a decentralized channel; that is, both the manufacturer and the retailer set positive markups. Because of the retailer's positive profit margins, the manufacturer does not capture the full gains from the introduction of an opaque good and thus may be better off setting such high wholesale prices that the retailer chooses not to offer an opaque product.

Interestingly, the results in Table 1 indicate that channel performance under PS improves as the degree of cost asymmetry between the products decreases. Notice that, if $c_A = c_B$, total channel profit when the opaque good is present $(t \le \hat{t})$ is the same for a decentralized channel as for a centralized one, thus indicating that PS can eliminate the negative effects of channel conflict when the products have equal production costs. However, in the case of unequal costs $(c_A \ne c_B)$, total channel profit is strictly lower in a decentralized channel, with this deficit increasing in the difference between the two products' costs. Yet, Proposition 2(b) establishes that, even though PS is not able to eliminate

Figure 2. (Color online) Effect of PS on Profits



Notes. (a) Low costs ($c_A = 0.35$, $c_B = 0.25$). (b) Moderate costs ($c_A = 0.75$, $c_B = 0.65$).

entirely the negative effects of channel conflict when there are unequal costs, it still raises total profit more for a decentralized channel than for a centralized one.

We now focus on how the emergence of the PS strategy affects each supply chain member in a decentralized channel by comparing a market setting in which offering opaque goods is feasible with one in which it is impractical. Proposition 3 compares the results of the two market settings:

Proposition 3 (Impact of PS in a Decentralized Channel). *Although the retailer's ability to implement PS always increases the manufacturer's profit, it decreases the retailer's profit if the products are sufficiently close substitutes. Specifically,* $\Pi_M^{PS} > \Pi_M^{TS}$ *for* $t < \hat{t}$, *and* $\Pi_R^{PS} > \Pi_R^{TS}$ *if* $\bar{t}/2 \le t < \hat{t}$, *but* $\Pi_R^{PS} \le \Pi_R^{TS}$ *if* $t \le \bar{t}/2$.

It is critical to note that the manufacturer's wholesale price decision depends on whether the retailer is or is not able to offer an opaque good. The latter setting might arise due to logistical constraints or the retailer's lack of familiarity with PS. In the former setting, it is important to recognize that opaque goods are offered in equilibrium only if, *given the wholesale prices*, the retailer's profit is higher if it sells an opaque good than if it does not. In other words, the retailer offers an opaque product only if the manufacturer's wholesale prices make it beneficial to do so.

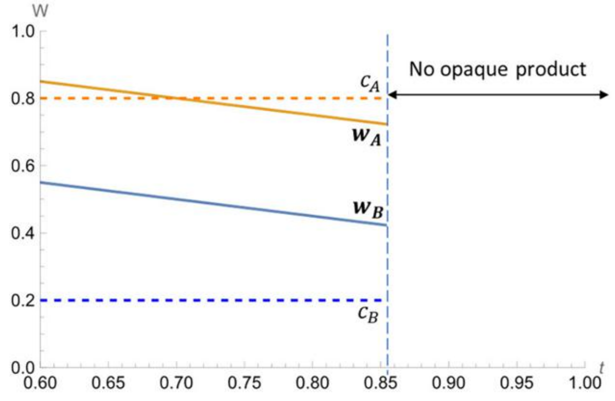
Our analysis of these two settings reveals that the emergence of PS typically shifts channel power toward the manufacturer. Figure 2 illustrates how each channel member's profit advantage (Δ) varies with the degree of product differentiation for two different cost levels. When costs are relatively low ($c_A = 0.35$, $c_B = 0.25$), both channel members benefit from the retailer's ability to offer an opaque good if $t > 0.7$. When costs are moderate ($c_A = 0.75$, $c_B = 0.65$), an advantage accrues to both channel members if $0.3 < t < 0.512$.

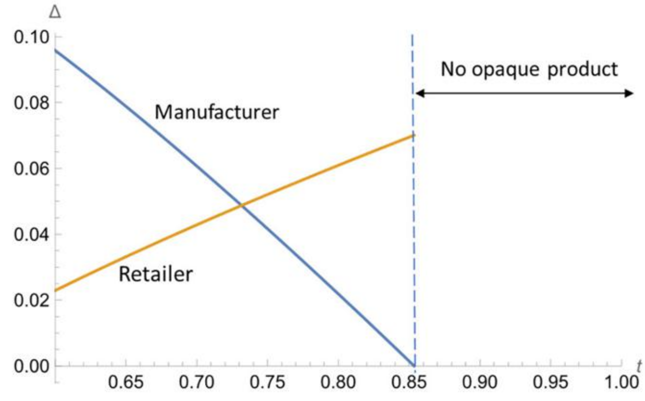
These changes in profit can be best understood by considering how the retailer's ability to offer an opaque good alters the wholesale prices that maximize the manufacturer's profit. Specifically, when offering opaque goods becomes feasible, the manufacturer responds by charging higher prices when the products are close substitutes ($t \le \bar{t}/2$). Increasing wholesale prices while inducing the retailer to sell an opaque product is counterintuitive because consumers value an opaque good less than a transparent one. Availability of an opaque good that caters to consumers with low willingness to pay, however, provides the retailer a strong and attractive mechanism for maintaining a high level of sales. The manufacturer can thus increase its wholesale prices without sacrificing sales, thereby enabling it to earn a higher profit. Higher wholesale prices diminish the retailer's profit margins, leading to the possibility that the retailer earns less profit than if selling opaque goods were not feasible.

