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Journal of Industry, Competition and Trade
From Theory to Policy

ISSN 1566-1679

J Ind Compet Trade
DOI 10.1007/s10842-020-00336-2

ONLINE FIRST

Springer

Journal of Industry, Competition and Trade
https://doi.org/10.1007/s10842-020-00336-2

Downstream Information Leaking and Information Sharing Between Partially Informed Retailers

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Received: 30 May 2019 / Revised: 21 November 2019
Accepted: 24 February 2020
Published online: 24 March 2020

Abstract
Retailers benefit under certain conditions from horizontal information sharing, sharing information with competing retailers. However, these benefits could be hindered by the mediation of the manufacturer. Information leaking occurs when the manufacturer filters information from one retailer to the other. We focus on analyzing the impact of horizontal information sharing and information leaking on the profits of the manufacturer and retailers. We develop an analytical model with partial and asymmetric demand signals of customers' valuation. Three scenarios are revised: no information sharing and no information leaking, information sharing, and information leaking. The originality of this study is the use of a demand process with distribution uncertainty, which imitates the information conditions of retailers who join a new market or start selling new products. These retailers own partial information but cannot determine if they are in a better information position than the other retailer. The results indicate that horizontal information sharing increases profits for the retailer with a higher demand signal, but it does not benefit the retailer with a lower demand signal. Additionally, retailers encounter their least preferred scenario if they do not agree to share information horizontally because the manufacturer will always respond by leaking information from the retailer with a higher demand signal to the other retailer. Managers of competing firms facing ambiguity about their demand information position should share information to benefit from a better demand estimation, or at least, prevent the manufacturer to use information leaking to his private benefit.

Keywords Common manufacturer · Demand ambiguity · Horizontal information sharing · Information leaking · Retailer coopetition

JEL Codes C72 · D82 · L14 · M10

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1 Introduction

Considerable work in supply chain and operations management has recognized the potential benefits of sharing information among competitors (hereafter referred in feminine). This is a mutual and voluntary sharing among competing companies at the same echelon defined as horizontal information sharing. In the service industry, competing airlines build alliances to improve their operational performance by sharing capacity and information about demand. These practices lead to a better performance at alliance level; for instance, Star Alliance and SkyTeam Alliance have grown in revenue at an average annual rate of 5.05% since 2015 (Flight Airline Business 2019). In the manufacture of energy-saving lighting, Phillips and LED Effect (LEI) were competitors who cooperated to the development of LED devices in 2006 by agreeing to share confidential business information and proprietary technologies. This partnership allowed them to increase their presence in the market and surpass their competitor, Color Kinetics.[1] However, when competitors purchase from the same upstream party, this upstream party (hereafter referred in masculine) has the potential incentives to share information from one downstream party to the other in order to increase his benefits. This practice is defined as information leaking and it is also visible in real business practice. For instance, the Israeli company, Bruno, distributed electronic components and represented US company, Vicor, to the Israeli manufacturers of the electronic industry for more than two decades. In 2011, Vicor decided to include another distributor, Migvan, to his network in Israel. Bruno sued Vicor in 2015 at the US District Court of Massachusetts because of sharing strategic information of Bruno's operations with Migvan. This information included prices, sales, engineering, design, and the list of customers that allowed Migvan to snatch old and potential customers from Bruno.[2] Although the previous scenarios' outcome is the transfer of information among competitors, there are strategic concerns that affect profit allocation among these parties. Horizontal information sharing is a mutual exchange, whereas information leaking is filtering information unidirectionally in the best interest of the upstream party. In this research, we focus on analyzing the impact of horizontal information sharing and information leaking on the performance of the supply chain, i.e., the profits of the upstream party (manufacturer) and downstream parties (retailers).

Previous work has extensively explored horizontal information sharing between retailers and vertical information between parties at different echelons in supply chain, e.g., manufacturer and retailer, supplier, and manufacturer. The large amount of contributions in information sharing leads us to concentrate on the work that studies information leaking from an upstream party to a downstream one. The results of influential studies in this stream of research agree that manufacturers always leak information voluntarily by informing some of the retailers (Anand and Goyal 2009; Kong et al. 2013) or indirectly through his pricing decisions (Li 2002; Li and Zhang 2008). We find a case of how a manufacturer uses information of downstream parties to price goods in his best intertest. In the construction industry, Firestone was the leading manufacturer of roofing products in the USA with two main distributors in Philadelphia area by 2010: Marjam, and Allied. In 2012, Marjam brought Firestone to court because of selling identical products at lower prices to direct competitors including promotion discounts, rebates, special financing, and more convenient payment terms. Presumably, Firestone's motivation was to reduce the market participation of Marjam to the point of terminating

[1] *Lighting Science Group v. Koninklijke Philips*, 624 F. Supp. 2d 1174 (E.D. Cal. 2008)
[2] *Bruno Int'l Ltd. v. Vicor Corp.*, CIVIL ACTION NO. 14-10037-DPW (D. Mass. Sep. 16, 2015)

her distribution agreement in December 2011 and benefit Allied, which remains as the only significant distributor of Firestone in the area. This claim of discriminatory pricing was granted to the plaintiff by the court of New Jersey.[3]

Previous work has built their analytical models with information asymmetries between retailers. They establish an incumbent retailer and entrant retailer, where the former has accurate knowledge of the upcoming condition of demand (Wang et al. 2018), or at least a signal about an uncertain demand (Anand and Goyal 2009). Jain and Sohoni (2015) consider the limitations of this assumption and allows the entrant retailer (second-mover in their original work) to have the possibility of having better information about demand. Following this direction, we argue that it is improbable for one retailer to determine the other retailer's information position about demand when both retailers enter a new market or start selling a new product whose demand is uncertain. To address this gap, this study investigates the retailers' decision of horizontal information sharing and manufacturer's decision of information leaking when retailers cannot determine their own information position with respect to others'.

The present study is organized as follows. Section 2 presents a literature review of the previous work including information leaking in supply chain. Section 3 develops the analytical model with three scenarios: no information sharing no information leaking, horizontal information sharing, and information leaking. Section 4 uses a numerical example to point out the insights of the model. Section 5 brings up a discussion about our findings and contribution to literature. Section 6 concludes the study.

2 Literature Review

Information leaking, horizontal information sharing, and vertical information sharing are three streams of research related to our study. We build on contributions of economics regarding the effect of horizontal information sharing on improving profits of an oligopoly (Clarke 1983; Novshek and Sonnenschein 1982; Vives 1984; Gal-Or 1985, 1986; Li 1985; Shapiro 1986; Raith 1996). Likewise, we use findings of the benefits of vertical information sharing among partners in supply chain (Cachon and Lariviere 2001; Özer and Wei 2006; Gal-Or et al. 2008; Dukes et al. 2011; Gal-Or et al. 2007; He et al. 2008; Guo and Iyer 2010). Horizontal information sharing and vertical information sharing converge in information leaking (Chen et al. 2019). The present study reviews in detail the previous work whose supply chain structure is represented in Fig. 1. This figure shows a single upstream manufacturer or supplier that is common to downstream competing retailers. The cash flow portrays retailers paying a wholesale price (w) to the manufacturer and the product flow is the quantities of product ordered by the retailer from the manufacturer to later sell to final customers (q). The information flow starts with retailers who receive a private signal about demand. Retailers choose to share information directly between them (horizontal information sharing) or with the manufacturer (vertical information sharing). The manufacturer chooses to unilaterally share the information of one retailer to others (information leaking).

A summary of work on information leaking is presented in Table 1. The table indicates with an "X" the presence of that characteristic in the analytical model of that work. Reading the table from left to right, number of retailers indicates the type of network structure used in their

[3] *Marjam Supply Co. v. Firestone Bldg. Prods. Co.*, Civ. No. 11-7119 (WJM) (D.N.J. Nov. 30, 2012)

