Strategic Ignorance: Managing Endogenous Demand in a Supply Chain

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Abstract

This paper studies a supply chain in which a manufacturer sells a product to consumers through a retailer. The retailer makes an endogenous demand improvement decision on whether or not to increase the potential market base, which is imperfectly observed by the manufacturer. Two common contract types, wholesale price and two-part tariff, are studied. The paper studies how the manufacturer's capability to acquire demand information affects the retailer's demand investment decision as well as each firm's profit. We find that the retailer benefits from the manufacturer's increased capability to acquire demand information, i.e., the more accurate the manufacturer's demand information, the higher the retailer's profit. We also show that when the manufacturer can choose the level at which it can acquire demand information, it prefers not to acquire demand information at all under wholesale price contracts and not to acquire perfect demand information under two-part tariff contracts. Our results offer some new insights into how a manufacturer's capability to acquire demand information and a retailer's demand investment decision interact in a supply chain and challenge some well-established results in the exiting literature.

Keywords: endogenous demand; information acquisition; supply chain; wholesale price contracts; two-part tariff contracts

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1. Introduction

In a two-tier supply chain, a retailer can influence the potential market size by investing in demand improvement activities. For example, retailers can improve their in-store aesthetic to stimulate their consumers' purchase intention or hire and train professional employees who are passionate and knowledgeable about the products they sell, thus offering exceptional customer service. Retailers may also use modern media technologies such as in-store media, mobile apps and push notifications on computers and smartphones to reach out to a larger base of consumers. For instance, Walmart launched Walmart TV in 1999 with more than 100,000 screens its retail stores, reaching hundreds of millions of consumers.

An upstream manufacturer, then, has an incentive to strengthen its connection to its downstream retailers and to acquire demand information from them. In some cases, a manufacturer may offer incentive contracts to infer demand information from the retailer's contract choice. After all, it is well-known that the more accurate the demand information a manufacturer gains, the higher the profit it can attain. To remain proactively market savvy, upstream manufacturers may also acquire information from channels other than downstream retailers. For instance, manufacturers can invest in demand acquisition activities such as hiring a consultancy team, conducting market research, and developing an information system to obtain demand information. For instance, the Procter & Gamble uses a range of methods to collect demand information, including surveys, digitally-connected appliances, smart sensors, and other innovative tools.[2]

We take these important characteristics of the manufacturer's information acquisition and the retailer's endogenous demand improvement decision into consideration to address the following managerially relevant research questions. First, how does the manufacturer's information about market demand affect the retailer's demand investment decision and each firm's profit? At first glance, one may assume that the retailer would prefer the manufacturer to have little demand information so as to preserve its own information advantage. However, whether or not this intuition holds is subject to formal investigation. Second, when a manufacturer can freely choose the capability of demand information acquisition, how would it make this important decision?

To answer these questions, we consider a supply chain in which a manufacturer employs a retailer to sell its product. In the game, the manufacturer first makes its long-term decision on information acquisition capability, and then the retailer makes the mid-term decision on whether or not to invest in improving the potential market base, and finally the manufacturer makes the

[2] https://informaconnect.com/how-pg-is-approaching-the-next-tide-of-market-research/

short-term contract decisions. We consider two types of contracts, including a wholesale price contract and a two-part tariff contract.

Our analysis shows several noteworthy findings. First, our results reveal that the retailer's expected profit can increase with the manufacturer's enhanced capability to acquire demand information. On the surface, it seems that the retailer would prefer to remain more knowledgeable about demand than the manufacturer; however, our analysis defies this intuition, showing instead that, when market demand is endogenously determined by the retailer's investment activities, the manufacturer's holding more accurate demand information actually benefits the retailer. This surprising result can be explained as follows: When the manufacturer possesses limited demand information, the retailer cannot help opportunistically improving demand while hoping that the manufacturer will not detect this investment and, thus, offer the retailer a low price on its product. However, when the manufacturer can more accurately acquire information, the retailer becomes reluctant to improve demand, knowing that doing so will likely induce the manufacturer to charge it a high price. As such, the retailer effectively commits to making no investments, which curbs its opportunistic behavior and ultimately improves its profit.

Second, we find that, when the manufacturer can freely choose its capability of demand information acquisition, it prefers to remain blind to market demand under a wholesale price contract, and to not know the demand *perfectly* under a two-part tariff contract. Although this seemingly paradoxical result starkly contrasts with the common wisdom, which suggests that better demand information always benefits a firm, we find that the manufacturer's improved capability to acquire information exerts two countervailing effects on the manufacturer's profit: on the one hand, more accurate demand information allows the manufacturer to fine-tune its wholesale price accordingly, which is unambiguously beneficial. On the other hand, the manufacturer's enhanced capability to acquire demand information reduces the retailer's information advantage, thereby discouraging the retailer from investing in demand improvement activities such as those previously introduced. As the retailer invests less, the market potential shrinks accordingly, which hurts the manufacturer. Therefore, the manufacturer must carefully balance the two effects when choosing its capability of information acquisition. In fact, we find that, under a wholesale price contract, the second effect is so strong that the manufacturer prefers to remain blind to market demand; under a two-part tariff contract, the manufacturer trades off between the two effects and chooses to observe the demand imperfectly.

For further exploration of these findings, the rest of this paper is organized as follows: Section 2 reviews past studies that relate to this present work. Section 3 presents the basic model. Sections 4 and 5 analyze equilibrium results under a wholesale price contract and a two-part tariff contract, respectively. Section 6 extends the basic model to situations in which a menus of contracts are offered to the retailer, the retailer's demand improvement activities do not always succeed, and the retailer can choose to disclose its demand investment to the manufacturer. Section 7 offers our final thoughts and recommendations for researchers who wish to augment this present work in the future.

2. Literature Review

Our work generally relates to the extensive literature on private demand information in a supply chain, particularly to those that assume retailers have private information about demand because they are closer to end consumers and naturally have better market information than manufacturers do. The literature in this area can be categorized into two streams according to whether or not information acquisition is costly.

The first stream assumes that retailers can acquire information without cost, and focuses on whether a retailer shares demand information with a manufacturer, the impact of information sharing on a manufacturer's operational decision and channel management, and whether channel coordination can be achieved under different supply chain contracts. For example, Lee et al. (2000), Cachon and Lariviere (2001), Özer and Wei (2006), Ha and Tong (2008), Taylor and Xiao (2010), Li and Zhang (2015), Shang et al. (2016), Dominguez et al. (2018), Liu et al. (2020), Wei et al. (2021), and Guan et al. (2022) have all investigated under these assumptions; Cachon (2003) and Chen (2003) also offer comprehensive reviews of research works in this area.

The other stream assumes that information acquisition is costly for retailers. Most works in this area focus on how a manufacturer can use incentive contracts to elicit information and/or motivate retailers to improve information acquisition. Shin and Tunca (2010) study two scenarios in which a retailer's investment in demand forecast is either observable (i.e., transparent) or unobservable (i.e., nontransparent) to manufacturers and investigate if channel coordination can be achieved under different types of supply chain contracts. Meanwhile, Fu and Zhu (2010) begin with the assumption that information is transparent and analyze the optimal level of information acquisition in a centralized supply chain when a retailer can acquire costly demand information by hiring forecasting experts; furthermore, they examine if the supply chain can be coordinated in a decentralized system by also exploring different types of contracts. Guo (2009) considers a supply chain in which a retailer not only decides if it wishes to acquire information, but also if it wishes to disclose this information to a manufacturer, who cannot observe the retailer's information acquisition decision. He investigates how a retailer's information acquisition and disclosure decisions affect its profit and its manufacturer's profit. Li et al. (2014) examine scenarios in which the retailer's information acquisition is transparent or nontransparent to the manufacturer and show that the retailer can benefit from disclosing the status of its information acquisition (i.e., informed or uninformed) rather than releasing the content of the acquired information under certain conditions. Huang et al. (2019) consider a supply chain in which a downstream retailer decides whether or not to exert a fixed cost to acquire private demand information and prove that the optimal contract for the manufacturer takes the form of quantity discounts. Note that all of the above papers assume that market demand is exogenously given while it may be random, and the retailer decides whether to acquire demand information and the level of demand information if it is acquired. However, our work considers that the demand state can be endogenously determined by investment activities exerted by the retailer, and the retailer decides whether to invest or not.

The present paper also adds to salesforce literature (e.g., Taylor 2002, Chen 2005, and Chen et al. 2016) which assumes that retailers can exert sales efforts to improve demand or demand forecasting. Among the available studies, Chen (2005) and Chen et al. (2016) both assume that demand is determined by market conditions and sales efforts made by the retailer. These works develop incentive contracts that induce retailers to exert such efforts; through a retailer's choice in contract, private information regarding demand is conveyed to the manufacturer. Chen (2005) assumes that the retailer is exogenously endowed with the market condition and shows that the manufacturer prefers a menu of linear contracts over a forecast-based contract. In contrast, Chen et al. (2016) assume that the retailer must exert efforts to acquire the market condition; then, the preference for linear contracts over forecast-based contracts can be reversed under certain conditions.