In contrast, the manufacturer lowers its wholesale prices in response to the retailer's ability to adopt PS when the products are moderately differentiated (i.e., $\bar{t}/2 < t < \hat{t}$). In the absence of an opaque good, wholesale and retail prices for such differentiated products are relatively high, which leads to some consumers choosing not to purchase either product. An opaque good can be sold to such consumers, but the retailer does so only if the wholesale prices are sufficiently low. The manufacturer's incentive to lower its wholesale prices in order to induce the retailer to offer an opaque good leads to the following intriguing result:

Remark 1 (Below-Cost Wholesale Price). The retailer's ability to adopt PS can make it optimal for the manufacturer to sell a product for less than it costs to produce. Specifically, for $t \le \hat{t}$ and a constant average production cost ($\bar{c}$), $w_A < c_A$ if $c_A - c_B > 2(2 - t - 2\bar{c})$.

Figure 3. (Color online) Wholesale Prices and Profit Advantages When the Cost Difference Is High ($c_A = 0.8$, $c_B = 0.2$)





Remark 1 indicates that, if the difference in production costs across the two products is sufficiently high, the manufacturer sets the wholesale price of product A below its production cost. Figure 3 illustrates such an example, showing that when $c_A = 0.8$ and $c_B = 0.2$, the wholesale price for product A is below its unit cost if $t > 0.7$. This surprising strategy of subsidizing sales of product A emerges because, by inducing the retailer to offer an opaque good, the manufacturer can significantly increase sales of product B which earns a substantial, positive profit margin. However, if the products are too differentiated ($t > \hat{t} = 0.85$), the subsidization necessary to induce offering an opaque good is too large and thus the manufacturer opts instead to maintain high wholesale prices to discourage the retailer from adopting PS.

The retailer clearly earns higher profit in this scenario in which the manufacturer lowers its wholesale prices in response to the retailer's ability to offer an opaque good ($\bar{t}/2 < t < \hat{t}$). Furthermore, the lower wholesale prices induce the retailer to reduce the retail prices of the transparent goods, which benefits consumers. Thus, introduction of an opaque good creates a win-win-win outcome in a moderate range of product differentiation. This finding is particularly interesting because, in a centralized channel, an integrated firm always increases the price of transparent goods when introducing an opaque good to implement price discrimination most effectively. Thus, while introduction of an opaque good always lowers consumer surplus in a centralized channel, it can benefit consumers in a decentralized channel.

5. Upstream Competition

In this section, we examine the impact of competition between manufacturers on the viability of PS and how it affects the channel members' profit. By assuming manufacturer A produces product A and manufacturer B produces product B, this model represents market settings whereby the retailer is a channel intermediary and the opaque good consists of products produced by competing manufacturers. Opaque goods that are drawn from multiple brands are currently offered in such product categories as electronics, cigars, capacitors, jewelry, and shoes (Amazon 2023; Cigars International 2023; JemLit 2023a, b, c).

The game proceeds as before, except that now, in Stage I, each of the two manufacturers, independently and simultaneously, chooses its wholesale price. Specifically, Equation (2) remains valid for describing how consumer demand depends upon retail prices and the assignment probability ϕ. Thus, Proposition 1 continues to hold; that is, the retailer maximizes its profit by setting $\phi = 1/2$.

Each manufacturer seeks to maximize its own profit, which now comes from sales of only one product. Specifically, manufacturer A chooses w_A to maximize its expected profit:

$$\Pi_A^{PS}(w_A) = (w_A - c_A)\left(\hat{x}_A + \frac{1}{2}(\hat{x}_B - x_o)\right). \qquad (5)$$

Manufacturer B chooses w_B in order to maximize its own expected profit:

$$\Pi_B^{PS}(w_B) = (w_B - c_B)\left(1 - \hat{x}_B + \frac{1}{2}(\hat{x}_B - x_o)\right). \qquad (6)$$

A Nash equilibrium occurs when each manufacturer's wholesale price is the best response to the other manufacturer's wholesale price. If the products are close substitutes ($t < t_{1c}$), we find that the unique equilibrium consists of the retailer offering an opaque good and earning a strictly positive profit margin on sales of this product. When the products are moderately differentiated ($t_{1c} \le t \le \hat{t}_c$), there is a continuum of equilibria in which $w_A + w_B = 2 - t$, so that the retailer receives the minimum incentive necessary to offer an opaque good. (In the vicinity of $\hat{t}_c$, as specified in Lemma 5 of the Online Appendix, in addition to the continuum of PS equilibria, there is also an equilibrium in which the retailer only sells transparent versions of the products.

