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Establishing a dual food supply chain for organic products in the presence of showrooming – A game theoretic analysis

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A R T I C L E I N F O

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A B S T R A C T

This study considers a retailer and a direct supplier (farmer) facing the strategic decision of whether to interact through a dual channel or to compete by selling different but comparable products. Consumers perceive the supplier's product as being of higher quality (e.g., an organic product as opposed to a conventional product, which is offered by the retailer) and the retailer as offering a superior service experience. In the dual-channel market, the retailer also offers the supplier's product, enabling customers to enjoy both higher quality and superior service. We assume that consumers are heterogeneous in their valuations of service and product quality. We consider the effects of showrooming and find that there are certain showrooming levels at which a retailer chooses to opt out of the dual channel despite that decision being detrimental to both parties. A strategic contract allows the parties to avoid this type of prisoner's dilemma. Our model can serve as a managerial decision tool for retailers and suppliers to evaluate whether it is worthwhile engaging in dual-channel collaboration and to assess the broader effects of showrooming in the markets in which they operate.

1. Introduction

In recent years, direct sales channels have proliferated in numerous sectors and industries. In agricultural markets, for example, it is increasingly common for suppliers (farmers) to market their products directly to consumers rather than relying on indirect sales through retailers. The U.S. Congress in 2018 initiated an umbrella program within the Farm Bill that offers technical assistance to farmers when creating or expanding direct-to-consumer markets (including online platforms) and the Value-added Producer Grant Program, which supports development and marketing of processed agricultural products, including foods marketed as local. On April 11, 2019, the U.S. Department of Agriculture (USDA) announced the results of the 2017 Census of Agriculture, which indicated that 130,056 farms in the United States sold directly to consumers in 2017 with sales of $2.8 billion (U.S., 2019). Those direct channels take different forms, including farmers' markets, community-based agriculture operations, and, recently, online sales platforms and marketplaces (Tongarlak et al., 2017; O'Hara and Low, 2020).

Direct channels have become particularly prevalent in the organic food market. In 2008, direct channels accounted for about 10% of sales of organic products in the United States (Oberholtzer et al., 2014). Direct sales and specialist shops constituted an average of 50% of all organic sales in European markets and more than 80% in some countries in Europe in 2008 (Wier et al., 2008). Numerous studies have shown that consumers generally perceive organic products as healthier and less damaging to the environment than conventional products and, therefore, as having "superior" quality (Ozinci et al., 2017; Perlman et al., 2019; Lau et al., 2020; Pu et al., 2020; Yu and He, 2021). Organic products also generally cost more than conventional ones. However, suppliers that sell directly to consumers can likely offer significantly lower prices than retailers since they retain the entire value of the sales and their overhead expenses when selling the products are generally quite low. This price advantage likely contributes to the popularity of direct channel sales of organic products among consumers.

Recently, a combination of online direct marketing and brick-and-mortar retail stores has emerged in the agro-food sector. Examples include Amazon acquiring the organic food chain Whole Foods in the United States and Alibaba's opening of grocery stores called Hema Fresh Market and collaborating with pop-up stores across China (Shi and Liu, 2018). These contracts were initiated by the online direct channel. Examples of combinations initiated by offline channels include the contract between Cofco, an offline-seller of fresh products, and online channel Womai.com and Bright Food Group's opening of an online channel in 2013 by acquiring 962360.com (Yang and Tang, 2019). The decision has consequences for carbon emissions associated with the

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supplier's product in terms of transport to the retailer (Xu et al., 2018).

Such contracts between direct suppliers and retail channels suggest that retailers offer some benefits that direct channels cannot. One such advantage could be retailers' ability to offer superior service by providing personal interactions, information tailored to consumers' needs, and opportunities for consumers to touch and feel the merchandise (Brynjolfsson et al., 2013). To avoid losing customers who attribute high value to such features, a supplier that sells directly to consumers can choose to offer its products through a traditional retail channel as well, creating a dual supply chain.

A dual supply chain creates a complex scenario in which sales of a product through one channel can cannibalize sales of the product through the other. Accordingly, it is critical for managers of suppliers and retailers to identify the conditions under which a dual supply chain will benefit them. There are likely to be conditions under which a retailer or supplier is better off operating a single channel and competing based on an advantage it has: a service experience perceived by consumers as superior for the retailer and products perceived by consumers as superior (e.g., organic) for the direct supplier.