Our model differs from Chen (2005) and Chen et al. (2016) in the following ways. First, they consider an exogenously given market condition and, thus, they focus on the interplay between moral hazard and adverse selection; our model does not study this focus since demand is completely endogenized. Second, in their models, the manufacturer offers contracts to the retailer before the retailer decides to acquire information and exert sales efforts while, in our model, the manufacturer only offers a contract *after* the retailer has already made the investment decision in demand improvement activities. Finally, in their models, the manufacturer cannot acquire information on its own; it can only solicit information through the contact chosen by the retailer. Our model, by contrast, allows the manufacturer to acquire information through its own channels. To clarify, we focus on how the manufacturer's capability to acquire demand information affects the retailer's demand investment decision and, thus, the profits of each party.

In our paper, the manufacturer acquires market information by investing in demand acquisition activities, e.g., hiring a third-party agency to help acquire demand information. Along this same line, Hopp et al. (2009), Khanjari et al. (2014), and Duan et al. (2021) consider cases in which a manufacturer can hire sales agents to boost consumer demand for its product. Hopp et al. (2009) focus on the effect that a wholesale-salesperson can have on the supply chain's performance and show that the manufacturer benefits more from a wholesale-salesperson than from a retail-salesperson. In Khanjari et al.'s (2014) model, demand is determined by both the market condition and efforts made by the manufacturer-hired sales agent. The retailer and the sales agent both have the same private information about the market condition, which is uncertain and exogenously given, and the manufacturer compensates the sales agent according to the retailer's order quantity. Their work focuses on how the strategic play between the manufacturer and sales agent affects the sales agent's efficiency as well as each partner's profit. Duan et al. (2021) consider a supply chain that consists of a manufacturer, an agent who operates both wholesale and retail businesses, and a retailer. In their model, the manufacturer can hire a sale manager to boost the downstream sales. Their work examines how the sales efforts and different modes of payment (manufacturer-paid sales manager mode or agent-paid sales manager mode) affect the equilibrium outcome of the supply chain. Our work differs from theirs in that, while they suggest that demand is affected by the efforts offered by the manufacturer's sales agents, we delineate market demand as being completely determined by the retailer's investment decision. Moreover, the manufacturer in our work can only acquire demand information through its own source and cannot change the market demand; the manufacturer in their works can increase demand via the hired sales agent. This fundamental difference in our models determines two separate sets of focal questions to be addressed in our paper and in theirs.

Finally, our research contributes to information design literature in economics, akin to Kamenica and Gentzkow (2010) and Rayo and Segal (2010). In a Bayesian persuasion problem, the sender commits to dispatching a signal structure to the receiver; in our setting, the manufacturer similarly commits to a selected capability of demand information acquisition. We ultimately show that the manufacturer does not always benefit from observing perfect demand information.

3. The Model

Consider a supply chain with an upstream manufacturer and a downstream retailer. The manufacturer produces a product and sells it to end consumers through the retailer. The marginal costs of production and selling are constant and normalized to zero for both firms. We assume that the firms are contracted through common supply chain contracts such as wholesale price or two-part tariff contracts. Both firms are risk-neutral and maximize their expected profits.

Market Demand. The aggregate market demand is given by $D(p) = A - p$, where A denotes the market potential, called "*demand state*" throughout this paper, and p is the price charged by the retailer. Although much of the literature assumes that A is exogenously given, we differ by endogenizing the market potential. More specifically, without any downstream effort, the market potential is $A = L$, and the retailer can improve the market potential to $A = H$ by investing in or incurring demand improvement efforts. The following list presents examples of the efforts the retailer can take: investing in complementary assets to be used in conjunction with the manufacturer's product, e.g., undertaking marketing expenditures or investments in specialized facilities to distribute the manufacturer's product; setting up retail outlets that are close to and convenient for consumers; analyzing detailed consumer needs to provide exceptional service to consumers; improving shopping experiences through designing better displays and shopping environments and applying state-of-the-art technologies such as virtual reality; hiring sales experts to promote and sell products. We assume that $H \leq 2L$ to guarantee that market demand is always nonnegative. The retailer incurs a fixed cost c when it invests in demand improvement activities, which are long-term investments and made before short-term pricing and selling decisions. Let $a \in \{0, 1\}$ represent the retailer's investment decision with $a = 1$ denoting the retailer's decision to invest while $a = 0$ denotes its forgoing of that same investment.

Information. We assume that the demand state (A) and the retailer's investment decision (a) are imperfectly observed by the manufacturer, who can, for instance, build up competitive intelligence or contract third-parties to acquire information about the retailer's investment decision. The manufacturer can also conduct market research to understand consumer preferences for its product or see what type of add-on services the retailer may offer on the product.

We assume that the manufacturer may not be able to perfectly acquire demand information. With probability $\lambda \in [0, 1]$, the manufacturer observes the demand state A (or equivalently, it observes a). Otherwise the manufacturer does not have any additional information about A. In the extreme case of $\lambda = 0$, the manufacturer never gains any information about the demand state and, in the extreme case of $\lambda = 1$, the manufacturer always knows the demand state. We allow the manufacturer to choose λ, which we call the "*capability to acquire demand information*". In practice, the manufacturer can control its information flow through a number of means. For example, it can adopt an information system which does not always successfully communicate the demand information, acquire demand information at different levels by changing its business intelligence team, or commission third-party agencies to collect and deliver information in a certain format. As noted by Kamenica and Gentzkow (2010), "procedures for information gathering in organizations often involve commitment, either formally through contracts, or informally through reputation."

While our assumption that the manufacturer can commit to its choice of information is restrictive to some extent, it is not crucial to our results. Alternatively, consider a manufacturer whose choice set is limited to $\lambda \in \{0, 1\}$ — it either perfectly observes the demand state or observes nothing at all. Our results suggest that the manufacturer may choose $\lambda = 0$; that is, it prefers not to gain any information about the demand state at all, at least under a wholesale price contract.

To focus on strategic incentives without muddying the waters with less relevant factors, we assume that the manufacturer does not experience any cost differences when choosing between various λ. We intend to show that, even in the absence of cost concerns, the manufacturer may prefer imperfect observability of the retailer's demand to perfect observability.

Timing and Decisions. Our game consists of four stages. In the first stage, the manufacturer chooses and commits to the capability $\lambda \in [0, 1]$ to acquire demand information. In the second stage, the retailer decides whether or not to invest in demand improvement at a cost c. If the retailer invests, the demand state is $A = H$; otherwise the demand state is $A = L$. Third, the manufacturer observes the demand state A with probability λ and, with probability $1 - \lambda$, does not gain any additional information about A. Depending on the information it receives, the manufacturer offers the retailer a contract. We consider wholesale price and two-part tariff contracts here. Fourth, the retailer sets its retail price and orders the manufacturer's product, and the demand is realized. Figure 1 illustrates this sequence of events.

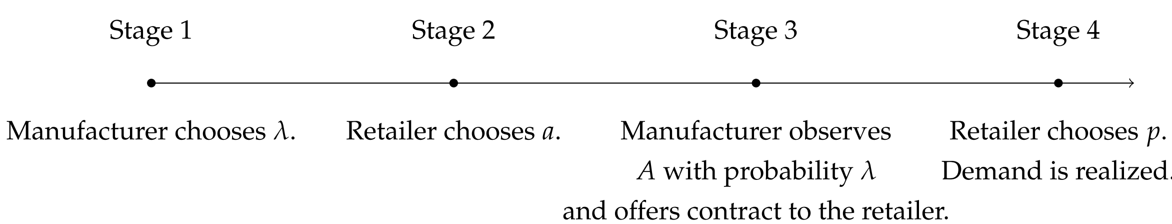

Figure 1 **Sequence of events**

Solution Concept. Because the manufacturer does not always observe the retailer's investment decision a, the game falls into one of imperfect information. Thus, we follow the literature and solve the game under the solution concept of a perfect Bayesian equilibrium (Li and Liu 2021, Li et al. 2022, Li and Xu 2022, Liu et al. 2020). Let $\tilde{\mu} = \Pr(a = 1)$ denote the manufacturer's belief about the retailer's investment decision when the manufacturer does not observe the demand. Note that $\tilde{\mu} = \Pr(a=1)$ must hold in equilibrium but not necessarily so off the equilibrium path.

4. Wholesale Price Contract

Suppose that the manufacturer offers the retailer a commonly used wholesale price contract. We work backward to solve the game. Given the manufacturer's wholesale price w, the retailer's decisions in Stage 4 (refer to Figure 1) are rather simple: choose a retail price $p = \frac{A+w}{2}$ and order $Q = \frac{A-w}{2}$ units from the manufacturer. The retailer's profit, then, is $\pi = \frac{(A-w)^2}{4} - \mathbb{1}\{a=1\} \cdot c$, where $\mathbb{1}$ is the indicator function.

In Stage 3, the manufacturer sets its wholesale price w according to whether or not it can observe the demand state for its product. If the manufacturer observes the demand state, its optimal wholesale price is $w_H = \frac{H}{2}$ when the demand state is high, leading to a profit of $\Pi = \frac{H^2}{8}$, and is $w_L = \frac{L}{2}$ when the demand state is low, which generates a profit of $\Pi = \frac{L^2}{8}$. Otherwise, the optimal wholesale price depends on the manufacturer's belief about the retailer's investment decision $\tilde{\mu}$. Simple calculations show that the manufacturer's optimal wholesale price $w_\varnothing$ when it cannot observe the demand state is $w_\varnothing = \frac{\tilde{\mu}H+(1-\tilde{\mu})L}{2}$, and its expected profit is $\Pi = \frac{(\tilde{\mu}H+(1-\tilde{\mu})L)^2}{8}$.