Table 2. Equilibrium Prices and Profit in the Presence of Upstream Competition

Condition	$t < t_{1c}$	$t_{1c} \le t \le \hat{t}_c$	$t > \hat{t}_c$
Wholesale prices	$w_A = 2t + \frac{2c_A+c_B}{3}$, $w_B = 2t + \frac{c_A+2c_B}{3}$	$w_A = 1 - \frac{3t-c_A+c_B}{6}$, $w_B = 1 - \frac{3t+c_A-c_B}{6}$	$w_A = \frac{1+c_A}{2}$, $w_B = \frac{1+c_B}{2}$
Retail prices	$P_A = 1 - \frac{3t-c_A+c_B}{12}$, $P_B = 1 - \frac{3t+c_A-c_B}{12}$, $P_o = 1 - \frac{t}{2}$	$P_A = 1 - \frac{3t-c_A+c_B}{12}$, $P_B = 1 - \frac{3t+c_A-c_B}{12}$, $P_o = 1 - \frac{t}{2}$	$P_A = \frac{3+c_A}{4}$, $P_B = \frac{3+c_B}{4}$
Each manufacturer's profit	$\Pi_A = \frac{(6t-c_A+c_B)^2}{36t}$, $\Pi_B = \frac{(6t+c_A-c_B)^2}{36t}$	$\Pi_A = \frac{(6-5c_A-c_B-3t)(6t-c_A+c_B)}{72t}$, $\Pi_B = \frac{(6-c_A-5c_B-3t)(6t+c_A-c_B)}{72t}$	$\Pi_A = \frac{(1-c_A)^2}{8t}$, $\Pi_B = \frac{(1-c_B)^2}{8t}$
Retailer's profit	$\Pi_R = \frac{(c_A-c_B)^2+36(2-c_A-c_B)t-171t^2}{72t}$	$\Pi_R = \frac{(c_A-c_B)^2+9t^2}{72t}$	$\Pi_R = \frac{(1-c_A)^2+(1-c_B)^2}{16t}$
Total channel profit	$\Pi_{Tot} = \frac{5(c_A-c_B)^2+36(2-c_A-c_B)t-27t^2}{72t}$	$\Pi_{Tot} = \frac{5(c_A-c_B)^2+36(2-c_A-c_B)t-27t^2}{72t}$	$\Pi_{Tot} = \frac{3[(1-c_A)^2+(1-c_B)^2]}{16t}$

Note. Where $t_{1c} = \frac{2-c_A-c_B}{5}$ and $\hat{t}_c = \frac{12-9c_A-3c_B+\sqrt{(8-7c_A-c_B)^2+8(1-c_A)(1-c_B)}}{12}$.

However, that equilibrium is Pareto-dominated by the PS equilibrium reported in the middle column of Table 2). When the manufacturers' products are highly differentiated ($t > \hat{t}_c$), the unique equilibrium consists of only transparent products being sold. Table 2 reports the equilibrium prices and resulting profit. Note, in the middle column of Table 2, we report the equilibrium in which wholesale prices remain linear in t and converge to the symmetric equilibrium prices in the equal-cost setting when $c_A = c_B = c$.

Table 2 indicates that, analogous to the case in which the opaque good consists of products procured from the same manufacturer, when the products are procured from different manufacturers, the opaque good is offered only if the production costs are sufficiently low and the products are not too differentiated. However, the specific threshold differs between these two cases. Comparing these thresholds, we arrive at the intriguing result summarized by Proposition 4.

Proposition 4 (PS with Upstream Competition). *Upstream competition reduces the likelihood that the retailer will adopt PS. Specifically, an opaque good is offered when there is (is not) upstream competition if* $t \le \hat{t}_c$ ($t \le \hat{t}$), *where* $\hat{t}_c$ *is defined in Table 2 and* $\hat{t}_c \le \hat{t}$.

One might expect that upstream competition would facilitate the introduction of an opaque good because competition puts downward pressure on wholesale prices and having sufficiently low wholesale prices is a prerequisite for a retailer to adopt PS. However, Proposition 4 demonstrates that upstream competition has the opposite effect: Competition between manufacturers actually lowers the likelihood that the retailer will adopt PS. Notice from Tables 1 and 2 that when costs are equal ($c_A = c_B$), $\hat{t}_c = \hat{t}$, and thus the conditions under which PS emerges in equilibrium for a decentralized channel are the same with and without competition. But, for unequal costs, $\hat{t}_c$ is strictly less than $\hat{t}$. Therefore, when costs are unequal and there is a moderate degree of product differentiation, that is, $\hat{t}_c < t < \hat{t}$, an opaque good is not offered in the presence of upstream competition but is offered in its absence.

This surprising and interesting result can be explained as follows. Recall that the retailer offers an opaque good only if the average wholesale price across the two products is sufficiently low. Taking this into account, in Remark 1, we showed that it can be optimal for a monopolist manufacturer to set the wholesale price of the high-cost product below its production cost in order to induce the retailer to offer an opaque good. Even if cost asymmetry is not so large as to cause the manufacturer to price below cost, the manufacturer may still charge a relatively low margin on the high-cost product to induce PS. By sacrificing profit on sales of the high-cost product, the manufacturer can generate substantially higher profit from its lower-cost, higher-margin product.