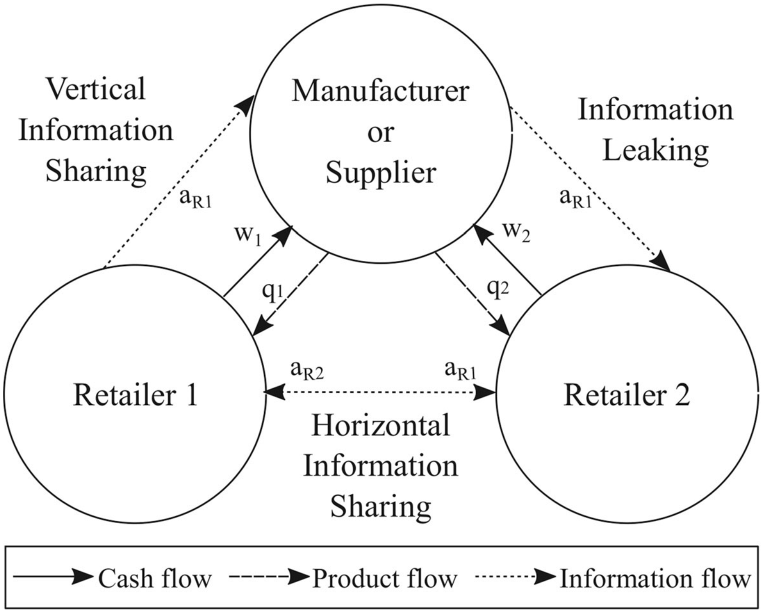

Fig. 1 Supply chain structure with information sharing and leaking

model: single manufacturer with two retailers, or single manufacturer with multiple retailers. Retailer competition establishes if the retailers were modeled competing in quantity simultaneously, in quantity sequentially, or in price. Type of products presents if retailers are selling homogenous or differentiated products. Demand uncertainty shows how the stochastic component of demand behaves. This could be following a probability distribution or a two-stage process (high and low condition). Then, an "X" means that the model in that work followed this assumption. Hence, previous work choose to model symmetric retailers or retailers with different information positions (incumbent and entrant retailer), information sharing agreed before or after receiving the demand signal (ex-ante information sharing), truthful information sharing or not, confidentiality agreements to prevent leaking or not, and retailer receiving a demand signal effortless or choosing to purchase demand information (retailer information acquisition). The notes of the table briefly describe peculiarities of a study.

Initially, economic papers (Gal-Or 1985, 1986; Vives 1984) discuss implicit collusion of competitors by establishing a trade association to share information. However, this association shares the information among all competitors without discrimination and profit-driven motivation. Bernheim and Whinston (1985) analyze the use of a single agency in search of collusion with strong assumptions as information symmetry among competitors and delegation of marketing decisions. Hence, Villas-Boas (1994) is the first work discussing information leakage in the context of information asymmetry and a profit-driven agency. His main research question is to determine under what circumstances competing firms should share the same advertising agency. Sharing a common advertising agency is a credible mean to transfer information to competitors because the advertising agency will accumulate private information about consumers from firms and it will leak information from one firm to others to increase the profits of the agency. The author finds three important effects that will shape the decision of firms. The first effect is the decision-making framework effect that is always positive toward

Table 1 Summary of literature on information leaking

Studies	Number of retailers		Retailer competition			Type of products		Demand uncertainty		Incumbent and entrant retailer	Ex-ante sharing	Truthful sharing	Confidentiality agreement	Retailer info. acquisition
	2	>2	Q Seq.	Q Sim.	P	Hom.	Diff.	HL	Other					
Li (2002)		X		X		X			$N(0,\sigma^2)$[i1]		X [k1]	X	X[m1]	
Zhang (2002)	X			X	X	X	X[g1]		$N(0,\sigma^2)$[i1]		X	X		
Li and Zhang (2008)		X		X	X		X		$N(0,\sigma^2)$[i1]		X	X	X	
Anand and Goyal (2009)	X		X			X		X		X			X[m2]	X
Jain et al. (2011)		X		X			X		$N(0,\sigma^2)$[i1]	j1	X	l1		
Shamir (2012)		X			X		X		$N(0,\sigma^2)$[i1]		X	X[l2]	X	
Kong et al. (2013)	X		X	X		X		X		X[j2]				
Guo et al. (2014)	X[a1]				X	X			$N(\theta,\sigma^2)$ [i2]	j3		X		
Jain and Sohoni (2015)	X		X				X		$N(0,\sigma^2)$[i1]	j4	X	X	X	X[n1]
Jiang and Hao (2016)	X[a2]			X		X			$N(0, \sigma^2)$	j5	X	X		X
Shamir (2017)		X			X	X		X			X	X		
Hao et al. (2018)	X			X	X	X			$N(0, \sigma^2)$		X [k2]	X	X	
Wang et al. (2018)	X		X			X		X		X[j6]		X	X[m3]	
Wu et al. (2018)	X			X		X		X		X[j7]	X	X		

Diff. differentiated, *Hom.* homogeneous, *HL* high and low demand, *N* normal distribution, *P* price, *RS* revenue-sharing, *Seq.* sequential, *Sim.* simultaneous, *U* uniform distribution, *W* wholesale price

a1. Model of competing channel on Section 4

a2. The authors revised 4 different systems. We consider the system of retailer competition RC

g1. The author analyzed independent, substitutes and complimentary products under different types of retailer competition

i1. The model is also suitable for prior-posterior distribution as gamma-Poisson and beta-binomial

i2. Truncated normal, Gamma, and all symmetric distributions

j1. Symmetric retailers. They receive random signals from demand distribution

j2. They also explore the case when the entrant retailer moves first

j3. Two retailers: centralized and decentralized. The decentralized retailer could be uninformed about demand signal

j4. First-mover and second-mover retailer. Any retailer could be better information about demand

j5. Symmetric retailers receiving correlated signal about demand j6. Incumbent retailer with high bargaining power. She establishes the wholesale price

j7. Their structure is single supplier and two manufacturers. One manufacturer has capacity constraints and the other has unlimited capacity

k1. Manufacturers have to decide ex ante to acquire information from retailers

k2. Simultaneous and sequential information acquisition from retailers

l1. The authors presented two different pricing mechanisms that motivate truthful information sharing: (1) rewards for retailers sharing optimistic information, and (2) wholesale price with a fixed payment

l2. Two scenarios with strategic incentives for truthful sharing: horizontal and public information sharing

m1. In spite of confidentiality, the authors recognize the involuntary leaking by reflecting the private information on pricing decisions

m2. Exclusivity sourcing strategies

m3. Information concealment

n1. Information acquisition refers to a retailer who invests to improve her demand information sharing a common advertising agency because the agency's information leakage will lead actions to better adjust to the real market situation. The other two effects are not necessarily positive: the strategic effect and the uncertainty effect. The former effect represents the reaction of competitors to the information leaked by the agency, and the latter effects focuses on the increasing variation of the reaction of competitors in presence of more available information. Later, the analytical model and findings of Villas-Boas (1994) inspire in future work replacing the advertising agency with an upstream party of the supply chain gathering information of competing downstream parties.

The majority of work in information leakage follows the analytical model of Li (2002) with demand signals. In Li's setup, demand has a stochastic component that distributes with mean in zero and fixed variance. This assumption applies for prior-post distributions like normal-normal, gamma-Poisson, and beta-binomial. Guo et al. (2014) extend the demand signal setup to all symmetric distributions. Our model follows the partial information about demand closer to the framework used by Jain and Sohoni (2015), but we establish an important difference. The demand distribution in our model is uncertain and retailers receiving information cannot determine their information position with respect to the average and other statistics of the distribution.

The latest work regarding information leakage in supply chains includes interesting variations to address specific scenarios. Fang and Ren (2019) study how retailers decide to share distorted information to suppliers to prevent suppliers' encroachment in the retail market. Their model includes non-truthful information sharing and retailers' adverse selection behavior. Their results show that retailers reduce the impact of information leakage by providing distorted information to the manufacturer and that acquiring information is not always beneficial to the retailer. Zhao et al. (2019) analyze a supply chain structure under revenue-sharing contract, similar to Kong et al. (2013), but they include two types of collusion between retailers: explicit and tacit, and retailers are both incumbent in the market. They conclude that the manufacturer needs to provide side payments to get information from retailers, and downstream retailers promote explicit collusion as the signal is more accurate and the quantity competition, weaker. Wang et al. (2019) consider a dominant entrant retailer that is wholesale price-maker and a weak incumbent retailer that is price-taker. They find cases where the manufacturer is better off by not leaking information and that manufacturers align with the weak incumbent as the variance of demand increases.

Most of previous work uses symmetric retailers who receive private signals about demand. The signals of all these retailers are random and follow the same distribution. However, scenarios with information asymmetry is the most prevalent in real business practice. Some work uses two retailers, setting them as incumbent retailer and entrant retailer. The former has better demand information than the latter. Wang et al. (2019) also present the possibility in which incumbent retailers are not the better-informed parties per se. Kong et al. (2013) build a model of sequential competition and they evaluate two cases: when the incumbent retailer orders first, and when the entrant retailer orders first. Jain and Sohoni (2015) allow the second-moving retailer to have a better-informed position about demand than the first-moving retailer. Our model posits that retailers may not be able to determine their information position with respect to others and that simultaneous competition is more suitable to this ambiguous scenario. Hence, we attempt to analyze how the decisions of horizontal information sharing and information leaking might change when retailers have partial and asymmetric information about demand, and they do not know if they are the better-informed than the other retailer.