Consider now the retailer's investment decision. If the retailer decides to invest in demand improvement activities, its expected profit, denoted by π_I, is

$$\pi_I = \lambda \left(\frac{H - w_H}{2}\right)^2 + (1-\lambda)\left(\frac{H - w_\varnothing}{2}\right)^2 - c. \tag{1}$$

The first term on the right-hand side is the retailer's gain when the demand state is observed by the manufacturer while the second term is the retailer's gain when the demand state remains unobserved by the manufacturer. Next, if the retailer forgoes the investment, its expected profit, denoted by π_N, is

$$\pi_N = \lambda \left(\frac{L - w_L}{2}\right)^2 + (1-\lambda)\left(\frac{L - w_\varnothing}{2}\right)^2. \tag{2}$$

The subscript I stands for investment and N stands for no investment. When $\pi_I > \pi_N$, the retailer strictly prefers to invest and when $\pi_I < \pi_N$, the retailer strictly prefers to forgo the investment. Finally, when $\pi_I = \pi_N$, the retailer is indifferent about investing or not and, thus, is willing to randomize between these two decisions. In equilibrium, the manufacturer must hold the correct belief about the retailer's investment decision. That is, if the retailer always invests, $\tilde{\mu} = 1$, but if it never invests, $\tilde{\mu} = 0$. Otherwise, $\tilde{\mu}$ equals the probability of the retailer investing.

Solving for the retailer's investment decision, we come up with the following lemma.

LEMMA 1. *Suppose that two firms are contracted through a wholesale price contract. For a given capability of the manufacturer's information acquisition λ ($0 \le \lambda < 1$), the retailer makes the following investment decision:*

(i) *When $c \le \underline{c} = (H-L)(\lambda H + (4-3\lambda)L)/16$, the retailer always invests in demand improvement activities.*

(ii) *When $\underline{c} \le c \le \overline{c} = (H-L)((4-3\lambda)H + \lambda L)/16$, the retailer invests in demand improvement activities with probability μ, where*

$$\mu = \frac{(H-L)((4-3\lambda)H + \lambda L) - 16c}{4(1-\lambda)(H-L)^2}. \tag{3}$$

(iii) *When $\overline{c} \le c$, the retailer never invests in demand improvement activities.*

Lemma 1 shows that the retailer's investment decision depends on the investment cost c. The retailer always invests when the investment cost is low but never when it is too high. When the investment cost is moderate, no pure strategy equilibrium exists in which the retailer always or never invests. The explanation for this result is as follows. Suppose that the retailer always invests, then, the manufacturer's belief must be $\tilde{\mu} = 1$. As a result, the manufacturer charges a high wholesale price $w_\emptyset = \frac{H}{2}$ even when it does not know the actual demand information. Anticipating this high price, the retailer forgoes the investment opportunity to save on the investment cost. Now, suppose that the retailer never invests. Accordingly, the manufacturer's belief is $\tilde{\mu} = 0$, and it always charges a low wholesale price $w_\emptyset = \frac{L}{2}$ when it does not observe the demand state. Then, anticipating this low price, the retailer takes the investment opportunity to build its profit. As can be seen, the retailer randomizes its investment decision in equilibrium. Accordingly, the manufacturer charges a price $\frac{L}{2} < w_\emptyset < \frac{H}{2}$ when it does not observe the demand state. This price leads the retailer to be indifferent about whether or not to invest. Moreover, the probability of investment, μ, naturally decreases with c.

The following lemma speaks to the manufacturer's pricing decision and profit.

LEMMA 2. *Suppose that the manufacturer and the retailer are contracted through a wholesale price contract. If the manufacturer observes the demand state A, it always charges $w = \frac{A}{2}$ and obtains the expected profit $\frac{A^2}{8}$. Otherwise, it charges*

$$w_\emptyset = \begin{cases} \frac{H}{2}, & \text{if } c \le \underline{c}, \\ \frac{\mu H + (1-\mu)L}{2}, & \text{if } \underline{c} \le c \le \overline{c}, \\ \frac{L}{2}, & \text{otherwise;} \end{cases}$$

and obtains the expected profit $\Pi = \frac{(\mu H + (1-\mu)L)^2}{8}$, where μ is given in (3).

As for the retailer's profit, we present the following lemma.

PROPOSITION 1. *Suppose that the manufacturer and the retailer are contracted through a wholesale price contract. Given λ, the retailer's profit is altered as follows.*

(i) *The retailer's profit decreases with c when $c \leq \underline{c}$ and increases with c when $\underline{c} \leq c \leq \bar{c}$.*

(ii) *When $c_0 \leq c \leq \bar{c}$, the retailer is worse off having the option to invest in demand improvement activities, where $c_0 = \frac{H^2-L^2}{16}$ and $c_0 \leq \underline{c}$.*

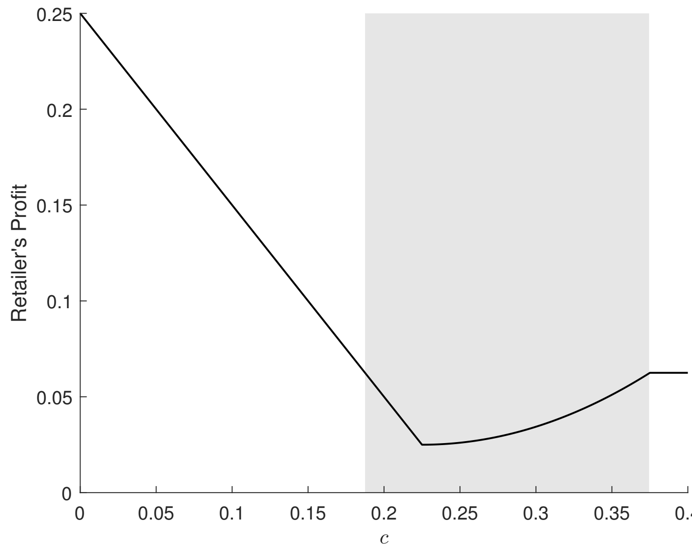

Figure 2 The retailer's profit under a wholesale price contract ($H = 2, L = 1, \lambda = 0.4$)

Figure 2 illustrates the results of Proposition 1. On the surface, it seems that the retailer should be, at the least, weakly worse off as c increases. With a higher cost c, the retailer obviously incurs an expensive toll to invest in demand improvement; but, if the retailer does not make such an investment, its profit remains unaffected by c. In either case, the retailer's profit should weakly decrease with c. However, as we can see from Figure 2, the retailer's profit actually increases with c when c is moderate.

To understand this seemingly counterintuitive result, consider the retailer's profit described in Equations (1) and (2). When c is moderate (i.e., $\underline{c} < c < \bar{c}$), the retailer is indifferent about whether or not to invest, implying that the retailer's profit when investing is equal to its profit when forgoing the investment:

$$\pi_I = \pi_N = \frac{\lambda L^2}{16} + (1-\lambda)\left(\frac{L - w_\emptyset}{2}\right)^2.$$

As c increases, the retailer becomes reluctant to invest, i.e., $\frac{\partial \mu}{\partial c} < 0$. In anticipation of this change, the manufacturer, when it does not observe any demand information, believes the retailer is less likely to invest and, thus, reduces the wholesale price $w_{\emptyset}$ accordingly. This, of course, benefits the retailer. In other words, a higher cost helps the retailer to commit to demand investment less likely, making the manufacturer lower its wholesale price $w_{\emptyset}$. Therefore, the retailer's expected profit increases with c when c is moderate.

Part (ii) of Proposition 1 further suggests that the availability of an investment opportunity does not necessarily benefit the retailer since, as just explained, a moderate investment cost can actually hurt the retailer. The parameter space for the retailer to be worse off with an opportunity to invest in demand improvement is illustrated in Figure 2's shaded area.

An investment opportunity has three effects on the retailer's profit. First, the retailer incurs an investment cost c when it takes the opportunity. Second, by investing, the retailer expands the market potential and benefits in terms of profit. Third, the investment opportunity has the strategic effect of raising the wholesale price $w_{\emptyset}$. When the manufacturer cannot perfectly observe the retailer's investment decision, the retailer always has an opportunistic incentive to invest in demand improvement activities, all the while hoping that the manufacturer does not observe this decision and charges the retailer a low wholesale price. The manufacturer, however, takes the retailer's opportunistic incentive into account when making its pricing decision, and responds by raising $w_{\emptyset}$. Hence, the increase in $w_{\emptyset}$ eventually backfires on the retailer's profit.

Next, we examine how the manufacturer's acquired information affects the retailer's investment decision and profit and summarize our results in the following proposition.

PROPOSITION 2. *Suppose that the manufacturer and the retailer are contracted through a wholesale price contract. The retailer is affected as such:*

(i) *The retailer's likelihood of making the investment, μ, weakly decreases with λ.*

(ii) *The retailer's expected profit weakly increases with λ.*

Part (i) suggests that the retailer hesitates to invest in demand improvement as the manufacturer becomes better informed about the demand state. This is because, if the retailer invests, it prefers that the manufacturer to not observe the demand state since this unobservability leads to a better wholesale price, $w_{\emptyset} < w_H$, for the retailer. If the retailer forgoes the investment, however, it prefers that the manufacturer observe the demand state, which also leads to a better price, $w_L < w_{\emptyset}$. Following this logic then, when λ increases, the retailer is more likely to be offered a higher price w_H once it makes an investment, which effectively discourages the retailer investing at all.