We develop and analyze a model aimed at deriving such insights based on the premise that consumers are heterogeneous in the extent to which they value attributes of product quality and service quality. Our model also considers the possibility that some consumers could try to "have it both ways"—they could visit the retailer to enjoy the service experience and then choose to purchase the product directly from the supplier at a lower price. This phenomenon in which consumers use retail stores to research products before purchasing them online is referred to as "showrooming" (Basak et al., 2017; Li et al., 2019). Showrooming can be considered to be free-riding behavior in which customers obtain the information from the retailer and then purchase the product through the direct channel (Balakrishnan et al., 2014; Mehra et al., 2018; Liu et al., 2020; Li et al., 2021). Lu and Reardon (2018) showed that consumers, once familiar with a food product through tactile observation, are comfortable making subsequent purchases of it online. Based on an empirical study of Chinese online grocery retailers that added physical stores, Liang et al. (2019) showed that, because of the showrooming effect, companies that added an offline store increased their non-store sales. Surveys have also suggested that more consumers are expected to engage in showrooming when purchasing food products (Kolehmainen, 2018). In the agricultural food industry information on food quality and safety have an important impact on customers' preferences (Akkerman et al., 2010). Therefore, the information provided by the brick-and- mortar retailer and the ability to assess a food's quality are particularly important for consumers of organic products (Yu and He, 2021).

To capture consumer heterogeneity, we model consumers' valuations of product quality and service quality as independent variables randomly drawn from uniform distributions. Based on the joint distribution, we construct a two-dimensional consumer preference model. First, we study the case of a duopolistic market in which the organic product is offered exclusively by a supplier (farmer) who sells it directly to consumers and the conventional product is offered exclusively through the retailer, who obtains it from a separate supplier. We use this duopolistic competition as the benchmark case and compare the supplier and retailer outcomes in the duopoly to their outcomes in a dual-channel market. In the dual market, the supplier sells the organic product both directly to consumers and through the retailer while the retailer continues to offer the conventional product as well. Thus, consumers who engage in showrooming can examine the products at the retail store to reduce uncertainty about the quality of the organic food product.

We find that the supplier always benefits from establishing a dual-channel market; the additional outlet for his products and showrooming behavior can only increase his sales and profits. Whether the retailer benefits from a dual-channel market depends on the effect of showrooming. When consumers do not engage in showrooming, we find that the retailer benefits from establishing a dual-channel market because it gains some sales that previously would have gone only to the supplier. When showrooming does occur, there is a threshold level of showrooming (captured by a coefficient as shown in the model formulation) beyond which the retailer chooses to withdraw from the dual channel. This decision represents a type of prisoner's dilemma as it reduces the profits of the supplier and the retailer.

We propose that the supplier and retailer can resolve the prisoner's dilemma by execution of a contract in which the retailer and supplier strategically choose to establish a dual-channel market and cannot opt out once it has been established. Execution of a contract ensures that the retailer will choose to establish the dual channel under any value of the showrooming coefficient that does not reduce her profit and that the supplier will avoid the loss of profit associated with termination of the dual channel. Because we consider a heterogeneous consumer base and provide detailed characterizations of market configurations for different scenarios in the presence of showrooming, our model can be used as a decision tool for supply chain members to evaluate whether a dual-channel supply chain would be beneficial when offering competing products with different attributes.

The reminder of this paper is organized as following. Section 2 discusses the related literature. In Section 3, the two-dimensional consumer choice model is formulated, and the pricing decisions of the supplier and retailer are studied under duopoly and dual-channel markets. Section 4 studies the effect of showrooming behavior on the strategic decision of establishing a dual channel. Section 5 further analyzes the retailer and supplier tactical decisions regarding the attribute level each offers (service level set by the retailer and quality level set by the supplier). The final section summarizes the key results and discusses opportunities for the future research.

2. Literature review

This study contributes to the stream of research examining dual-channel markets. In recent years, due to introduction of e-commerce, much of the literature in this vein has focused on the distinction between direct online channels and conventional brick-and-mortar retailers. Brynjolfsson et al. (2009) empirically studied competition between internet commerce and traditional retailers and revealed that internet channels face significant competition from retailers when selling mainstream products but are virtually immune to competition when selling niche products. Forman et al. (2009) also empirically examined attributes that affect consumer choices between online and offline channels. They found that consumers tended to substitute away from online purchases after a store opened locally, suggesting that consumers prefer the convenience of the offline option.