In contrast, when there is upstream competition, the high-cost manufacturer does not profit from sales of the low-cost product and thus is unwilling to provide the subsidy necessary to induce PS, especially if the products are differentiated enough that the manufacturer can earn sizable profit from its product being sold only as a transparent good. As a result, when there is a difference in production costs and the products are moderately differentiated, upstream competition prevents the emergence of opaque goods.

Because competition restricts the conditions for which PS is viable, the retailer may find it more difficult to identify products from competing manufacturers that meet the required parameters. This insight may help explain the proliferation of opaque goods that are comprised of products of the same brand despite the fact that using a single manufacturer reduces the retailer's channel power. For example, as noted previously, each of SwimOutlet's grab bags specifies the brand of swimsuit that the consumer will receive. Specifically, grab bags are available for a Sporti Jammer, a Dolfin Jammer, an Arena Open Back, a TYR Training One Piece, and a Nike Cut Out, among others. However, the website does not offer any grab bags that include a selection of different brands. It may be that the retailer can only find suitable combinations of products that are sufficiently close substitutes and have acceptably low wholesale prices if the set of products is procured from a single manufacturer.

Our analysis also reveals interesting insights into how upstream competition impacts the effect of PS on wholesale prices and the distribution of channel profit. One expects that competition drives down wholesale prices and shifts profit away from the manufacturers. Consistent with this standard intuition with regard to profits, we find that the retailer benefits more and the manufacturer(s) benefits less from the introduction of an opaque good when it is comprised of products from competing manufacturers rather than from a single manufacturer. However, surprisingly, we find that the retailer's ability to adopt PS can diminish price rivalry between the manufacturers even though an opaque good targets price-sensitive consumers. Specifically, the equilibrium wholesale prices may be strictly higher when the retailer has the capability to offer an opaque good than when it lacks this capability. This counterintuitive finding arises because the retailer has a strong incentive to maintain the opacity of the product so that it can most effectively price-discriminate between consumers. That is, even when wholesale prices differ across manufacturers, the retailer maximizes its profit by adopting a procurement strategy whereby each product is used to fulfill an equal portion (half) of the demand for the opaque good (Proposition 1). Such a strategy weakens competition between manufacturers because their market share of the opaque good stays the same regardless of the wholesale prices. However, manufacturers still compete because wholesale prices do impact the market share of each transparent product.

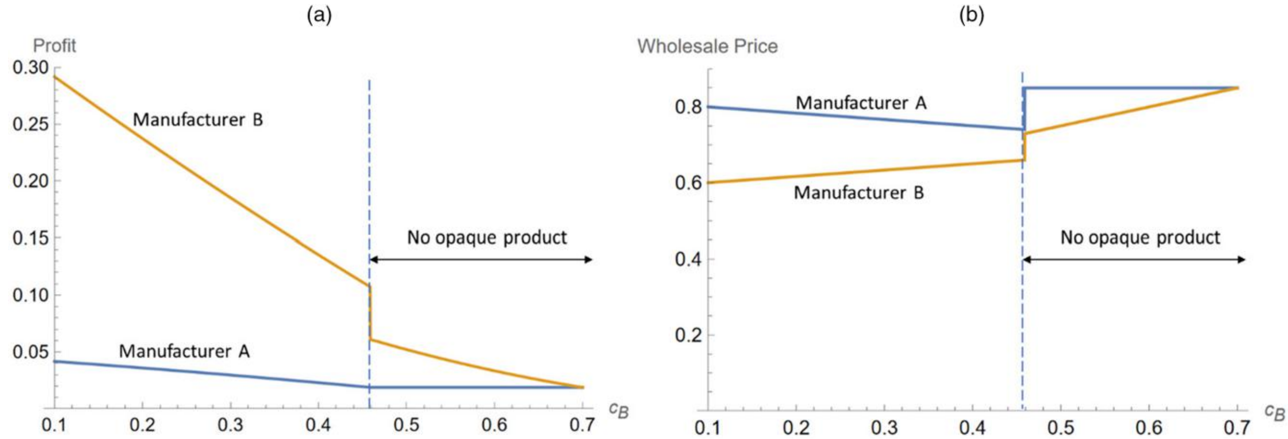
The counterbalancing forces of manufacturers competing for sales of traditional versions of their products while mutually benefiting from the introduction of an opaque good create a form of coopetition between manufacturers. As a result, the retailer's ability to offer opaque goods leads to interesting and counterintuitive effects of production costs on manufacturers' profit. Proposition 5 reports our most intriguing findings.