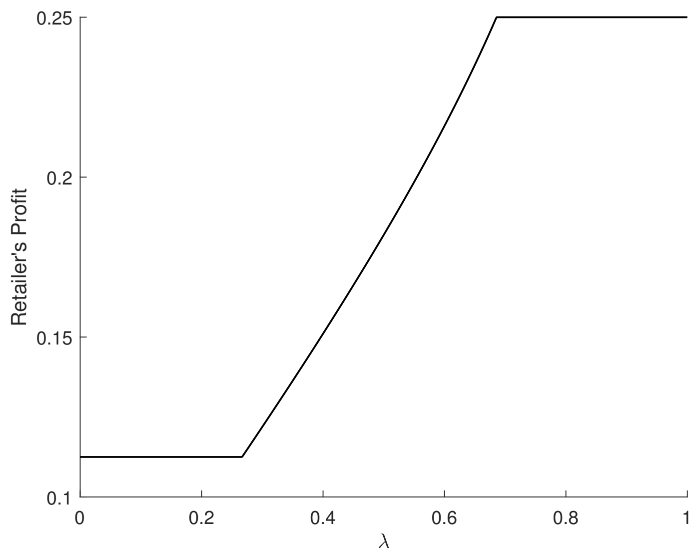

Figure 3 The effect of the manufacturer's information acquisition capability on the retailer's profit ($H = 3, L = 2, c = 0.45$)

Part (ii) speaks to the retailer's profit. The available literature suggests that the retailer should be better off when the manufacturer's capability to acquire demand information is low, thus preserving the retailer's private information. Nonetheless, we find that the opposite is true: The retailer prefers the manufacturer to become more capable of acquiring information, a result that is illustrated in Figure 3. In particular, when $0 \leq \lambda \leq 0.2667$, the retailer always invests in demand improvement and its profit is constant. When $0.2667 \leq \lambda \leq 0.6857$, the retailer randomizes in its investment decision, and its profit increases with λ. When $0.6865 \leq \lambda \leq 1$, the retailer never invests, and its profit peaks and then remains constant. The explanation for these results is as follows: as discussed before, when the manufacturer is unlikely or less likely to observe the retailer's investment decision (i.e., λ is small), the retailer cannot help investing in demand improvement, even when doing so hurts its profit. But when λ increases, the retailer is less likely to invest and ultimately benefits without incurring the investment cost, according to part (i) of Proposition 2. In other words, a high λ helps the retailer commit to investing less or not investing at all, thus curbing its opportunistic behavior and improving its profit.

Next, we solve for the manufacturer's optimal choice of λ. The following proposition summarizes our results.

PROPOSITION 3. *Suppose that the manufacturer and the retailer are contracted through a wholesale price contract. Then, the manufacturer chooses not to acquire any information about the demand state, i.e., it chooses* $\lambda = 0$.

Figure 4 illustrates how the manufacturer's profit changes or, more specifically, decreases with λ, which indicates that the manufacturer would not want to gain any information about the actual demand state even when doing so is costless. This result flies in the face of precedents that state more information about demand always benefits a firm.

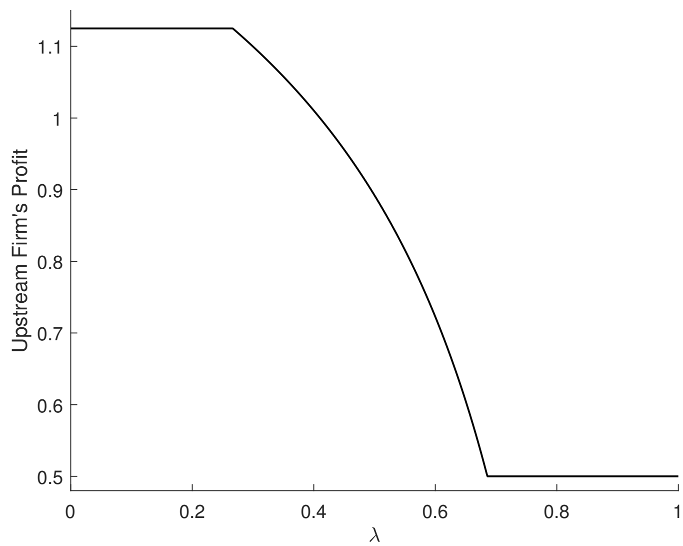

Figure 4 The manufacturer's profit under wholesale prices ($H=3, L=2, c=0.45$**)**

In this case, an increase in λ has two countervailing effects on the manufacturer's profit. First, it allows the manufacturer to know better about the demand state and accordingly fine-tune its wholesale price, making this effect unambiguously beneficial. But, as described in Proposition 2, an increase in λ reduces the retailer's private information, allowing the manufacturer to expropriate the retailer once the retailer invests in demand improvement; however, we now know that this behavior by the manufacturer discourages the retailer from investing to avoid the investment cost and high wholesale prices. As the retailer becomes reluctant to invest, the total market potential shrinks, which, in turn, backfires on the manufacturer — this is the second effect. Overall, under a wholesale price contract, this second effect dominates the benefits of the first, and the manufacturer is worse off knowing about the demand state.

Note that the second effect only exists when the demand state can be endogenously influenced by the retailer's investment activities. When the market condition is exogenously given, as studied in previous works, the manufacturer earns a higher profit when equipped with an increased capability to acquire information (i.e., a higher λ), because this information allows the manufacturer to adjust prices without affecting the demand state. With that being said, Proposition 2 shows that the manufacturer obtains a higher profit without knowing the retailers' investment decision when faced with an endogenous market condition, conveying that ignorance can be bliss for the manufacturer when the downstream retailer endogenously makes demand investment decisions and alters the demand state.

For the total supply chain profit, we have the following proposition.

PROPOSITION 4. *Suppose that the manufacturer and the retailer are contracted through a wholesale price contract. The total supply chain profit weakly decreases with λ.*

The intuition is as follows. As λ increases, the retailer invests less often in demand improvement, which reduces the market potential and hurts the channel profit. In addition, an increase in λ allows the manufacturer to fine-tune its prices, thereby worsening double marginalization. Both effects work to the disadvantage of industry profit and accordingly, the channel profit decreases with λ.

5. Two-Part Tariff Contract

Consider now that the firms are contracted through two-part tariffs, which has a nonlinear pricing schedule in the form $P(Q) = K + w \cdot Q$ if $Q > 0$, where K is the fixed fee and w is the marginal wholesale price. The contract reverts to linear pricing contract upon setting $K = 0$. Two-part tariff contracts are widely used in business-to-business environments, and their popularity is second only to wholesale price contracts.

First, consider a benchmark case in which the manufacturer perfectly observes the market demand, i.e., $\lambda = 1$. In this case, if $a = 1$, the manufacturer will offer the retailer a contract $(K, w) = (H^2/4, 0)$. Because the retailer's investment is already sunk, it does not take the investment cost into consideration and simply accepts the contract, making its payoff zero (net of the investment cost). When $a = 0$, the manufacturer just offers a contract $(K, w) = (L^2/4, 0)$, and the retailer's payoff is, again, zero. In any case, the manufacturer always expropriates the retailer, who can never profit from investing in demand improvement, thus creating a holdup in which the retailer never invests. The following lemma summarizes this result.

LEMMA 3. *Suppose that $\lambda = 1$ and the manufacturer and the retailer are contracted through a two-part tariff contract. In equilibrium, the retailer never invests in demand improvement activities.*

Now, consider the subgame in which $\lambda \in [0, 1]$. We first characterize the manufacturer's pricing decision, and then solve for the retailer's investment decision.

Manufacturer's Pricing Decision. If the manufacturer observes the demand, its pricing decision is straightforward: It offers a contract $(K, w) = (H^2/4, 0)$ when the demand state is high and contract $(K, w) = (L^2/4, 0)$ when the demand state is low. In either case, the manufacturer fully expropriates the retailer's profit. This situation becomes more complex when the manufacturer fails to observe the demand state.

Again, let $\tilde{\mu} = \Pr(a = 1)$ denote the manufacturer's belief about the demand state when it cannot observe it. Suppose that the manufacturer offers a contract (K, w) to the retailer, who reacts in one of two ways: (1) It only accepts the contract when the demand state is high, or (2) it always accepts the contract regardless of the demand state. Note that if the retailer is willing to accept the manufacturer's contract when the demand state is low, it always accepts the contract when the demand state is high.

In the first instance, the manufacturer chooses (K, w) to maximize its expected profit

$$\Pi = \tilde{\mu}\left(K + \frac{H - w}{2} \cdot w\right),$$

subject to the retailer's individual rationality constraint, i.e., the retailer is willing to take the offer when the demand state is high:

$$\left(\frac{H - w}{2}\right)^2 - K \geq 0.$$

In the second instance, the manufacturer chooses (K, w) to maximize its expected profit

$$\Pi = K + \tilde{\mu} \cdot \frac{H - w}{2} \cdot w + (1 - \tilde{\mu}) \cdot \frac{L - w}{2} \cdot w,$$

subject to the retailer's individual rationality constraint, i.e., the retailer is willing to take the offer when the demand state is low:

$$\left(\frac{L - w}{2}\right)^2 - K \geq 0.$$

We solve the manufacturer's profit maximization problems, compare the payoffs, and summarize the results in the following lemma.