3 Model

The present study builds an analytical model with a supply chain structure of single manufacturer and two retailers with different private information about demand. The manufacturer provides a homogeneous product using a wholesale price contract. Retailers do not modify the purchased products and they compete in quantity simultaneously under a duopoly market structure to produce the volume that maximizes their benefits. The quantities ordered by both retailers are aggregated and sold in the market. The information sharing agreements are established ex ante, and retailers do not need to make decisions to acquire information about demand. In addition, all parties share information truthfully and no confidentiality agreements are implemented. Retailers receive a demand signal (a_{Ri}) but they cannot determine if their own information position is better than the others'. The flow of cash, product and information are represented in Fig. 2 and the notations and parameters of the analytical model are listed in Table 2.

This model imitates a market scenario in which a new product is sold by retailers or a new market is opened. There is limited data available to have a distribution, a central tendency, or a dispersion measure that characterizes demand. These scenarios are consistent with real business practice. Bouncken et al. (2018) shows empirical evidence of German machinery and medical firms which operate in markets with radical and incremental innovations, and they opt to collaborate with other competing firms as a way to reduce market uncertainties. Therefore, the demand process is said to be ambiguous because the demand distribution is uncertain (Camerer and Weber 1992).

Facing demand ambiguity, retailers still commit to gather some information. We model this effort as a signal a_i that retailers receive about customers' valuation of the product. This signal contains partial information of the total valuation. The total customers' valuation is the summation of the private signals of the retailers, $a = \sum_i a_i$ (Wu et al. 2018). In the scenario of a new product, partial information occurs when one retailer focuses on the value of certain features of the new product, while the other retailer focuses on the value of the rest of the features. Similarly, in the scenario of opening a new market, partial information occurs when a retailer has information of the valuation from a few niches, and the other retailer knows the valuation of the rest of niches.

We address the retailer whose signal presents higher customers' valuation as overestimating retailer (retailer O) and the retailer whose signal presents lower customers' valuation as underestimating retailer (retailer U). When there is no information sharing, retailer O will take decisions with an inflated demand because she assumes that the other retailer holds a similar

Table 2 Notations and parameters of the analytical model

Indices	
i	Subject; $i = M$ manufacturer, RU retailer U, RO retailer O
r	Scenario; $r = NS$ no sharing and no leaking information, S information sharing, L information leaking from retailer O to retailer U
Parameters	
a_i	Information about base demand of retailer $i = RU, RO$
b	Slope of inverse demand function
c	Production cost
Decision variables	
p	Retail price
q_i	Units ordered and sold by retailer $i = RU, RO$
w_i	Wholesale price charged to retailer $i = RU, RO$
π_i^r	Profit of i in scenario r

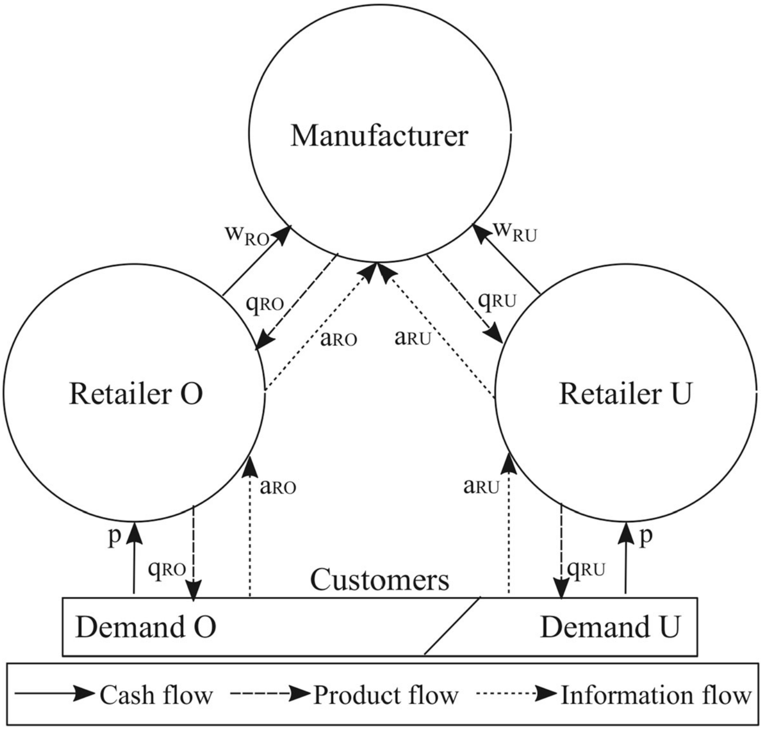

Fig. 2 Supply Chain Model with Partially and Asymmetric Informed Retailers

demand signal. In contrast, retailer U will take decisions with an understated demand using the same heuristic (Mukhopadhyay et al. 2011).

Our analytical model has assumptions to focus on the research questions.

(1) Manufacturer provides homogeneous products and the product demand is not backlogged. His operations always fulfill the orders of retailers at the time requested (Kaminsky and Kaya 2009) because the penalty cost of delaying is high.
(2) Inventory clearing. Sales units equal to retailers' inventories which equal to manufacturer's production units. Hence, the production is available and sold at the same time of demand realization.
(3) No fixed setup cost when placing an order and no production or capacity constraints.
(4) All firms are risk neutral, which means that they only focus on maximizing their expected profits.
(5) Retailers' benefit of sharing fake information with the manufacturer is lower than the cost of production shortage and penalties of delay to the final customers. Similarly, retailers share true information horizontally because the benefit of more precise expectations about demand is greater than the benefit of sharing fake. Hence, the manufacturer and the retailers share their information truthfully to isolate the mistrust issue embedded to information sharing (Kong et al. 2013).
(6) Both retailers have already agreed to share their private signal vertically with the manufacturer. Previous literature supports this assumption because sharing demand information toward upstream echelons generates benefits to retailers by reducing the

overall demand uncertainty and retailer's penalty cost of delay; a summary of relevant studies supporting vertical information sharing is reviewed by Rached et al. (2016).

The sequence of events starts when each retailer decides whether to share information horizontally or not. Next, each retailer receives a demand signal, a_{RU} and a_{RO}. They will share it vertically by default and horizontally depending on their decisions. Later, if horizontal information does not occur, the manufacturer decides whether to leak information or not. Then, the manufacturer sets a wholesale price, w_{RU} and w_{RO}. Next, retailers determine their order quantity under Cournot competition and set a retail price. Retailers order units by paying a wholesale price for later selling these units at a retail price to customers. Finally, the market demand is realized, and the production and sales take place.

The model represents a single period game. The proofs of all lemmas and theorems of the analytical model are given in the appendices. The objective function is to maximize profits by optimizing decision variables as wholesale price and order quantity. We employ an inverse linear demand function $p(q)$ with a stochastic base demand. The retail price p is a decreasing function of the total order quantity $Q = q_{RU} + q_{RO}$ from both retailers, $p(q) = a - b(q_{RU} + q_{RO})$. The base demand a represents total customers' valuation and it is computed by adding the signals of retailer U and retailer O, $a = a_{RU} + a_{RO}$. Each of these signals follows a uniform distribution, $a_i \sim U(a\_ - x, a - x)$ with an uncertain parameter $x \sim U(0, a\_)$. Since the domain of function a_i changes, its mean value changes accordingly and the retailers cannot determine whether their signal is at, below, or over the mean of the distribution. In presence of ambiguity, Nickerson (2001) suggests that own private information is the best estimation of the other retailers' position.

The income of the manufacturer comes from selling quantities to both retailers at a wholesale price per unit, $w_i q_i$. Under certain conditions, the manufacturer could charge different prices to each retailer. Whereas, the expenses of the manufacturer is represented by total cost of production, cQ. Then, the profit of the manufacturer is given by

$$\pi_M = w_{RU} q_{RU} + w_{RO} q_{RO} - c(q_{RU} + q_{RO}). \tag{1}$$

The income of retailers comes from sales, $p(Q)q_i$, while the expenses is the amount paid to the manufacturer for the order quantity, $w_i q_i$. The profit functions of retailers equal to

$$\pi_{RU} = [a_{RU} + a_{RO} - b(q_{RU} + q_{RO})] q_{RU} - w_{RU} q_{RU}, \tag{2}$$

$$\pi_{RO} = [a_{RU} + a_{RO} - b(q_{RU} + q_{RO})] q_{RO} - w_{RO} q_{RO}. \tag{3}$$

There are three different scenarios for this setup. The first scenario is when there is no information sharing among supply chain members, and the manufacturer will not leak information. The second scenario is information sharing. Retailers practice horizontal information sharing by exchanging their private demand information before ordering from the manufacturer. Notice that a leaking decision from the manufacturer loses relevance in the second scenario because both retailers have already shared information and leaking has no effect. The third scenario is information leaking. Retailers decide not to share information between them and the manufacturer leaks information from one retailer to the other retailer before ordering.

3.1 No Information Sharing and No Information Leaking Scenario

In this scenario, we review the case when there is no information sharing between retailers and manufacturers cannot leak information to retailers. No information exchange drives all parties to only rely on their own information. This scenario also includes when retailers do not reach a horizontal information sharing agreement.