Proposition 5 (Impact of Cost Competition). *If the retailer can offer opaque goods, it is possible for both manufacturers' profit to increase when (a) their rival's production cost declines, specifically, for* $t \in [t_{1c}, \hat{t}_c]$, $\partial\Pi_A/\partial c_B < 0$ $(\partial\Pi_B/\partial c_A < 0)$ *if* $2c_A + c_B > 3 - 9/2\,t$ *(if* $c_A + 2c_B > 3 - 9/2\,t$*), and (b) their production costs become more similar, specifically, letting* $\delta = c_A - c_B$ *and holding the average production cost* $(\bar{c})$ *constant,* $\partial\hat{t}_c/\partial\delta < 0$ *and thus, as* δ *decreases, there emerge new levels of t at which PS is adopted in equilibrium, which can improve both manufacturers' profit.*

In our model, when an opaque good is not feasible, a manufacturer's profit decreases in its own cost and increases in its rival's production cost. This result aligns with conventional wisdom and is consistent with previous research that has shown a firm may benefit from engaging in costly actions that raise its rivals' costs (Salop and Scheffman 1983, Ordover et al. 1990, Banerjee and Lin 2003). In contrast, Proposition 5(a) indicates that the presence of an opaque good can flip this relationship. In particular, the low-cost manufacturer's profit can increase when the high-cost manufacturer's production cost decreases, thus suggesting that a manufacturer who has a more efficient production process may profit from sharing some of this technology with a rival. Likewise, a high-cost manufacturer's profit can decrease in the low-cost manufacturer's cost. Figure 4 illustrates this result using an example with $t = 0.6$ and $c_A = 0.7$. Specifically, for $c_B < 0.458$, a decrease in c_B increases manufacturer A's profit (Figure 4(a)). This example showcases a particularly interesting and surprising result because a reduction in c_B leads to manufacturer A being at an even greater cost disadvantage. As one would expect, manufacturer B charges a lower wholesale price when it has a lower production cost. In the absence of an opaque good, a reduction in one product's wholesale price would decrease demand for competing products and thus also rival manufacturers' profit. However, a lower level of one manufacturer's wholesale price creates a greater incentive for the retailer to offer an opaque good. This allows the other manufacturer, that is, manufacturer A, to charge a higher wholesale price and still maintain half of the market share for the opaque good (as illustrated by the downward-sloping portion of its wholesale price curve in Figure 4(b)). This heightened profit margin enables the high-cost manufacturer to share in the profit gains from PS that occur when the low-cost manufacturer experiences a decline in production costs.

Now consider Proposition 5(b), which examines how the extent of cost asymmetry impacts the manufacturers' profit. Specifically, holding the average production cost constant, that is, $(c_A + c_B)/2 = \bar{c}$, we find that both firms can earn higher profit when the difference in production costs (δ) diminishes. Figure 5 illustrates each manufacturer's profit as a function of δ when $t = 0.5$ and $\bar{c} = 0.6$. As can be observed from the figure, the retailer adopts PS if $\delta < 0.371$ but only sells transparent products otherwise. Let us compare two cases in order to illustrate the effects of cost asymmetry: (1) $c_A = 0.8$ and $c_B = 0.4$, and (2) $c_A = 0.75$ and $c_B = 0.45$. In the first case, manufacturer B has a large cost advantage. The equilibrium wholesale prices are $w_A = 0.9$ and $w_B = 0.7$, which lead to the retailer choosing not to offer an opaque good. Manufacturer A earns a profit of $\Pi_A = 0.01$, and manufacturer B earns a profit of $\Pi_B = 0.09$. In the

Figure 4. (Color online) The Impact of c_B ($t = 0.6$, $c_A = 0.7$)

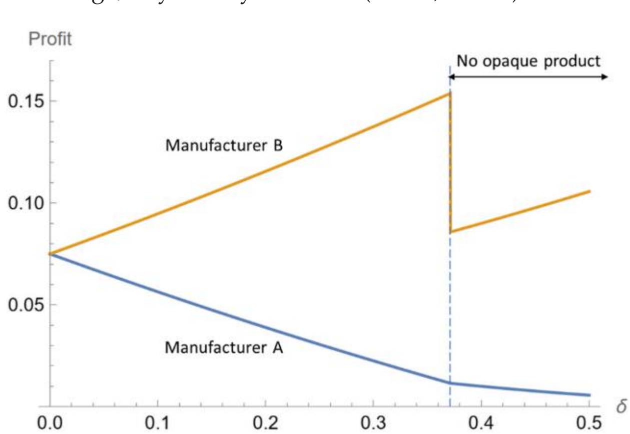


Notes. (a) Effect on profit. (b) Effect on wholesale prices.

second case, the manufacturers have more similar production costs. A lower c_A increases the benefit that manufacturer A obtains from the higher sales that result from the retailer offering an opaque good. To induce the adoption of PS, manufacturer A lowers its wholesale price to $w_A = 0.8$ whereas manufacturer B charges $w_B = 0.7$. The market expansion from sales of the opaque good leads to both manufacturers earning higher profits. Specifically, the manufacturers' profits rise to $\Pi_A = 0.0225$ and $\Pi_B = 0.1375$.