LEMMA 4. *Suppose that the manufacturer and the retailer are contracted through a two-part tariff contract and that the manufacturer does not observe the demand state. Let $\tilde{\mu}$ denote the manufacturer's belief about the retailer's investment decision. The manufacturer's contract offers are the following:*

(i) *If $\tilde{\mu} > \mu_0$, the manufacturer offers a contract $(K, w) = (H^2/4, 0)$.*

(ii) *If $\tilde{\mu} < \mu_0$, the manufacturer offers a contract $(K, w) = (((1 + \tilde{\mu})L - \tilde{\mu}H)^2/4, \tilde{\mu}(H - L))$.*

(iii) *If $\tilde{\mu} = \mu_0$, the manufacturer is willing to randomize between the above two contracts, where*

$$\mu_0 = \frac{H^2 - \sqrt{H^4 - 4H^2L^2 + 8HL^3 - 4L^4}}{2(H - L)^2}.$$

Lemma 4 shows that when $\tilde{\mu}$ is high, the manufacturer expects the retailer to invest in demand improvement activities, incentivizing the manufacturer to charge a high price and focus exclusively on the high demand state while forgoing the low demand state. By contrast, when $\tilde{\mu}$ is low, the manufacturer designs a contract that caters to both demand states. Then, the retailer's payoff is zero when the demand state is low but is positive when the demand state is high. Finally, when $\tilde{\mu} = \mu_0$, i.e., the likelihood of the retailer investing is neither low nor high, the manufacturer is indifferent about which contract to select; therefore, the manufacturer is willing to randomize between the choices.

Retailer's Investment Decision Given the manufacturer's pricing strategy discussed above, we continue on to consider the retailer's investment decision. In equilibrium, the manufacturer correctly anticipates the retailer's decision, i.e., $\tilde{\mu} = \mu$.

First, we find that, the retailer never invests in the demand improvement activity with an overwhelming probability, as summarized in the following lemma.

LEMMA 5. *Suppose that the manufacturer and the retailer are contracted through a two-part tariff contract. For any λ, no equilibrium exists in which the retailer invests with a probability $\mu > \mu_0$.*

Lemma 5 states that the retailer never invests in demand improvement with overwhelming probabilities. To understand this result, assume for contradiction that there does exist an equilibrium in which the retailer invests with a high probability of $\mu > \mu_0$. If the retailer invests, Lemma 4 states that it will be offered a contract $(K, w) = (H^2/4, 0)$ regardless of whether or not the manufacturer observes the actual demand state. In this case, the manufacturer always fully expropriates the retailer, who cannot gain anything from its investment opportunity. It is simple to see, then, the retailer strictly prefers to forgo this opportunity and save on the investment cost, a contradiction.

Next, we solve for the retailer's investment decision and present the following proposition.

PROPOSITION 5. *Suppose that the manufacturer and the retailer are contracted through a two-part tariff contract. The retailer's investment decision and the manufacturer's contract offers are as follows.*

(i) *If $c \le \underline{c} = (\sqrt{H^4 - 4H^2L^2 + 8HL^3 - 4L^4} - L^2)(1-\lambda)/4$, the retailer invests in demand improvement activities with probability μ_0. When the manufacturer does not observe the demand state, it offers the retailer a contract $(((1+\mu)L - \mu H)^2/4, \mu(H-L))$ with probability ϕ, and a contract $(H^2/4, 0)$ with probability $1-\phi$, where*

$$\phi = \frac{4c}{(1-\lambda)(\sqrt{H^4 - 4H^2L^2 + 8HL^3 - 4L^4} - L^2)}.$$

(ii) *If* $\underline{c} \leq c \leq \bar{c} = (H^2 - L^2)(1 - \lambda)/4$*, the retailer invests in demand improvement activities with probability* μ*. When the manufacturer does not observe the demand state, it offers the retailer a contract* $(K, w) = (((1 + \mu)L - \mu H)^2/4, \mu(H - L))$*, where*

$$\mu = \frac{H + L}{2(H - L)} - \frac{2c}{(1 - \lambda)(H - L)^2}.$$

(iii) *If* $\bar{c} \leq c$*, the retailer never invests in demand improvement activities. When the manufacturer does not observe the demand state, it offers the retailer a contract* $(K, w) = (L^2/4, 0)$*.*

Proposition 5 shows that, under a two-part tariff contract, the retailer does not always invest even when the cost c is very low. This differs from what would happen with a wholesale price contract, under which the retailer always invests when c is low. This is because, as stated in Lemma 5, if the retailer always invests (or invests with an overwhelmingly high probability), the manufacturer will offer the retailer a contract that fully expropriates its profit.

In the equilibrium characterized above, the retailer invests with probability μ_0, and the manufacturer, upon not observing the demand state, is indifferent about offering a contract that focuses exclusively on the high demand state or one that caters to both demand states. Hence, the manufacturer randomizes its decision between the two contracts, which, in turn, leaves the retailer indifferent about whether or not to invest.

When c is moderate, the retailer invests less frequently, i.e., $\partial\mu/\partial c < 0$. Given the low probability of the retailer investing, the manufacturer always offers it a contract that caters to both demand states. Again, the manufacturer's contract offer leaves the retailer indifferent about investing and, therefore, willing to randomize its choice.

Finally, when c is high, the retailer is deterred from investing at all. Because the retailer never invests, the manufacturer knows the demand state with certainty even if it does not observe the demand information. In this case, the manufacturer always offers the retailer a contract $(K, w) = (L^2/4, 0)$, which fully expropriates the retailer's profit.

Speaking of the retailer's profit, we have the following proposition.

PROPOSITION 6. *Suppose that the manufacturer and the retailer are contracted through a two-part tariff contract. In equilibrium, the retailer's profit is always zero.*

Interestingly, Proposition 6 shows that the retailer never profits when the firms are contracted through two-part tariffs. This is because a retailer's profit is always zero when it does not invest: the manufacturer either offers a contract that fully expropriates the retailer's profit, or offers a contract that the retailer is not willing to accept. In either case, the retailer cannot turn a positive profit. When $c \le \bar{c}$, the retailer indifferently randomizes between investing and not investing, and its profit is as such: $\pi_I = \pi_N = 0$. When $c \ge \bar{c}$, the retailer never invests, and its profit is, again, $\pi_N = 0$. The retailer always breaks even regardless of the investment cost and the manufacturer's capability to acquire demand information.

Lastly, we analyze the manufacturer's profit and solve for the manufacturer's choice of λ and obtain the following proposition. Note that because the retailer's profit is always zero, the total channel profit is equal to the manufacturer's profit.

PROPOSITION 7. *Suppose that the manufacturer and the retailer are contracted through a two-part tariff contract. The manufacturer will choose the optimal level of its demand acquisition capability, λ^*, given by*

$$\lambda^* = \max\left\{1 - \frac{4c}{\sqrt{H^4 - 4H^2L^2 + 8HL^3 - 4L^4} - L^2}, 0\right\}.$$

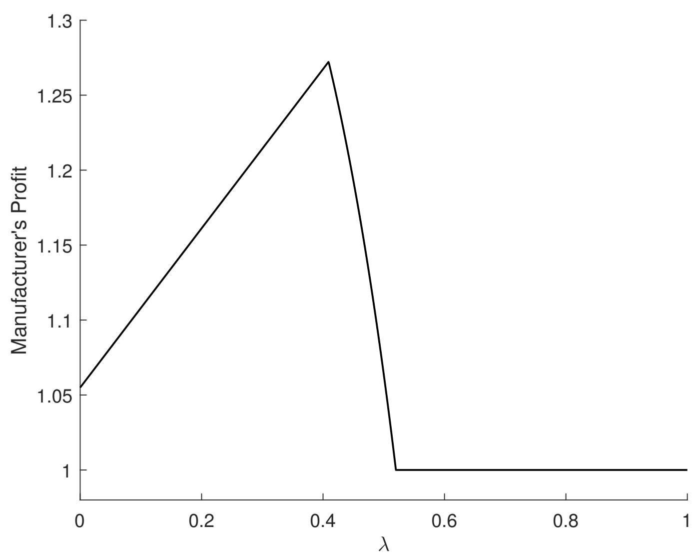

Figure 5 The manufacturer's profit under a two-part tariff contract ($H = 3, L = 2, c = 0.6$)

Figure 5 illustrates the result of Proposition 7. As can be seen, when c is not too high, the optimal λ is an interior solution, indicating that the manufacturer prefers a moderate capability to acquire demand information. This result contrasts with what happens under wholesale price contracts: recall Proposition 3, which states that the manufacturer's profit is maximized at $\lambda = 0$.

To understand Proposition 7, consider the effect of the manufacturer's capability to acquire information on the retailer's investment decision. Denote

$$\underline{\lambda} = 1 - \frac{4c}{\sqrt{H^4 - 4H^2L^2 + 8HL^3 - 4L^4} - L^2}, \quad \bar{\lambda} = 1 - \frac{4c}{H^2 - L^2}.$$

When $\lambda < \underline{\lambda}$, the retailer invests in demand improvement with probability μ_0. When $\underline{\lambda} < \lambda < \bar{\lambda}$, the retailer invests with probability $0 < \mu < \mu_0$; moreover, the probability μ decreases with λ. Finally, when $\lambda \geq \bar{\lambda}$, the retailer does not invest at all.