We first solve the Cournot reaction functions of retailer U and retailer O. In presence of ambiguity, each retailer's best guess about the information owned by the other retailer is her own private information (Nickerson 2001). The optimal quantity for each retailer is

$$q_{RU} = (1/3b)(2a_{RU} - w_{RU}), \tag{4}$$

and

$$q_{RO} = (1/3b)(2a_{RO} - w_{RO}). \tag{5}$$

Substituting Eqs. 4 and 5 in the inverse demand, the optimal retail price is

$$p = (1/3)(a_{RU} + a_{RO} + w_{RU} + w_{RO}), \tag{6}$$

and substituting them in the manufacturer profit function equals to

$$\pi_M = (1/3b)[(w_{RU} - c)(2a_{RU} - w_{RU}) + (w_{RO} - c)(2a_{RO} - w_{RO})]. \tag{7}$$

Now, we maximize the manufacturer's profit function. The optimal wholesale prices are

$$w_{RU}^* = a_{RU} + c/2, \tag{8}$$

and

$$w_{RO}^* = a_{RO} + c/2. \tag{9}$$

It is evident that the manufacturer can benefit from applying price discrimination to retailers depending on their signal. Equations 4, 5, and 6 are rewritten as $q_{RU}^* = (1/3b)(a_{RU} - c/2)$, $q_{RO}^* = (1/3b)(a_{RO} - c/2)$, and $p^* = (1/3)(2a_{RU} + 2a_{RO} + c)$. Finally, the optimal profits for each retailer and the manufacturer equal to

$$\pi_{RU}^{NS\,*} = (1/36b)\left(-4a_{RU}^2 + 8a_{RU}a_{RO} - 4a_{RO}c + c^2\right), \tag{10}$$

$$\pi_{RO}^{NS\,*} = (1/36b)\left(-4a_{RO}^2 + 8a_{RU}a_{RO} - 4a_{RU}c + c^2\right), \tag{11}$$

$$\pi_M^{NS\,*} = (1/3b)\left[(a_{RU} - c/2)^2 + (a_{RO} - c/2)^2\right]. \tag{12}$$

Note that no leaking and no sharing is the default scenario in this model and both retailers are initially earning positive profits.

Lemma 1

$$\pi_{RU}^{NS\,*} > 0 \text{ and } \pi_{RO}^{NS\,*} > 0 \text{ if } 0 < c < (a_{RU} + c/2) < (a_{RO} + c/2) < 2a_{RU}.$$

Theorem 1 ${\pi_{RU}^{NS}}^* > {\pi_{RO}^{NS}}^*$ if lemma 1.

Although retailer O holds higher levels of information about customers' valuation, the profit of retailer O is reduced because she assumes that retailer U holds similar private information, which drives her to take decisions with an inflated demand. In addition, the manufacturer applies price discrimination charging a higher wholesale price to retailer O.

3.2 Information Sharing Scenario

This scenario presents the case when retailers agree to share their demand information. Hence, both retailers have full information about customers' valuation for their decision-making. We perform the same computations as in the previous scenario. After maximizing the profit of the manufacturer, the optimal wholesale price equals to

$$w_U^* = w_O^* = (1/2)(a_{RU} + a_{RO} + c). \tag{13}$$

The manufacturer is unable to price discriminate among retailers. The optimal quantities for retailer U and retailer O are

$$q_{RU}^* = q_{RO}^* = (1/6b)(a_{RU} + a_{RO} - c). \tag{14}$$

Then, the optimal retail price is

$$p^* = (1/3)(2a_{RU} + 2a_{RO} + c) \tag{15}$$

and the optimal profits for each retailer and the manufacturer equals to

$${\pi_{RU}^{S}}^* = {\pi_{RO}^{S}}^* = (1/36b)(a_{RU} + a_{RO} - c)^2, \tag{16}$$

$${\pi_{M}^{S}}^* = (1/6b)(a_{RU} + a_{RO} - c)^2. \tag{17}$$

Theorem 2 ${\pi_{RO}^{S}}^* > {\pi_{RO}^{NS}}^*$ if lemma 1.

Corollary 1 ${\pi_{RU}^{S}}^* = {\pi_{RO}^{S}}^*$ and ${\pi_{RU}^{NS}}^* > {\pi_{RU}^{S}}^*$ if lemma 1.

3.3 Information Leaking Scenario

In this scenario, retailers decide not to share information between them and the manufacturer leaks information. The manufacturer has the information of both retailers who had previously agreed to involve in vertical information sharing. Leaking information is voluntary and explicit by revealing the demand information of one retailer to the other retailer.

We analyze the case when the manufacturer provides the demand information of retailer O to retailer U. The manufacturer earns higher profits from leaking from retailer O to retailer U than vice versa. After information leaking, retailer U obtains full information, whereas retailer O only has her own information and needs to guess about the information of retailer U. The best guess of retailer O is to infer that retailer U has the same demand information. We first solve the Cournot reaction functions, the optimal order quantities are

$$q_{RU} = (1/3b)(a_{RU} + a_{RO} - w_{RU}), \tag{18}$$

and

$$q_{RO} = (1/3b)(2a_{RO} - w_{RO}). \tag{19}$$

Substituting Eqs. 18 and 19 in the inverse demand function, the optimal retail price is

$$p = (1/3)(2a_{RU} + w_{RU} + w_{RO}). \tag{20}$$

Maximizing the profit of the manufacturer with respect to the wholesale price, we obtain optimal wholesale prices

$$w_{RU}{}^{*} = (1/2)(a_{RU} + a_{RO} + c), \tag{21}$$

and

$$w_{RO}{}^{*} = a_{RO} + c/2. \tag{22}$$

Then, Eqs. 18, 19, and 20 are rewritten as $q_{RU}{}^{*} = (1/6b)(a_{RU} + a_{RO} - c)$, $q_{RO}{}^{*} = (1/3b)(a_{RO} - c/2)$, and $p^{*} = (1/6)(5a_{RU} + 3a_{RO} + 2c)$, respectively. Finally, the profit for each retailer and the manufacturer are

$$\pi^{L}_{RU}{}^{*} = (1/36b)\left(2a_{RU}{}^{2} + 2a_{RU}a_{RO} - 3a_{RU}c - a_{RO}c + c^{2}\right), \tag{23}$$

$$\pi^{L}_{RO}{}^{*} = (1/36b)(2a_{RO} - c)(5a_{RU} - 3a_{RO} - c), \tag{24}$$

$$\pi^{L}_{M}{}^{*} = (1/12b)\left[(a_{RU} + a_{RO})^{2} + 4a_{RO}{}^{2} - 2c(3a_{RO} + a_{RU} - c)\right]. \tag{25}$$

The manufacturer has no incentives to leak information from retailer U to retailer O because he will earn lower profits than leaking in the opposite direction. Leaking information from retailer U to retailer O generates profits equal to

$$\pi^{L\ U\to O^{*}}_{M} = (1/12b)\left[(a_{RU} + a_{RO})^{2} + 4a_{RU}{}^{2} - 2c(3a_{RU} + a_{RO} - c)\right] \tag{26}$$

Using Lemma 1, the profits of leaking from retailer O to retailer U is higher than the profits of leaking from retailer U to retailer O,

$$\pi^{L}_{M}{}^{*} - \pi^{L\ U\to O^{*}}_{M} = (a_{RO} - a_{RU})(a_{RO} + a_{RU} - c)/3b > 0 \tag{27}$$

Consequently, in this study, the leaking scenario only considers the leaking direction from retailer O to retailer U because it is the decision in which the manufacturer is better off.

Theorem 3 $\pi_{RU}^{L\ *} > \pi_{RO}^{L\ *}$ if lemma 1.

Analyzing retailer O position, we compare her profits in the different scenarios. First, we assess the profit of retailer O in the no sharing and no leaking and information leaking scenarios.

Theorem 4 $\pi_{RO}^{NS\ *} > \pi_{RO}^{L\ *}$ if lemma 1.

Second, we review the profit of retailer O in the information sharing and information leaking scenarios.

Theorem 5 $\pi_{RO}^{S\ *} > \pi_{RO}^{L\ *}$ if lemma 1.

Corollary 2 $\pi_{RO}^{S\ *} > \pi_{RO}^{NS\ *} > \pi_{RO}^{L\ *}$ if lemma 1.

Corollary 2 indicates that retailers should always prefer to share their information horizontally. If not sharing information, retailer O will earn lower profit and, in the worst scenario, the manufacturer could leak information reducing the profit of both retailers.

The profit of the manufacturer is also subjected to the different scenarios. We compare the profit of the manufacturer in the information sharing scenario against the information leaking scenario.

Theorem 6 $\pi_M^{L\ *} > \pi_M^{NS\ *}$if lemma 1.

Later, we compare the profit of the manufacturer in the no sharing and no leaking scenario against the information sharing scenario.

Theorem 7 $\pi_M^{NS\ *} > \pi_M^{S\ *}$ if lemma 1.