This example illustrates that a low-cost manufacturer can benefit from experiencing a rise in production costs if this change is accompanied by its rival incurring lower production costs. This finding is highly surprising and counterintuitive. As noted previously, extant research has shown that a higher production cost can benefit a firm only if its rival also experiences higher production costs. In contrast, we show that the retailer's ability to offer PS can create a situation in which a low-cost manufacturer benefits from having higher costs and a smaller cost advantage over a rival. In other words, a more operationally competitive setting can be favorable to both manufacturers. This result hinges on the fact that a wide operational efficiency gap (cost asymmetry) can undermine the introduction of an opaque good. That is, a more similar cost structure can lead to heightened viability of PS and both manufacturers can benefit from the growth in sales that ensues.

Figure 5. (Color online) The Impact of Cost Advantage/Asymmetry on Profits ($t = 0.5$, $\bar{c} = 0.6$)



6. Concluding Remarks

This paper provides key insights as to how opaque goods can impact manufacturer-retailer interactions, affecting both total channel profit and the allocation of this profit across channel members. We show that a supply chain benefits more from the introduction of an opaque good if it is decentralized rather than centralized because an opaque good can partially mitigate the inefficiency that arises from double marginalization. Despite this potential for greater channel profit, we find that PS is less likely to arise in a decentralized channel because a retailer's introduction of an opaque good shifts channel power toward the manufacturer, thus undermining its incentive to offer such a product. Upstream competition between manufacturers helps counterbalance this shift in channel power. However, such competition further shrinks the set of market conditions under which PS arises.

Our results have important managerial implications. First, our paper encourages manufacturers to be proactive participants in the offering of opaque goods. A manufacturer should be especially supportive of retailers who use several of the manufacturer's products to construct an opaque good. Such support could facilitate adoption of PS by a larger range of retail settings than is currently observed. For example, manufacturer brands such as New Balance, Hanes, Crest, and General Electric (GE) currently offer multiple versions of shoes, undergarments, toothpaste, and refrigerators, respectively. Lowering the wholesale price of one or more models would encourage their retailers (e.g., Kohl's, Target, Best Buy, Walmart, and Lowe's) to introduce opaque goods on their e-commerce sites in these product categories, thus boosting the manufacturers' sales of all models, including those whose wholesale prices have not been reduced.

Furthermore, our results indicate that a manufacturer may still benefit from a retailer offering opaque goods even if the retailer combines its product with that of a rival manufacturer. This benefit of PS under upstream competition arises because a retailer splits demand for the opaque product equally across the two products even when the products have different wholesale prices. While such balanced assignments enable the retailer to construct a product mix that is most effective at price discriminating on the basis of consumers' strength of preferences, balanced assignments relax price rivalry, thus allowing manufacturers to increase unit sales while still maintaining substantial profit margins. This result is especially noteworthy because it may help assuage some manufacturers who are reluctant to support retailers' offerings of opaque goods due to concerns about potential dilution of brand image and/or the necessity to discount wholesale prices.

Second, our paper establishes that a retailer's adoption of PS can turn the competition dynamics into a form of coopetition leading to mutual benefits in situations which would conventionally hurt at least one manufacturer. Specifically, when PS is feasible, a manufacturer may be better off if its rival improves the efficiency of its production process. Furthermore, both manufacturers can benefit from a more operationally competitive environment in which production costs are more similar. These findings further encourage manufacturers' participation in PS as it identifies advantages from the resulting coopetition.

Third, our findings suggest ways in which retailers can enhance their profits by introducing opaque goods. Specifically, we find that the retailer obtains the largest gains from PS if it constructs opaque goods by using similar goods that are produced by competing manufacturers. For example, Lowe's may benefit most from offering an opaque medium-size refrigerator if it combines the stainless-steel top-freezer refrigerators from GE and Whirlpool with 17.5-cubic-feet (cu-ft) and 17.6-cu-ft capacities, respectively. Similarly, when offering multiitem bundles, a retailer should use products procured from more than one manufacturer; for example, Macy's could offer mystery bags of skin care products where a customer would potentially receive products from a variety of brands such as Chanel, Elemis, Elizabeth Arden, and La Mer. Such a strategy prevents manufacturers from enlarging their channel power, thus averting substantial increases in wholesale prices. Furthermore, even if current wholesale prices are not sufficiently low to make it profitable to offer an opaque good, the retailer may benefit from investing in the capability to offer opaque goods. This is because, once this capability is acquired, the manufacturers of sufficiently substitutable products will have an incentive to lower their wholesale prices so as to entice the retailer to adopt PS. Such a preemptive investment by the retailer, as long as the PS technology is not too expensive, can lead to a win-win-win outcome in which all supply chain members earn higher profit and consumers also benefit from introduction of an opaque good.

The current paper has several limitations, which represent opportunities for future research. Future studies might employ a more general model of demand to verify the robustness of our results and to identify additional insights. Although our approach of using the Hotelling line to model heterogeneity in consumers' tastes has been commonly used in the extant literature, it has some stylized features that are unlikely to hold perfectly in practice (such as homogeneous expected values for the opaque good when each product has the same probability of being received). Such stylized features may make it difficult to generalize the results to alternate market settings. For example, an opaque good may provide an easier and less costly way for a retailer to attract new customers than developing a private brand or introducing an additional transparent product (Fay et al. 2015). However, demand for new products is notoriously hard to predict (Devlin et al. 2022), and thus new product introduction is not adequately modeled as simply choosing a point on a Hotelling line populated by consumers with known locations. As a result, additional work is needed to evaluate the relative advantages of introducing an opaque good versus expanding one's product mix to include an additional transparent product.