When $\lambda \leq \underline{\lambda}$, the manufacturer's profit increases with λ, because an increase in λ helps the manufacturer acquire better information about the demand state and adjust its prices accordingly. In addition, within this regime, the retailer always invests with probability μ_0; that is, an increase in λ has no effects on the retailer's investment decision. As a result, the manufacturer enjoys its acquired information without deterring the retailer from investing.

When $\underline{\lambda} < \lambda < \bar{\lambda}$, an increase in λ has, again, two countervailing effects on the manufacturer's profit. First, the manufacturer knows more about the demand state and, thus, can refine its contract with the retailer. Second, as λ increases, the retailer is more likely to be exploited by the manufacturer once it invests in demand improvement; as a result, the retailer becomes reluctant to invest. And as the retailer invests less frequently, the market potential shrinks, thus hurting the manufacturer. Ultimately, the second effect dominates the first, and the manufacturer's profit decreases with λ.

Finally, when $\bar{\lambda} < \lambda$, the retailer never invests, and the manufacturer knows for certain that demand is low regardless of whether or not it receives any information. Therefore, an increase in λ does not provide the manufacturer with additional information, and the manufacturer's profit is constant with λ.

Following the above discussion, we find that the manufacturer's profit is maximized at $\lambda = \underline{\lambda}$. Note that because the retailer's profit is always zero, the total channel profit is also maximized when $\lambda = \underline{\lambda}$.

Lastly, we compare the manufacturer's profit under wholesale price and two-part tariff contracts, and illustrate the results in Figure 6. As can be seen from the figure, even though the manufacturer cannot fully exploit the retailer under two-part tariffs, its profit is always higher under two-part tariff contracts. This result holds because two-part tariff contracts eliminate the double marginalization problem, which benefits the manufacturer.

6. Extensions

In this section, we extend the model in three directions to expand the insights. First, we examine a case in which the manufacturer offers a menu of contracts to the retailer. Second, we consider a scenario in which the retailer's demand improvement activities are not always successful. Third, we examine what happens when the retailer can choose to disclose its investment to the manufacturer.

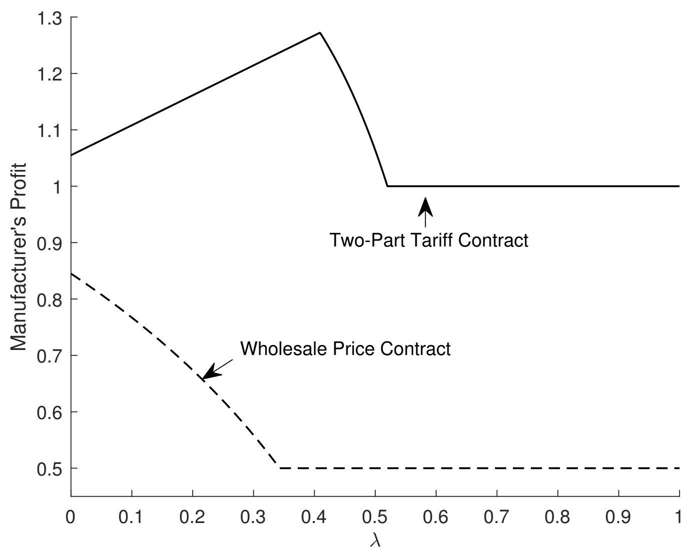

Figure 6 **The manufacturer's profit under different contracts (**$H = 3, L = 2, c = 0.6$**)**

6.1. Menu of Contracts

In this section we examine the case in which the manufacturer is able to offer the retailer a menu of quantity/price bundles $(Q_L, T_L), (Q_H, T_H)$ to the retailer, where Q_i is the quantity delivered to the retailer and T_i is transfer from the retailer to the manufacturer.

Clearly, when the manufacturer perfectly observes the demand state, it does not need to offer such a menu of contracts to the retailer; it can simply offer a single contract $(Q, T) = (\frac{A}{2}, \frac{A^2}{4})$ to the retailer which fully extracts the retailer's profit. The problem is more complicated when the manufacturer does not observe the retailer's demand state.

LEMMA 6. *Suppose that the manufacturer can offer the retailer a menu of price/quantity contracts. Let $\tilde{\mu}$ denote the manufacturer's belief about the retailer's investment decision. The manufacturer's contract offer is*

- *if $\tilde{\mu} > \frac{L}{H}$, the manufacturer offers a contract $(Q, T) = (\frac{H}{2}, \frac{H^2}{4})$;*
- *if $\tilde{\mu} < \frac{L}{H}$, the manufacturer offers a menu of contracts $(Q_L, T_L) = \left(\frac{L - \tilde{\mu} H}{2(1-\tilde{\mu})}, Q_L(L - Q_L)\right), (Q_H, T_H) = \left(\frac{H}{2}, \frac{H^2}{4} - (H - L)Q_L\right)$;*
- *if $\tilde{\mu} = \frac{L}{H}$, the manufacturer is willing to mix between the above two contract offers.*

Lemma 6 suggests that the manufacturer offers the retailer a menu of price/quantiy bundles as long as μ is not too high. Under the contract menu, a retailer with high demand state self-selects the contract (Q_H, T_H), whereas a retailer with low demand state self-selects the contract (Q_L, T_L). The high demand retailer enjoys a profit of $(H - L)Q_L$ (net of its investment cost), whereas the low demand retailer does not make any profit.

As for the retailer's investment decision, we have the following proposition.

PROPOSITION 8. *Suppose that the manufacturer offers the retailer a menu of price/quantity bundles. The retailer's investment decision is as follows.*

- *If* $c \leq \frac{1}{2}(1-\lambda)(H-L)L$, *the retailer invests with probability* $\mu = \frac{(1-\lambda)(H-L)L-2c}{(1-\lambda)(H-L)H-2c}$.
- *If* $c \geq \frac{1}{2}(1-\lambda)(H-L)L$, *the retailer never invests in downstream improvement activities, i.e.,* $\mu = 0$.

Immediately following Proposition 8, we can see that μ, the probability for the retailer to invest in demand improvement activities, is decreasing with λ. The intuition is that, as λ increases, the manufacturer can better extract the retailer's profit improvement from downstream investment, thereby discouraging the retailer to make the investment.

As for the manufacturer's optimal choice of λ, we have the followings.

PROPOSITION 9. *Suppose that the manufacturer offers the retailer a menu of price/quantity bundles. When* $c < \frac{(H-L)L}{2}$, *the manufacturer's profit is maximized at some* $0 < \lambda^* < 1 - \frac{2c}{(H-L)L}$.

The result of Proposition 9 is illustrated in Figure 7. We can see that the manufacturer's profit is again maximized at a moderate λ. An increase in λ has two countervailing forces for the manufacturer: It allows the manufacturer to offer more accurate contracts but at the same time discourages the retailer from making the investment. When λ is low, the former effect dominates and the manufacturer's profit increases with λ; when λ is high, the latter effect dominates and the manufacturer's profit decreases with λ.

6.2. Imperfect Improvement of Demand

In the basic model, we assume that, whenever the retailer invests in demand improvement activities, the market potential always elevates, i.e., demand improvement is always successful. We now relax this assumption and allow some demand improvement activities to fail as they reasonably could in real-life settings.

We modify the retailer's demand improvement endeavors as follows. Once more, if the retailer does not invest in demand improvement, the demand state is L. If the retailer invests, with probability ψ ($0 < \psi < 1$), the improvement is successful and the demand state becomes H; if it invests, with probability $1-\psi$, the improvement fails and the demand state remains low as L. Again, the cost to improve demand is c.

We first characterize the retailer's investment decision in the following lemma.

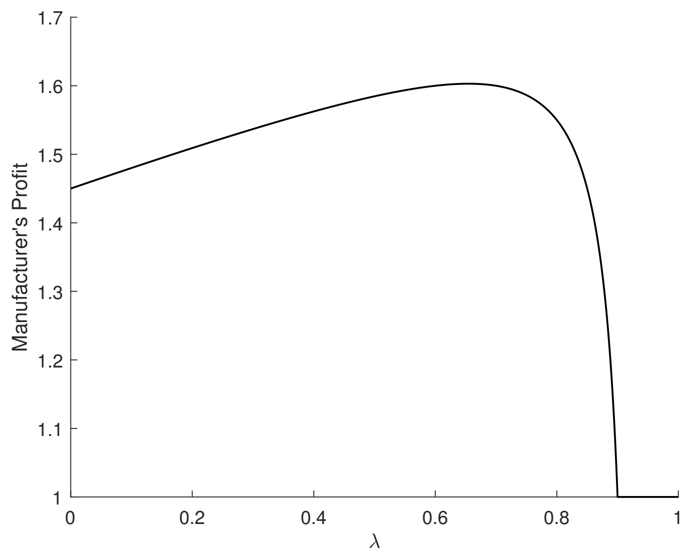

Figure 7 The manufacturer's profit a menu of price/quantity bundles ($H = 3, L = 2, c = 0.1$)

LEMMA 7. *Suppose that the retailer's demand improvement activities are not always successful, and the manufacturer observes the demand state with probability λ. Then, the retailer's investment decisions are as follows:*

(i) *When $c \leq \underline{c} = \psi(H-L)(4H - 3\lambda H + \lambda L - 4(1-\lambda)\psi(H-L))/16$, the retailer always invests in demand improvement activities.*

(ii) *When $\underline{c} \leq c \leq \bar{c} = \psi(H-L)((4-3\lambda)H + \lambda L)/16$, the retailer invests in demand improvement activities with probability μ, where*

$$\mu = \frac{(H-L)((4-3\lambda)H + \lambda L)\psi - 16c}{4(1-\lambda)\psi(H-L)^2}.$$

(iii) *When $\bar{c} \leq c$, the retailer never invests in demand improvement activities.*

As in the basic model, the retailer's investment decision hinges on c. The retailer always invests when $c \leq \underline{c}$ and never invests when $c \geq \bar{c}$; when $\underline{c} \leq c \leq \bar{c}$, it randomizes its investment decision. Then, the likelihood of investment, μ, decreases with c.