Corollary 3 $\pi_M^{L\ *} > \pi_M^{NS\ *} > \pi_M^{S\ *}$if lemma 1.

Corollary 3 indicates that the manufacturer prefers the information leaking scenario. If retailers do not agree to share information horizontally, the manufacturer will prefer to leak information from the retailer with higher demand information to the other retailer.

4 Numerical Example

After solving the analytical model, we conduct a numerical example to illustrate the supply chain interaction. We recall the expressions in Table 3 to compute decision variables and profits. The values assigned to the parameters of the model are demand uncertainty $x = 0$ and demand distribution is between 10 and 20; demand signals are $a_{RU} = 12$ and $a_{RO} = 18$; slope of inverse demand is $b = 1$; and production cost is $c = 3$. Table 4 presents the computations of the numerical example for the three scenarios and Fig. 3 illustrates the profits of each firm.

We run a sensitivity analysis establishing that the parameter of uncertainty x is a value between 0 and 10, and that demand signals follow uniform distributions, $a_i \sim U(10-x, 20-x)$. Accordingly, we build a matrix of profits with two axis: the integer values of a_{RU} and a_{RO} from

Table 3 Summary of optimal profit by subject and scenario

Firm/scenario	Profit
Retailer U/NS	$\pi_{RU}^{NS\ *} = \frac{1}{36b}\left(-4a_{RU}^2 + 8a_{RU}a_{RO} - 4a_{RO}c + c^2\right)$
Retailer O/NS	$\pi_{RO}^{NS\ *} = \frac{1}{36b}\left(-4a_{RO}^2 + 8a_{RU}a_{RO} - 4a_{RU}c + c^2\right)$
Manufacturer/NS	$\pi_{M}^{NS\ *} = \frac{1}{3b}\left[(a_{RU} - c/2)^2 + (a_{RO} - c/2)^2\right]$
Retailer U/S	$\pi_{RU}^{S\ *} = \frac{1}{36b}(a_{RU} + a_{RO} - c)^2$
Retailer O/S	$\pi_{RO}^{S\ *} = \frac{1}{36b}(a_{RU} + a_{RO} - c)^2$
Manufacturer/S	$\pi_{M}^{S\ *} = \frac{1}{6b}(a_{RU} + a_{RO} - c)^2$
Retailer U/L	$\pi_{RU}^{L\ *} = \frac{1}{36b}\left(2a_{RU}^2 + 2a_{RU}a_{RO} - 3a_{RU}c - a_{RO}c + c^2\right)$
Retailer O/L	$\pi_{RO}^{L\ *} = \frac{1}{36b}(2a_{RO} - c)(5a_{RU} - 3a_{RO} - c)$
Manufacturer/L	$\pi_{M}^{L\ *} = \frac{1}{12b}\left[(a_{RU} + a_{RO})^2 + 4a_{RO}^2 - 2c(3a_{RO} + a_{RU} - c)\right]$

0 to 20. The cells of the matrix represent the level of profits reached with a combination of signals, a_{RU} and a_{RO}.

In order to find the conditional distribution of profits given x, profits need to satisfy two conditions: $a_{RO} > a_{RU}$, and that both signals are within the interval $(10 - x, 20 - x)$ given a value of x. For each integer value of x, 55 possible profits satisfy these two conditions. Hence, the probability of observing a specific profit is 1/55 for given a value of x. We compute the probability of observing a profit for any x, $Pr\left[(a_{RU} \cap a_{RO}) \cap x\right] = Pr\left[(a_{RU} \cap a_{RO})\right] * Pr(x) =$ (1/55)(1/11) = 1/605. Since some combinations a_{RU} and a_{RO} are possible at different levels of x, n_x is the number of times that a signal combination is possible in the interval $(10 - x, 20 - x)$. For instance, $\pi(a_{RU}, a_{RO}) = \pi(0, 1)$is only possible once when $x = 10$, and the probability is $Pr[\pi(0, 1)] = 1/605$. Likewise, $\pi(a_{RU}, a_{RO}) = \pi(9, 10)$ is possible 10 times when $x = 0, 1, \ldots, 8, 9$, and the probability is $Pr[\pi(9, 10)] = 10/605$. Consequently, the distribution function of profits is $Pr\left[\pi(a_{RU}, a_{RO})\right] = n_x/605$.

The expected value of profits given a value of x is graphically represented by firm and scenario in Figs. 4, 5, and 6 (the values in the graphs are listed in Table 5 in the appendices). The results of the sensibility analysis consistently illustrate the propositions of the analytical model. Lower values of x imply higher values of demand signals. The differences of retailers' profits between scenarios increase as x decreases. In general, the

Table 4 Decision variables and profits by scenario in the numerical example

Scenario variables	No sharing no leaking	Information sharing	Information leaking
p	21	21	20
q_{RU}	3.5	4.5	4.5
q_{RO}	5.5	4.5	5.5
w_{RU}	13.5	16.5	16.5
w_{RO}	19.5	16.5	19.5
π_{RU}	26.25	20.25	15.75
π_{RO}	8.25	20.25	2.75
π_M	127.5	121.5	151.5
π_{Total}	162	162	170

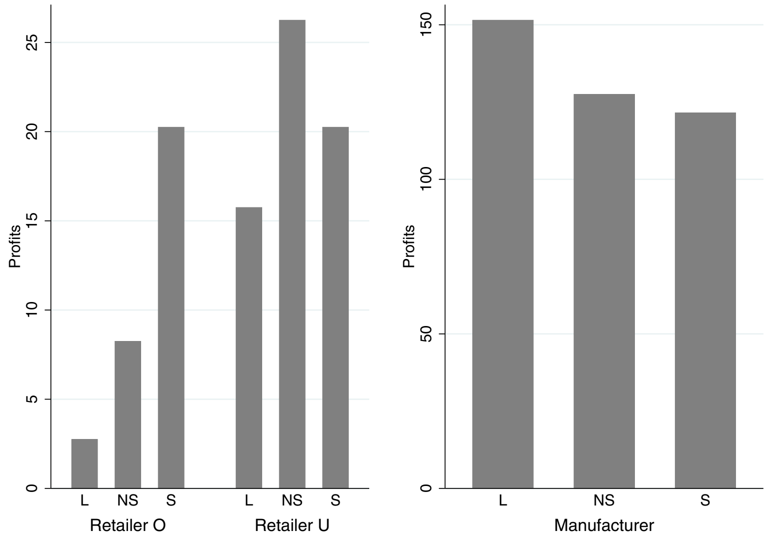

Fig. 3 Bar graph of profits by scenario and firm in the numerical example

larger the values of demand signals are, the greater are the differences between the three analyzed scenarios. This result is more salient for retailer O whose profits in the information sharing scenario grow exponentially as the value of *x* decreases. We can also observe that retailer U prefers information sharing when the value of *x* is large. In this case, theorem 1 that establishes that the profits of retailer U are higher in the no sharing scenario seems not to be consistent. This is because the propositions of the analytical model are conditioned to lemma 1, which guarantees that both retailers have a positive profit in the no sharing and no leaking scenario.