Finally, exploring the impact of retail competition under more complex channel structures and with larger product mixes can be a fruitful avenue for future research. For example, our model assumes consumers buy from a single retailer who procures at most two products from either one or two manufacturers. Several papers have considered the situation in which service providers' direct channels for transparent products compete against a retailer who exclusively sells opaque products (Fay 2008, Jerath et al. 2010, Anderson and Xie 2012, Chen et al. 2014). However, future research could generate further insights by considering competition between multiple retailers, each of whom offers a sizable portfolio of transparent and opaque products.

Appendix

Proof of Proposition 1. The Online Appendix contains a detailed proof for the result that $\phi = 1/2$ in any subgame perfect Nash equilibrium (SPNE) in which the retailer sells an opaque product. While that proof covers the entire range of ϕ, that is, $0 \le \phi \le 1$, here we provide a brief sketch of the proof for $\phi \le 1/2$ in order to convey the intuition.

1. First, we examine consumers' purchasing decision in Stage III and derive the demand functions for the retailer's Stage II profit-maximization problem as follows:

$$D_A(P_A) = \hat{x}_A = \frac{1-P_A}{t}$$

$$D_B(P_B, P_o, \phi) = 1 - \hat{x}_B = \frac{-P_B + P_o + t\phi}{2t\phi}$$

$$D_o(P_B, P_o, \phi) = \hat{x}_B - x_o = \frac{P_B - P_o + (2-2P_B - t)\phi}{2t\phi(1-2\phi)}$$

$$D_n(P_A, P_o, \phi) = x_o - \hat{x}_A = \frac{P_A + P_O + t - 2 + (2 - 2P_A - t)\phi}{t(1-2\phi)}$$

where D_A, D_B, and D_O are demand for products A and B and the opaque product, respectively, and D_N is the size of the consumer population that does not buy any of the offered products.

2. Next, we formulate the retailer's problem:

$$\max_{P_A, P_B, P_o, \phi} \Pi_R^{PS}(P_A, P_B, P_o, \phi) = (P_A - w_A)D_A(P_A) +$$
$$(P_B - w_B)D_B(P_B, P_o, \phi) + (P_O - \phi w_A - (1-\phi)w_B)D_o(P_B, P_o, \phi)$$

$s.t.$

(1) $\phi \le 1/2$
(2) $D_n(P_A, P_o, \phi) \ge 0$
(3) $D_A(P_A) \ge 0$
(4) $D_B(P_B, P_o, \phi) \ge 0$
(5) $D_o(P_B, P_o, \phi) \ge 0$
(6) $\phi \ge 0$

and show that the profit function is convex in ϕ and, thus, no interior solution exists for this problem. That is, the global maximum of the retailer's profit must occur at an extreme value of ϕ. Therefore, one or more constraints must bind at the optimum.

3. Finally, we analyze the constraints and demonstrate that if the retailer offers an opaque good, the corner solution in which $\phi = 1/2$ is optimal; that is, Constraint (1) must bind. □

Proof of Proposition 2. The derivation of the equilibrium prices and profits shown in Table 1 is provided in Lemmas 1 and 2 in the Online Appendix.

a. Table 1 shows that, in a centralized (decentralized) channel, the opaque good is sold if $t \le \bar{t} = 2 - c_A - c_B$ $\left(t \le \hat{t} = \frac{2+\sqrt{2}}{4}(2 - c_A - c_B)\right)$, which can be rewritten as $c_A + c_B \le 2 - t = \overline{\varsigma}$ $(c_A + c_B \le 2 - 2(2-\sqrt{2})t = \hat{\varsigma})$. The result immediately follows from comparing $\bar{t}$ with $\hat{t}$ and $\overline{\varsigma}$ with $\hat{\varsigma}$.

b. Using Lemmas 1 and 2, assuming $t \le \hat{t}$, the increase in total profit from an opaque good in a decentralized channel (DC) versus a centralized channel (C) is

$$(\Pi_{DC,TOT}^{PS} - \Pi_{DC,TOT}^{TS}) - (\Pi_{C,TOT}^{PS} - \Pi_{C,TOT}^{TS})$$
$$= \begin{cases} 0 & if\ t \le \frac{\bar{t}}{4} \\ \frac{(4t-\bar{t})(3\bar{t}-4t)}{32t} > 0 & if\ \frac{\bar{t}}{4} < t \le \frac{\bar{t}}{2} \\ \frac{\bar{t}}{32t} > 0 & if\ \frac{\bar{t}}{2} < t < \hat{t}. \end{cases} \quad \square$$