Next, we endogenize the manufacturer's choice in its level of information acquisition. Solving for the manufacturer's profit maximization problem, we find that:

PROPOSITION 10. *Suppose that the retailer's demand improvement activities are not always successful. When the manufacturer and the retailer are contracted through wholesale price contract, the manufacturer optimizes its capability to acquire information, λ^*, given by*

$$\lambda^* = \max\left\{\min\left\{\frac{4(4c + \psi(H-L)((1-\psi)H + \psi L))}{(H-L)\psi((3-4\psi)H + (4\psi - 1)L)}, 1\right\}, 0\right\}.$$

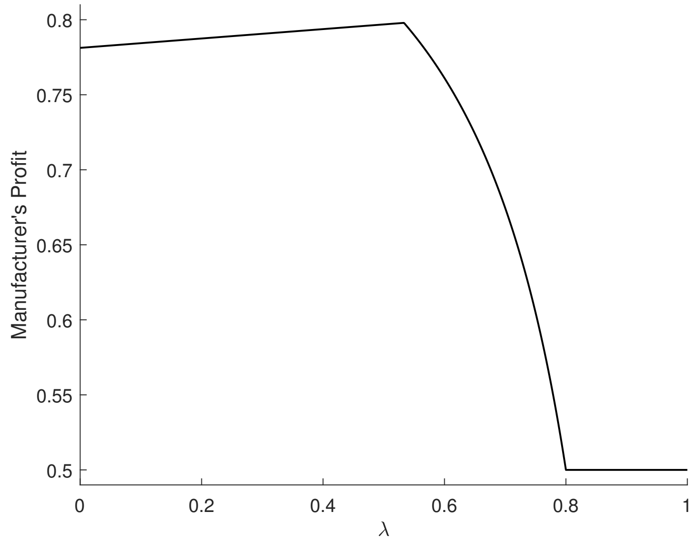

Figure 8 The manufacturer's profit when demand improvement is imperfect ($H = 3, L = 2, c = 0.2, \psi = 0.5$)

Figure 8 illustrates the result of Proposition 10. Unlike Proposition 3, which states that the manufacturer always prefers $\lambda = 0$ when the retailer's demand improvement activities are surely successful, Proposition 10 finds that the manufacturer can benefit from a positive λ when the retailer's activities are not always successful. To understand this, let

$$\underline{\lambda} = \frac{4(4c + \psi(H-L)((1-\psi)H + \psi L))}{(H-L)\psi((3-4\psi)H + (4\psi-1)L)}, \quad \bar{\lambda} = \frac{4(H(H-L)\psi - 4c)}{(3H-L)(H-L)\psi}.$$

When $\lambda \leq \underline{\lambda}$, the retailer always invests. However, because the retailer's demand improvement efforts are not always successful, the manufacturer remains uncertain about the demand state even though it knows that the retailer invested. An increase in λ helps the manufacturer resolve this demand uncertainty and fine-tune its prices.

When $\underline{\lambda} \leq \lambda \leq \bar{\lambda}$ and as λ increases, the retailer invests less frequently, which shrinks the market potential and harms the manufacturer. This effect turns out to overshadow the benefit of resolving any demand uncertainty, and leaves the manufacturer worse off with a higher λ.

Finally, when $\bar{\lambda} \leq \lambda$, the retailer never invests in demand improvement activities, and the manufacturer always knows that the market potential is equal to L regardless of whether or not it receives any demand information. As such, the manufacturer's profit is constant with λ.

Overall, the manufacturer's profit is maximized at $\underline{\lambda}$ if $0 \leq \underline{\lambda} \leq 1$.

6.3. Voluntary Disclosure of Downstream Investment

In the basic model, we find that the retailer prefers the manufacturer to perfectly observe its investment and the demand state since Proposition 2 suggests that the retailer's profit increases with the manufacturer's information acquisition capability. This, then, raises the question of if the retailer can improve its profit by disclosing its investment decision to the manufacturer.

To examine this issue, we add a new stage to our basic sequence of events, specifically after the retailer has made its investment decision. If the retailer has invested in demand improvement at that stage, i.e., $a = 1$, it can credibly disclose this decision to the manufacturer. If $a = 0$, the retailer cannot disclose anything. This is because, once the retailer invests, it can bring hard evidence of this decision to the manufacturer, which can be credibly verified; however, it has no way of credibly proving that it *did not* invest since it always has the option to conceal its investment. Figure 9 presents the modified sequence of events.

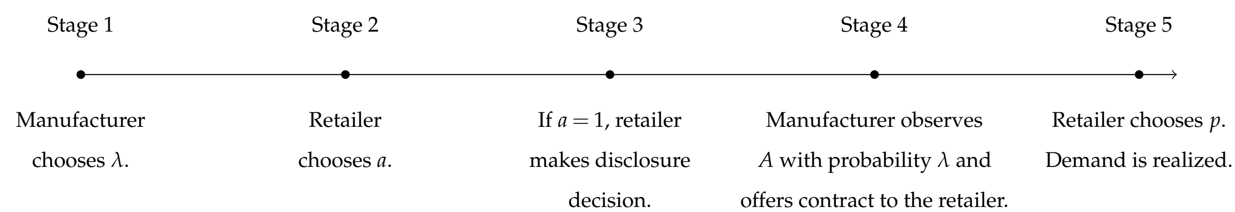

Figure 9 Sequence of events under voluntary disclosure

So, would a retailer voluntarily disclose its investment to the manufacturer? The following proposition indicates that the retailer does not have an incentive to disclose.

PROPOSITION 11. *Suppose that the retailer can disclose its investment in demand improvement to the manufacturer. In equilibrium, the retailer never discloses this information.*

Suppose that the retailer has indeed invested. By disclosing this decision, the retailer will be charged a high wholesale price, w_H, by the manufacturer. But if it conceals its investment, the retailer can secure a better wholesale price, $w_\emptyset \leq w_H$, from the manufacturer, with probability $1 - \lambda$. Disclosure, then, only goes to boost wholesale prices, which the retailer never has an incentive to do. And because the retailer never discloses its investment to the manufacturer, having the option of disclosure does not affect our analysis. The equilibrium outcome for the entire game remains unchanged.

Note that the retailer always prefers to let the manufacturer know when it has *not* invested, i.e., $a = 0$, since this decision will help it negotiate a low wholesale price w_L. However, as mentioned before, the retailer does not have any hard evidence to convince the manufacturer that it did not invest. Hypothetically, if the retailer can credibly disclose $a = 0$, it will always do so when it forgoes an investment to then secure a low price w_L from the manufacturer. Applying the standard unraveling principle (Milgrom 1981), the manufacturer always learns about the demand state through the retailer's voluntary disclosure, regardless of its level of information acquisition. In this case, the retailer's profit is maximized and the manufacturer's profit is minimized.

7. Conclusions

The existing literature on supply chain with private demand information typically assumes that demand is exogenously given and retailers have better demand information than manufacturers do. This paper defies these assumptions by considering that market demand can be endogenously determined by a retailer's decision to invest in demand improvement activities, which are imperfectly observed by a manufacturer. If the demand state is enlarged by the retailer's investment efforts and can be observed by the manufacturer, the retailer will be charged a higher wholesale price. In anticipation of this wholesale price adjustment, the retailer may become reluctant to invest. Our results hinge on this interaction between the manufacturer's capability to acquire demand information and the retailer's endogenous demand investment.

Diverging from common wisdom, we find that the retailer can benefit when the manufacturer becomes better at acquiring demand information. This is because a manufacturer with enhanced information acquisition capabilities discourages the retailer from overinvesting in demand improvement, which increases the retailer's profit. Similarly counterintuitive is the manufacturer's choice to acquire demand information: our results show that the manufacturer does not always benefit from more accurate demand information. In fact, under a wholesale price contract, the manufacturer prefers not to gain any demand information at all. This is because enhanced capability to acquire demand information may help the manufacturer fine-tune its wholesale price, but it also discourages the retailer from investing in demand improvement, resulting in a smaller market base.

This and other primary insights we gained from our basic model remain robust even when the two firms are under a two-part tariff contract or a menu of contracts, or when the retailer's demand improvement activities fail or are voluntarily disclosed.

Our research can be extended in several directions. First, our work focuses on pricing and information acquisition decisions when market demand is endogenized. Future studies may explore how other decisions surrounding factors such as inventory and production are affected by endogenous demand. Second, we consider two prevailing contract types, namely wholesale price and two-part tariff contracts. It would be of interest to see how other contracts perform under endogenous market demand. Lastly, we study a monopoly supply chain with a single manufacturer and a single retailer. Future researcher may examine whether or not our results would change under upstream and downstream competition.

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Appendix

A. Proofs

Proof of Lemma 1. Suppose that in equilibrium, the retailer invests with probability μ. Then $\tilde{\mu} = \mu$, and the wholesale price when the manufacturer does not observe demand is $p_\emptyset = (\mu H + (1-\mu)L)/2$.