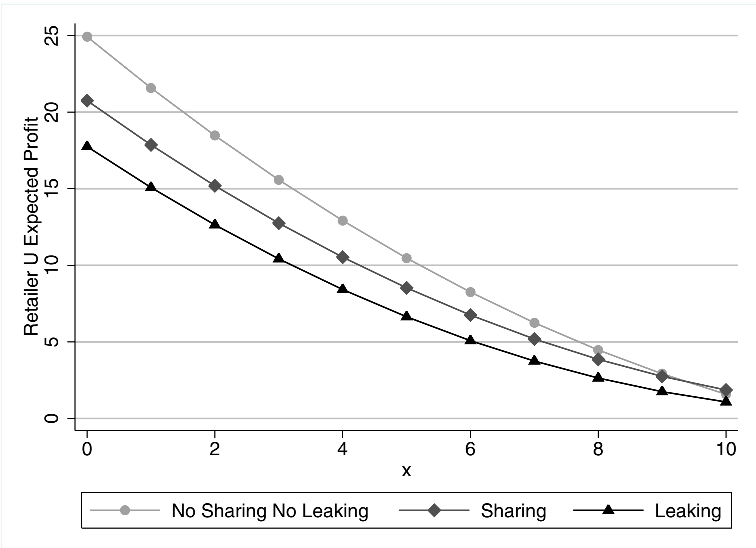

Fig. 4 Expected profit of retailer U by scenario and demand uncertainty

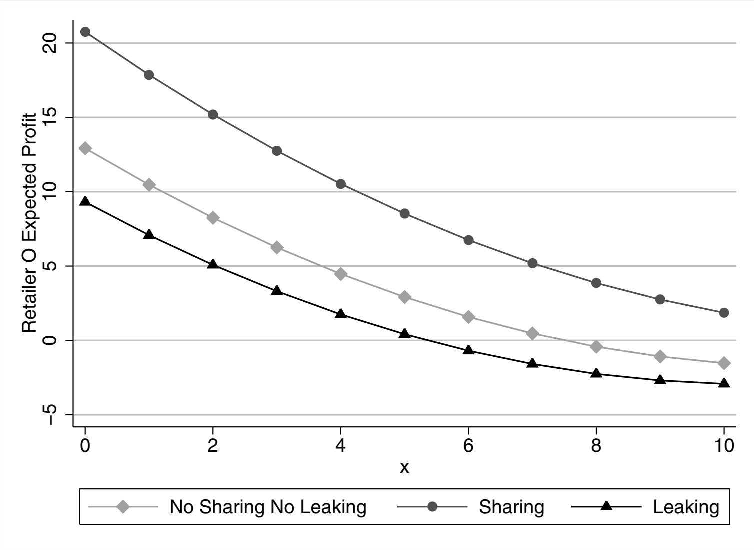

Fig. 5 Expected profit of retailer O by scenario and demand uncertainty

5 Discussion

The previous sections present a literature review with the analytical models use to understand information leaking in supply chain. This review allows us to build a model including the case when retailers cannot determine their information position. The model portrays retailers with partial and asymmetric information about an ambiguous demand base, which imitates the conditions of demand incertitude when selling a new product or entering a new market. Later,

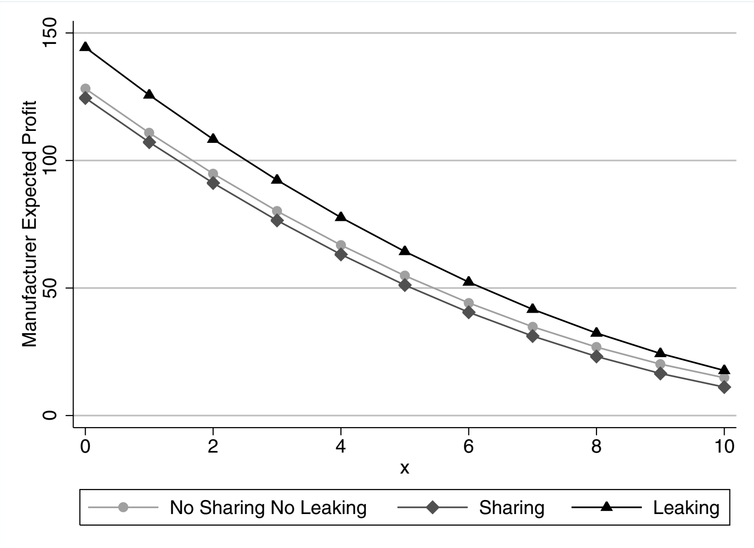

Fig. 6 Expected profit of manufacturer by scenario and demand uncertainty

we provide a numerical example to understand the theorems proposed in the analytical model. Hence, the main results of this study are as follows. First, retailers who have an ambiguous information position should favor information sharing to prevent the negative effect of information leaking. Second, the benefits of horizontal information sharing are asymmetric because it favors retailer O who is the retailer with a larger valuation signal. Third, the manufacturer will always leak information if retailers do not reach agreements of horizontal information sharing.

The first result identifies retailers' motivations to prevent the information leaking scenario. These motivations are consistent with Kong et al. (2013) who use the revenue sharing contract to discourage leaking from the manufacturer and improve the performance of the whole supply chain. It also aligns with the motivations of those contracts to prevent information leaking: confidentiality agreements (Li 2002; Li and Zhang 2008), exclusivity sourcing (Anand and Goyal 2009), and information concealment (Jain and Sohoni 2015; Wang et al. 2018). Our findings support that both retailers face their less profitable scenario if they fail to share horizontally and the manufacturer leaks information. Hao et al. (2018) recognize that once the manufacturer owns the demand signals of the retailers (potential information leaking), horizontal information sharing is a strategic move to improve their profits. Particularly, bidirectional sharing between retailers has a greater impact when competition is not intense, and the variance of the demand signal is high. Either the retailer is retailer O or retailer U, horizontal information sharing between retailers turns into a valid alternative that is at least better than the information leaking scenario.

The second result shows that the retailer O with higher information signal receives more benefits than retailer U after agreeing to share information. This conflicts with previous research because the better-informed retailer, commonly addressed as incumbent, is not willing to exchange information with the less-informed retailer (Kong et al. 2013; Li 2002). Guo et al. (2014) detect that the better-informed retailer prefers not to disclose when the demand condition is expected to be low. Jiang and Hao (2016) notice that horizontal information sharing requires a low competition environment to motivate the incumbent retailer to agree to share. Anand and Goyal (2009) point out that the incumbent retailer has no incentives to share horizontally and holds an information imperative to use her additional information to manipulate the other firms for her benefits. Low uncertainty levels drive the incumbent retailer to follow the strategy to always order a fixed average order (pooling equilibrium) or ordering low when knowing that demand condition is high (separate equilibrium). However, we recognize that this difference is possibly attributable to the fact that retailers know they are the better-informed among others in the previous work.

The third result portrays the manufacturer favoring information leaking. This supports the results of previous work. Li (2002) and Anand and Goyal (2009) detect that the manufacturer always decides to leak information from one retailer to another by sharing the demand signal, order quantity of the other retailer, or through the wholesale price. Wu et al. (2018) detect that the manufacturer leaks information through the wholesale price to influence the action of retailers. Shamir (2017) recognizes that retailers use the manufacturer to communicate their private signals to the other retailers because manufacturer always leaks information for his own benefit. Our model results show that the manufacturer is better off by leaking information from retailer O to retailer U. Leaking in the opposite direction is not a rational decision because it generates lower profits to the manufacturer.

Our analytical model represents a new approach to retailers' information position in supply chain. The assumption of ambiguous information position is realistic because it accurately corresponds to the cases when new markets are created, or new products are launched without previous information about its demand. In absence of additional information, a retailer imputes her demand information to the other competing firm. When the information asymmetry is not severe ($a_{RO} + c/2 < 2a_{RU}$), this study confirms that the single manufacturer benefits from leaking information, and that retailers could prevent that scenario using horizontal information sharing strategically. After leaking information, retailer O continues ordering expecting an inflated demand and the information position of a retailer U improves, driving her to order more quantity at a higher wholesale price and increasing, thus, the profit of the manufacturer. Whereas, horizontal information sharing is at least preferred by both retailers because it prevents that the manufacturer profits from manipulating their demand information. The retailer O obtains greater benefits from this action, but these benefits rapidly decrease as the parameter x increase (base demand becomes smaller). In general, the size of the demand generates positive and growing differences in the profits of the supply chain parties for every strategic decision.

Our results are encouraging and should be validated with data from new industries or from controlled experiments. Future work could relax the three traditional assumptions in this stream of research that are also applied in our model: truthful information sharing, no information acquisition by retailers, and ex ante information sharing. Extensions of this research could include different types of competition among retailers, competition in the upstream echelon, and penalties for information leaking against manufacturers.

The insights of our research have a potential application when managers need to make collaboration decisions with competing firms. Managers of competing firms should consider the potential benefits of horizontal information sharing to prevent leaking when dealing with common manufacturers or suppliers. If sharing horizontally is not a suitable option, we suggest that managers sign confidentiality agreements to protect the strategic information that will be vertically shared with the upstream party. It is also important to mention the duty of confidentiality when meeting with representatives of other firms in search of trust-based relationships. The risk of information leakage could also lead retailers to share distorted information with the manufacturer, but these distortions would influence the reaction of the other retailer (her order quantity) affecting the retail price and bring up retaliation from the manufacturer in future purchases. Moreover, retailers facing ambiguity about their demand information position should share information to benefit from a better demand estimation, or at least, prevent the common manufacturer to use information leakage to his private benefit. However, before proceeding to share information with competitors, it is crucial to revise the local antitrust laws because sharing certain strategic information could be punished as collusion. For instance, the structure of the supply chain in our study could be considered as a hub-and-spoke conspiracy if the vertical and horizontal agreements promote anticompetitive practices and harm other market participants.