Proof of Proposition 3. Using Lemma 2 in the Online Appendix, for $t \le \hat{t}$, we get

a. $\Pi_M^{PS} - \Pi_M^{TS} =$

$$\begin{cases} \frac{t}{2} > 0 & if\ t \le \frac{2-c_A-c_B}{4} \\ \frac{1}{2}\left(2 - c_A - c_B - t - \frac{(2-c_A-c_B)^2}{8t}\right) > 0 & if\ \frac{2-c_A-c_B}{4} \le t < \hat{t} \end{cases}$$

where the bottom difference is positive because it is a concave function of t and positive at both boundaries.

b. $\Pi_R^{PS} - \Pi_R^{TS} =$

$$\begin{cases} -\frac{3t}{8} < 0 & if\ t \le \frac{2-c_A-c_B}{4} \\ \frac{t}{8} - \frac{(2-c_A-c_B)^2}{32t} \begin{cases} \le 0\ if\ t \le \frac{2-c_A-c_B}{2} \\ > 0\ if\ t > \frac{2-c_A-c_B}{2} \end{cases} & if\ \frac{2-c_A-c_B}{4} \le t < \hat{t}. \end{cases}$$

□

Proof of Remark 1. Holding the average cost ($\bar{c}$) constant, we can rewrite $\hat{t}$ as $\hat{t} = \left(1 + \frac{\sqrt{2}}{2}\right)(1 - \bar{c})$. Thus, when $t \le \hat{t}$, from Table 1 equilibria (derived in the Online Appendix), we get $w_A < c_A$ if $c_A - c_B > 2(2 - t - 2\bar{c})$. □

Proof of Proposition 4. Let $\eta = \hat{t} - \hat{t}_c$ where the t thresholds are defined in Tables 1 and 2. We show that $\eta \ge 0$. We have $\frac{\partial^2 \eta}{\partial c_A^2} = \frac{6(1-c_B)^2}{[72+49c_A^2-(24-c_B)c_B-2c_A(60-11c_B)]^{3/2}} \ge 0$ for $0 \le c_B \le c_A \le 1$ (the bracketed term in the denominator is positive in the costs range). Thus, η is convex in c_A. Hence, from $\frac{\partial \eta}{\partial c_A}\Big|_{c_A=c_B} = \frac{3+2\sqrt{2}}{12} > 0$ and $\eta\,|_{c_A=c_B} = 0$, it follows that $\eta \ge 0$ in the $0 \le c_B \le c_A \le 1$ range (note that if $c_A > 1$, manufacturer A cannot earn a positive margin on its product and thus the effective upper bound for c_A is Min $[c_B + t, 1]$). □

Proof of Proposition 5.

a. Note from Table 2 that, for $t_{1c} \le t \le \hat{t}_c$, $\frac{\partial \Pi_A}{\partial c_B} = \frac{6-4c_A-2c_B-9t}{72t} < 0$ if $2c_A + c_B > 3 - 9/2\,t$, and $\frac{\partial \Pi_B}{\partial c_A} = \frac{6-2c_A-4c_B-9t}{72t} < 0$ if $c_A + 2c_B > 3 - 9/2\,t$. (It is straightforward to show that $\frac{\partial \Pi_A}{\partial c_A} = -\frac{6-10c_A+4c_B+27t}{72t} < 0$ and $\frac{\partial \Pi_B}{\partial c_B} = -\frac{6+4c_A-10c_B+27t}{72t} < 0$ in this t range.)

b. Let $\delta = c_A - c_B$ denote the degree of cost asymmetry. We show that $\frac{\partial \hat{t}_c}{\partial \delta} < 0$. Fixing the average cost at $\bar{c}$ and expressing the costs as $c_A = \bar{c} + \frac{\delta}{2}$ and $c_B = \bar{c} - \frac{\delta}{2}$, we get the total derivative of $\hat{t}_c$ with respect to δ as follows: $\frac{d\hat{t}_c}{d\delta} = \frac{\partial \hat{t}_c}{\partial c_A} \cdot \frac{\partial c_A}{\partial \delta} + \frac{\partial \hat{t}_c}{\partial c_B} \cdot \frac{\partial c_B}{\partial \delta} = \frac{1}{2}\left(\frac{\partial \hat{t}_c}{\partial c_A} - \frac{\partial \hat{t}_c}{\partial c_B}\right)$. Because $\frac{\partial^2 \hat{t}_c}{\partial \delta \partial c_A} = -\frac{3(1-c_B)(2-c_A-c_B)}{[72+49c_A^2-(24-c_B)c_B-2c_A(60-11c_B)]^{3/2}} \le 0$ for $0 \le c_B \le c_A \le 1$ and $\frac{\partial \hat{t}_c}{\partial \delta}\Big|_{c_A=c_B} = -\frac{1}{2}\left(\frac{1}{2} + \frac{\sqrt{2}}{3}\right) < 0$, it follows that $\frac{\partial \hat{t}_c}{\partial \delta} < 0$ for $0 \le c_B \le c_A \le 1$. Therefore, as the degree of cost asymmetry decreases (increases), there emerge new levels of t at which PS is (is not) adopted in equilibrium, which can improve (diminish) both manufacturers' profit, as demonstrated in Figure 5. □

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