Consider first the pure strategy equilibrium in which the retailer always invests, i.e., $\mu = 1$. This leads to $p_\emptyset = H/2$. The equilibrium exists when $\pi_I \geq \pi_N$, which translates to

$$c \leq \underline{c} = \frac{(H-L)(\lambda H + (4-3\lambda)L)}{16}.$$

Second, consider the pure strategy equilibrium in which the retailer never invests, i.e., $\mu = 0$. This leads to $p_\emptyset = L/2$. The equilibrium exists when $\pi_I \leq \pi_N$, which translates to

$$c \geq \bar{c} = \frac{(H-L)((4-\lambda)H + \lambda L)}{16}.$$

Third, consider the mixed strategy equilibrium in which the retailer randomizes between investing and not investing. In such an equilibrium, we have $p_\emptyset = (\mu H + (1-\mu)L)/2$ and $\pi_I = \pi_N$. Solving for μ we come up with

$$\mu = \frac{(H-L)((4-3\lambda)H + \lambda L) - 16c}{4(1-\lambda)(H-L)^2}.$$

Note that the above equilibrium exists only when $\mu \in [0,1]$. This leads to the following existing condition: $\underline{c} \leq c \leq \bar{\mu}$. This completes the proof. Q.E.D.

Proof of Proposition 1. We prove part (i) first. Following Lemma 1, when $c \leq \underline{c}$, the retailer's profit is $\pi = \frac{H^2}{16} - c$, which clearly decreases with c. When $\underline{c} \leq c \leq \bar{c}$, straightforward calculation shows that

$$\frac{\partial \pi}{\partial c} = \frac{16c - ((4-3\lambda)H - (4-5\lambda)L)(H-L)}{8(H-L)^2(1-\lambda)},$$

and it can be shown that $\partial \pi / \partial c \geq 0$ whenever $c \geq \underline{c}$.

Next, consider part (ii). If the retailer cannot invest in demand improvement activities, its profit will be $\pi = \frac{L^2}{16}$. The proof follows immediately by comparing the retailer's profit with $\frac{L^2}{16}$. Q.E.D.

Proof of Proposition 2. Consider two cases: (1) $c \leq \frac{H^2-L^2}{16}$. In this case, the retailer always makes the investment and its profit is constant with λ. (2) $c > \frac{H^2-L^2}{16}$. There exist $\underline{\lambda} = \frac{4(4c-HL+L^2)}{(H-L)(H-3L)}$ and $\bar{\lambda} = \frac{4(H^2-HL-4c)}{(3H-L)(H-L)}$ such that $\mu = 1$ ($\mu = 0$) when $\lambda \leq \underline{\lambda}$ ($\lambda \geq \bar{\lambda}$). When $\underline{\lambda} < \lambda < \bar{\lambda}$, we have

$$\frac{\partial \mu}{\partial \lambda} = \frac{H^2 - L^2 - 16c}{4(H-L)^2(1-\lambda)^2} < 0.$$

Moreover, when $\underline{\lambda} < \lambda < \bar{\lambda}$,

$$\frac{\partial \pi}{\partial \lambda} = \frac{3(3L-H)(3H-L) + (16c - H^2 + L^2)^2}{(H-L)^2(1-\lambda)^2)} > 0.$$

This completes the proof. Q.E.D.

Proof of Proposition 3. Note that when $c \leq \underline{c}$ ($c \geq \bar{c}$), the retailer always (never) makes the investment, and the manufacturer's profit is constant with λ. It suffices to show that the manufacturer's profit decreases with λ when c is in between.

When $\underline{c} \leq c \leq \bar{c}$, we have

$$\frac{\partial \Pi}{\partial \lambda} = \frac{1}{128}\left(3H^2 - 10HL + 3L^2 + \frac{(16c - H^2 + L^2)(16c - 5H^2 + 5L^2)}{(H-L)^2(1-\lambda)^2}\right).$$

Simple calculation shows that

$$\left.\frac{\partial \Pi}{\partial \lambda}\right|_{c=\underline{c}} = -\frac{(3L-H)((2-\lambda)H + \lambda L)}{4(1-\lambda)} < 0.$$

$$\left.\frac{\partial \Pi}{\partial \lambda}\right|_{c=\bar{c}} = -\frac{(3H-L)(\lambda H + (2-\lambda)L)}{4(1-\lambda)} < 0.$$

Noting that $\frac{\partial \Pi}{\partial \lambda}$ is convex in c, we can prove that $\frac{\partial \Pi}{\partial \lambda} < 0$ whenever $\underline{c} \leq c \leq \bar{c}$. This completes the proof. Q.E.D.

Proof of Proposition 5. Consider first the case in which $c \leq \underline{c}$. If the retailer does not invest in demand improvement activities, its profit will be $\pi_N = 0$. Otherwise, the retailer's profit is

$$\pi_I = -c + (1-\rho)\phi\left(\left(\frac{H - \mu(H-L)}{2}\right)^2 - \frac{((1+\mu)L - \mu H)^2}{4}\right) = 0.$$

Therefore, the retailer is willing to mix. As for the manufacturer, according to Lemma 4, the manufacturer is indifferent between the two contracts when it does not observe the demand. As such, the manufacturer is willing to mix. Also, it can be verified that when $c \leq \underline{c}$, $\phi \leq 1$.

Consider next the case in which $\underline{c} \leq c \leq \bar{c}$. If the retailer does not invest in demand improvement activities, its profit will be $\pi_N = 0$. Otherwise, the retailer's profit is

$$\pi_I = -c + (1-\rho)\left(\left(\frac{H - \mu(H-L)}{2}\right)^2 - \frac{((1+\mu)L - \mu H)^2}{4}\right) = 0.$$

Therefore, the retailer is willing to mix. As for the manufacturer, according to Lemma 4, the manufacturer's contract offer is optimal. Note also that when $c \leq \bar{c}$, we have $\mu \geq 0$.

Finally, consider the case in which $\bar{c} \leq c$. If the retailer does not invest in demand improvement activities, its profit will be $\pi_N = 0$. Otherwise, if the retailer deviates and makes the improvement, it profit will be

$$\pi_I = -c + (1-\rho)\left(\frac{H^2}{4} - \frac{L^2}{2}\right) \leq 0.$$

Therefore, the retailer is not willing to invest. This proves the proposition. Q.E.D.

Proof of Proposition 7. Let

$$\underline{\lambda} = 1 - \frac{4c}{\sqrt{H^4 - 4H^2L^2 + 8HL^3 - 4L^4} - L^2}, \quad \bar{\lambda} = 1 - \frac{4c}{H^2 - L^2}.$$

When $\lambda \leq \underline{\lambda}$, the manufacturer's profit is

$$\Pi = \lambda \cdot \frac{\mu_0 H^2 + (1-\mu_0)L^2}{8} + (1-\lambda) \cdot \frac{(\mu_0 H + (1-\mu_0)L)^2}{8},$$

which is increasing with λ.

When $\underline{\lambda} \leq \lambda \leq \bar{\lambda}$, calculation shows that

$$\frac{\partial \Pi}{\partial \lambda} = \frac{1}{16}\left((H+L)^2 + \frac{8c(2c - H^2 + L^2)}{(H-L)^2(1-\lambda)^2}\right).$$

It can be shown that $\partial\Pi/\partial\lambda < 0$ whenever $\underline{\lambda} \leq \lambda \leq \bar{\lambda}$.

When $\bar{\lambda} \leq \lambda$, the retailer never makes the investment and the manufacturer's profit, $\Pi = L^2/4$, is constant with λ. Therefore we can show that the manufacturer's profit is maximized at $\lambda = \underline{\lambda}$. Q.E.D.

Proof of Proposition 10. Let

$$\underline{\lambda} = \frac{4(4c + \psi(H-L)((1-\psi)H + \psi L))}{(H-L)\psi((3-4\psi)H + (4\psi-1)L)}, \quad \bar{\lambda} = \frac{4(H(H-L)\psi - 4c)}{(3H-L)(H-L)\psi}.$$

When $\lambda \leq \underline{\lambda}$, the retailer always makes the investment, and the manufacturer's profit is

$$\Pi = \lambda \cdot \frac{\psi H^2 + (1-\psi)L^2}{8} + (1-\lambda) \cdot \frac{(\psi H + (1-\psi)L)^2}{8},$$

which is increasing with λ.

When $\underline{\lambda} \leq \lambda \leq \bar{\lambda}$, calculation shows that

$$\left.\frac{\partial \Pi}{\partial \lambda}\right|_{c=\bar{c}} = -\frac{(3H-L)(\lambda H + (2-\lambda)L)}{32(1-\lambda)} < 0.$$
$$\left.\frac{\partial \Pi}{\partial \lambda}\right|_{c=\underline{c}} \leq -\frac{(3H-L)((2-\lambda H) + \lambda)L}{32(1-\lambda)} < 0.$$

Because Π is convex in λ when $\underline{\lambda} \leq \lambda \leq \bar{\lambda}$, it follows that $\partial\Pi/\partial\lambda < 0$ whenever $\underline{\lambda} \leq \lambda \leq \bar{\lambda}$.

When $\bar{\lambda} \leq \lambda$, the retailer never makes the investment and the manufacturer's profit, $\Pi = L^2/4$, is constant with λ. Therefore we can prove the proposition. Q.E.D.