5.1 The Case of Single Manufacturer and Multiple Retailers

We solve the case with n-retailers for the information sharing scenario, and no information sharing and no information leaking scenario. For this section, we include this notation for the total information about demand, $a = \sum_{i=1}^{n} a_{Ri}$ and $a = a_{Ri} + a_{-Ri}$. Under the information sharing scenario, the values for profit of manufacturer, profit of retailer i, total quantity in the market, quantity ordered by retailer i, wholesale price paid by retailer i, and retail price. As n increases, the profit of manufacturer and total order quantity increase, whereas the profit of retailer i, quantity ordered by retailer i, and retail price decrease. When n tends to infinity, the profit of manufacturer converges to $(a-c)^2/4b$, the profit and quantity ordered of retailer i converges to 0, the total order quantity converges to $(a-c)/2b$, and the retail price converges to the wholesale price, $(a+c)/2$. The expressions are listed as it follows,

$$\pi_M = [n/(n+1)]\left[(a-c)^2/4b\right] \tag{28}$$

$$\pi_{Ri} = \left[1/(n+1)^2\right]\left[(a-c)^2/4b\right] \tag{29}$$

$$q = (n/n+1)[(a-c)/2b] \tag{30}$$

$$q_{Ri} = [1/(n+1)][(a-c)/2b] \tag{31}$$

$$w_{Ri} = (a+c)/2 \tag{32}$$

$$p = [(n+2)/(n+1)](a/2) + [n/(n+1)](c/2) \tag{33}$$

Under the no information sharing and no information leaking scenario, as n increases, the profit of manufacturer, the wholesale price, the total order quantity and quantity ordered by retailer i increase, whereas the profit of retailer i and retail price decrease. When n tends to infinity, the profit of manufacturer and his wholesale price grows to infinity, the profit of retailer i decreases to negative infinity, the total quantity converges to $(a-c)/2b$, the quantity ordered by retailer i converges to $a_{Ri}/2b$, and the retail price converges to $(a+c)/2$.

$$\pi_M = \left[n^2/(n+1)\right]\left[\left(\sum_{i=1}^{n} a_{Ri}^2\right)/4b\right] - [n/(n+1)](ac/2b) + [n/(n+1)]\left(c^2/4b\right) \tag{34}$$

$$\pi_{Ri} = -\left[n^3/(n+1)^2\right]\left[a_{Ri}^2/4b\right] + \left[n^2/(n+1)^2\right]\left[a_{Ri}(a_{-Ri}+c)/4b\right] + \left[n/(n+1)^2\right]\left[(2a_{Ri}-c)(a_{Ri}+a_{-Ri})/4b\right] - \left[1/(n+1)^2\right]\left[c(2a_{Ri}+2a_{-Ri}-c)/4b\right] \tag{35}$$

$$q = [n/(n+1)][(a-c)/2b] \tag{36}$$

$$q_{Ri} = [n/(n+1)](a_{Ri}/2b) - [1/(n+1)](c/2b) \tag{37}$$

$$w_{Ri} = (na_{Ri}+c)/2 \tag{38}$$

$$p = [(n+2)/(n+1)](a/2) + [n/(n+1)](c/2) \tag{39}$$

Under the information leaking scenario, we predict that retailers O build their reaction functions assuming that all the other retailers have their same inflated information, while retailers U have complete information about demand because the manufacturer has already filtered the information of all other retailers including other retailers U and all retailers O.

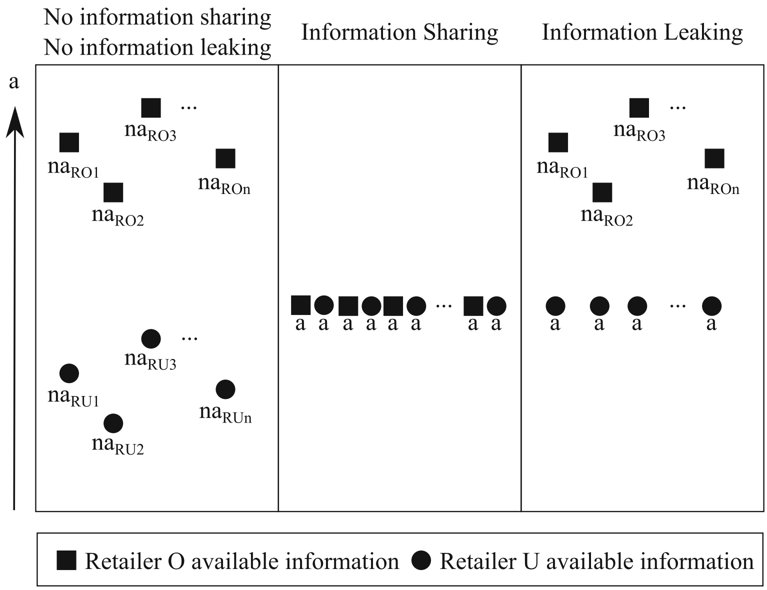

Fig. 7 Representation of information availability per scenario

Observing the case of $n = 2$ and the two previous scenarios of n-retailers, manufacturers earn more when leaking information than in the other two scenarios because the retailers O continue paying a high wholesale price and maintain the order quantity as in the no information sharing no information leaking scenario, as well as the retailers U also accept the wholesale price and keep the same quantity of the information sharing scenario. The increase of total order quantity also pushes the retail price to fall. Since retailers are being charge higher wholesale prices and the retail prices decrease, information leaking greatly reduces the sales margin of retailers and, consequently, their profits. Figure 7 summarizes the available information to both type of retailers when taking their strategic decisions for the three studied scenarios.

6 Conclusions

This study analyzes a supply chain model with a single manufacturer and two retailers competing in a market with homogenous products. Retailers receive a partial and asymmetric demand signal, and they cannot establish their information position. We analyze three different scenarios: no information sharing and no leaking, information sharing, and information leaking in supply chain, where manufacturer leaks one of the retailer's private information to another retailer. We prove with the analytical model and illustrate with a numerical example that competing retailers prefer a non-leaking scenario. Retailer O enjoys better profits in the information sharing scenario, while retailer U requires further incentives to agree to share information horizontally. For instance, the threat of having lower profits because of information leaking could motivate retailer U to share information. When retailers do not reach agreement to share information, manufacturer will always respond by leaking information from retailer O to retailer U to increase his profit. Finally, we present the case of n-retailers to provide robustness to our results.

Funding information The Ministry of Science Technology of the Republic of China, Taiwan, financially supported this research under project MOST 107-2410-H-006-036.

Appendix

Proof of Lemma 1

In the no sharing no leaking scenario, we focus on the profit of retailer U in Eq. (4) to find the solutions of the inequality

$$\pi_{R1}{}^{*} = \frac{1}{36b}\left(-4a_{RU}{}^{2} + 8a_{RU}a_{RO} - 4a_{RO}c + c^{2}\right) > 0.$$

Since $b > 0$, we multiply both sides of the inequality times $36b$ and divide by 4,

$$-a_{RU}{}^{2} + 2a_{RU}a_{RO} - a_{RO}c + \frac{c^{2}}{4} > 0.$$

We factorize the expression,

$$\left[\frac{c}{2} - a_{RU}\right]\left[\frac{c}{2} + a_{RU}\right] - 2a_{RO}\left[\frac{c}{2} - a_{RU}\right] > 0,$$

$$\left[\frac{c}{2} - a_{RU}\right]\left[\frac{c}{2} + a_{RU} - 2a_{RO}\right] > 0.$$

We deduce the solutions from the two factors,

$$0 < \frac{c}{2} < a_{RU} < 2a_{RO} - \frac{c}{2}.$$

For the profit of retailer O,

$$0 < \frac{c}{2} < a_{RO} < 2a_{RU} - \frac{c}{2}.$$

Assuming that retailer O is the overestimating retailer $a_{RU} < a_{RO}$,

$$0 < \frac{c}{2} < a_{RU} < a_{RO} < 2a_{RU} - \frac{c}{2},$$

$$0 < c < a_{RU} + \frac{c}{2} < a_{RO} + \frac{c}{2} < 2a_{RU}.$$

In the information sharing scenario, this lemma also guarantees the positive profit of the manufacturer.

$$\pi_{M}^{S\ *} = \frac{1}{3b}(a_{RU} + a_{RO})(a_{RU} + a_{RO} - c),$$

${\pi_M^S}^* > 0$ if $c < a_{RU} + a_{RO}$.

The lemma establishes that the production cost c is less than two times the demand information of the underestimating retailer a_{RU}. Therefore, $c < 2a_{RU} < a_{RU} + a_{RO}$ guarantees ${\pi_M^S}^* > 0$.

Proof of Theorem 1

We equate the two profits of retailers in Eqs. (4) and (5),

$$\pi_{RU}^* = \pi_{RO}^*$$

$$\frac{1}{36b}\left(-4a_{RU}^2 + 8a_{RU}a_{RO} - 4a_{RO}c + c^2\right) =$$

$$\frac{1}{36b}\left(-4a_{RO}^2 + 8a_{RU}a_{RO} - 4a_{RU}c + c^2\right),$$

We factorize to find solutions,

$$a_{RO}^2 - a_{RU}^2 + a_{RU}c - a_{RO}c = 0,$$

$$(a_{RO} - a_{RU})(a_{RU} + a_{RO}) - c(a_{RO} - a_{RU}) = 0,$$

$$(a_{RO} - a_{RU})(a_{RU} + a_{RO} - c) = 0.$$

Following Lemma 1, $(a_{RU} + a_{RO} - c)$ is always positive. Therefore,

$\pi_{RU}^* > \pi_{RO}^*$, if $a_{RO} > a_{RU}$,

Proof of Theorem 2

Assuming that retailer O is the overestimating retailer; we compare the profit of retailer O in the no sharing no leaking and the information sharing scenario,

$${\pi_{RO}^S}^* - {\pi_{RO}^{NS}}^* = 0,$$

$$\frac{1}{36b}(a_{RU} + a_{RO} - c)^2 - \frac{1}{36b}\left(-4a_{RO}^2 + 8a_{RU}a_{RO} - 4a_{RU}c + c^2\right) = 0,$$

$$\left(a_{RU}^2 + a_{RO}^2 + c^2 + 2a_{RU}a_{RO} - 2a_{RU}c - 2a_{RO}c\right) -$$

$$\left(-4a_{RO}^2 + 8a_{RU}a_{RO} - 4a_{RU}c + c^2\right) = 0,$$

$$\left(a_{RO}{}^2 - 2a_{RU}a_{RO} + a_{RU}{}^2\right) + \left(4a_{RO}{}^2 - 4a_{RU}a_{RO}\right) - 2c\left(a_{RO} - a_{RU}\right) = 0,$$
$$\left(a_{RO} - a_{RU}\right)\left(5a_{RO} - a_{RU} - 2c\right) = 0.$$

The factor $(a_{RO} - a_{RU})$ is positive because retailer O is the overestimating retailer. The factor $(5a_{RO} - a_{RU} - 2c)$ is always positive using Lemma 1, this is $0 < \frac{a_{RU}+2c}{5} < a_{RU} + \frac{c}{2} < a_{RO} + \frac{c}{2} < 2a_{RU}$. Consequently, the overestimating retailer earns higher profit in the information sharing scenario than in the no sharing no leaking scenario $\pi_{RO}^{S\,*} > \pi_{RO}^{NS\,*}$.

Proof of Theorem 3

Assuming that the information is leaked from the overestimating retailer O to the underestimating retailer U, we compare the profits of both retailers in the information leaking scenario,

$$\pi_{RU}^{L\,*} - \pi_{RO}^{L\,*} = 0,$$

$$\left(2a_{RU}{}^2 + c^2 - 3ca_{RU} - ca_{\mathrm{RO}} + 2a_{RU}a_{RO}\right) +$$

$$\left(6a_{RO}{}^2 - c^2 + 5a_{RU}c - a_{RO}c - 10a_{RU}a_{RO}\right) = 0,$$

$$2\left(a_{RU} - a_{RO}\right)\left(a_{RU} - 3a_{RO} + c\right) = 0.$$

The factor $(a_{RU} - 3a_{RO} + c)$ is always negative using Lemma 1. The factor $(a_{RU} - a_{RO})$ is negative because retailer O is the overestimating retailer $a_{RO} < a_{RU}$. Consequently, the underestimating retailer earns higher profit than the overestimating retailer in the information leaking scenario $\pi_{RU}^{L\,*} > \pi_{RO}^{L\,*}$.

Proof of Theorem 4

Assuming that the information is leaked from the overestimating retailer O to the underestimating retailer U, we compare the profit of retailer O in the no sharing no leaking and the information leaking scenario,

$$\pi_{RO}^{NS\,*} - \pi_{RO}^{L\,*} = 0,$$

$$\frac{1}{36b}\left(-4a_{RO}{}^2 + 8a_{RU}a_{RO} - 4a_{RU}c + c^2\right) -$$

$$\frac{1}{36b}\left(-6a_{RO}{}^2 + c^2 - 5a_{RU}c + a_{RO}c + 10a_{RU}a_{RO}\right) = 0$$

$$\left(-4a_{RO}{}^2 + 8a_{RU}a_{RO} - 4a_{RU}c + c^2\right) +$$

$$\left(6a_{RO}{}^2 - c^2 + 5a_{RU}c - a_{RO}c + 10a_{RU}a_{RO}\right) = 0,$$

$$2a_{RO}(a_{RO}-a_{RU})-c(a_{RO}-a_{RU})=0,$$

$$(a_{RO}-a_{RU})(2a_{RO}-c)=0.$$

The factor $(2a_{RO}-c)$ is always positive using Lemma 1. The factor $(a_{RO}-a_{RU})$ is positive since retailer O has a higher level of demand information $a_{RO}>a_{RU}$. Consequently, retailer O is better off in the no sharing no leaking information scenario than in the scenario in which her information is leaked $\pi_{RO}^{NS^*}>\pi_{RO}^{L^*}$.

Proof of Theorem 5

Assuming that the information is leaked from the overestimating retailer O to underestimating retailer U, we compare the profit of retailer O in the information sharing and the information leaking scenario,

$$\pi_{RO}^{S^*}-\pi_{RO}^{L^*}=0,$$

$$\frac{1}{36b}(a_{RU}+a_{RO}-c)^2-$$

$$\frac{1}{36b}\left(-6a_{RO}{}^2+c^2-5a_{RU}c+a_{RO}c+10a_{RU}a_{RO}\right)=0,$$

$$a_{RU}{}^2-8a_{RU}a_{RO}+7a_{RO}{}^2+3a_{RU}c-3a_{RO}c=0,$$

$$(a_{RU}-a_{RO})(a_{RU}-7a_{RO}+3c)=0.$$

The factor $(a_{RU}-7a_{RO}+3c)$ is always negative using Lemma 1. The factor $(a_{RU}-a_{RO})$ is negative since retailer O is the overestimating retailer $a_{RO}>a_{RU}$.Consequently, retailer O is better off in the information sharing than in the scenario in which her information is leaked $\pi_{RO}^{S^*}>\pi_{RO}^{L^*}$.

Proof of Theorem 6

Assuming that the information is leaked from the overestimating retailer O to underestimating retailer U, we compare the profit of manufacturer in the information leaking and the no sharing no leaking scenario,

$$\pi_M^{L^*}-\pi_M^{NS^*}=0,$$

$$\frac{1}{12b}\left[(a_{RU}+a_{RO})^2+4a_{RO}{}^2-2c(3a_{RO}+a_{RU}-c)\right]-$$

$$\frac{1}{3b}\left[\left(a_{RU}-\frac{c}{2}\right)^2+\left(a_{RO}-\frac{c}{2}\right)^2\right]=0,$$

$$\frac{(a_{RU}+a_{RO})^2-4a_{RU}{}^2-2c(a_{RO}-a_{RU})}{12b}=0$$

Evaluating this expression in the case where $a_{RO}=a_{RU}$, the value is exactly zero. Since $a_{RO}>a_{RU}$ from Lemma 1, this expression will always be greater than zero. Consequently, $\pi_M^{L*}>\pi_M^{NS*}$.

Proof of Theorem 7

We compare the profit of manufacturer in the no sharing no leaking scenario and information sharing scenario,

$$\pi_M^{NS*}-\pi_M^{S*}=0,$$

Table 5 Results of sensibility analysis changing uncertainty

	No sharing no leaking			Information sharing			Information leaking		
x	$E(\pi_{RU})$	$E(\pi_{RO})$	$E(\pi_M)$	$E(\pi_{RU})$	$E(\pi_{RO})$	$E(\pi_M)$	$E(\pi_{RU})$	$E(\pi_{RO})$	$E(\pi_M)$
10	1.58	−1.53	14.83	1.86	1.86	11.17	1.08	−2.92	17.67
9	2.92	−1.08	20.17	2.75	2.75	16.5	1.75	−2.69	24.33
8	4.47	−0.42	26.83	3.86	3.86	23.17	2.64	−2.25	32.33
7	6.25	0.47	34.83	5.19	5.19	31.17	3.75	−1.58	41.67
6	8.25	1.58	44.17	6.75	6.75	40.5	5.08	−0.69	52.33
5	10.47	2.92	54.83	8.53	8.53	51.17	6.64	0.42	64.33
4	12.92	4.47	66.83	10.53	10.53	63.17	8.42	1.75	77.67
3	15.58	6.25	80.17	12.75	12.75	76.5	10.42	3.31	92.33
2	18.47	8.25	94.83	15.19	15.19	91.17	12.64	5.08	108.33
1	21.58	10.47	110.83	17.86	17.86	107.17	15.08	7.08	125.67
0	24.92	12.92	128.17	20.75	20.75	124.5	17.75	9.31	144.33
Any x	11.58	4.03	61.50	9.64	9.64	57.84	7.75	1.53	71.00

$$\frac{1}{3b}\left[\left(a_{RU}-\frac{c}{2}\right)^2+\left(a_{RO}-\frac{c}{2}\right)^2\right]-\frac{1}{6b}(a_{RU}+a_{RO}-c)^2=$$

$$\frac{(a_{RO}-a_{RU})^2+2c(a_{RO}+a_{RU})}{6b}=0$$

This expression is always greater than zero. Consequently, $\pi_M^{NS*}>\pi_M^{S*}$.

Sensibility Analysis Appendix

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