Existing studies have focused on dual agro-food supply chains bringing agricultural products from the farm to the table, either directly (e.g., farmers' markets, online sales platforms) or via retailers. Our work extends the literature by developing quantitative methodologies relying on game theoretical models and practical decision tools for supply chain members to evaluate whether a dual-channel supply chain would be beneficial. In their extensive review of operations management models applied to food supply chains, Ahumada and Villalobos (2009) distinguished between papers that mostly focused on perishable products and papers that focused on nonperishable products. Our analysis extends the latter stream. Quantitative operations management in food supply chains was also extensively reviewed by Akkerman et al. (2010), who classified the literature into three decision types: strategic, tactical, and operational. We study and analyze the strategic decision faced by a direct farmer and a brick-and-mortar retailer regarding whether to interact through a dual channel or to compete and their operational decisions with respect to pricing strategies. Specifically, in our dual-channel game, prices for the organic direct and conventional retail products are determined by the farmer (supplier) and retailer, respectively. The price for the organic product offered by the retailer equals the sum of the margins determined by the supplier and retailer. We further extend our model to study tactical decisions of the retailer and supplier in which each can choose the level of service and product quality to provide.

Over the past year, sustainability has gained increasing importance in the agro-food supply chain. In their work on sustainable supply chains of organic and conventional products, Sazvar et al. (2018) provide an excellent summary of related papers published from 2010 through 2017. Similar to their study, we also consider an organic version as substitutable for the conventional one. According to Accorsi and Manzini, 2019, one of the main concerns in sustainable food supply chain management is intensive use of genetically modified organisms (GMOs), pesticides, and chemical fertilizers. Organic food production processes and outputs of organic farming contribute to sustainable development and are safer for both the environment and customers (Lau et al., 2020; Yu and He, 2021). Since consumers perceive organic agricultural products as healthier and environmentally friendlier than conventional products (Lau et al., 2020; Pu et al., 2020; Yu and He, 2021), we model the additional utility gained by consumers who prefer the organic version of the product.

Numerous studies have used game theoretic approaches to examine competition between direct marketers and conventional intermediaries such as retailers. Tsay and Agrawal (2004), for example, reviewed competitive and coordinated models in multi-channel distribution systems. Cattani et al. (2004) reviewed research related to coordination of traditional and internet supply chains. Additional work addressing competition between direct marketers and conventional marketers includes studies of pricing strategies when a product is offered in a direct channel and a retail channel (e.g., Chiang et al., 2003; Huang and Swaminathan, 2009). Other studies have examined service decisions in addition to pricing decisions based on the assumption that retailers can offer a higher level of service to compensate for the higher prices they must charge (e.g., Dumrongsiri et al., 2008; Dan et al., 2012).

In this work, we model duopolistic and dual-channel supply chains to study competition between a direct channel and retail channel that offer different levels of service to consumers and competition between an organic and conventional version of a product that offer different levels of quality since the organic product is considered to be superior. We extend the existing literature by considering the showrooming phenomenon explicitly, thereby providing a more realistic representation of the factors that affect competition between online and offline sellers. A study by Balakrishnan et al. (2014) was among the first to examine the effect of showrooming on pricing strategies and profits of online and brick-and-mortar retailers. The impact of showrooming on managing sustainable supply chains and its implications for carbon emissions were first studied by He et al. (2016). Basak et al. (2017) studied both pricing and service strategies in the presence of showrooming using different power structures in the supply chain. Mehra et al. (2018) considered several strategies by which to combat showrooming, including price matching as a short-term strategy and product exclusivity as a long-term strategy. These works focused on the influence of showrooming on competition between direct online channels and conventional brick-and-mortar retailers.

Our study addresses the effects of showrooming in a dual-channel supply chain in which the farmer sells his products directly to consumers and via a brick-and-mortar retail store. To the best of our knowledge, only a few papers have addressed showrooming in this type of supply chain. He et al. (2016) investigated the impact of showrooming on carbon emissions in a dual-channel closed-loop supply chain in which the manufacturer collected used products. Li et al. (2019) considered pricing strategies of a manufacturer and retailer and three service strategies by the retailer. Recently, Li et al. (2021) considered in-store demonstration strategies that allow consumers to physically inspect the attributes of the product to confirm their quality preferences in dual-channel supply chains under the influence of showrooming behavior.

Notably, Li et al. (2019) assumed that customers were homogeneous in their preferences for service quality. Thus, they proposed linear demand functions (which are sensitive to prices and levels of service) for the product offered in each channel. On the other hand, He et al. (2016) and Li et al. (2021) assumed that consumers are heterogenous and uniformly distributed on a linear hoteling horizonal line, thus proposing a one-dimensional horizontal-differentiation consumer choice model. Our work extends the literature by proposing a unique two-dimensional vertical-differentiation consumer choice model. Specifically, we assume that consumers are heterogeneous in their willingness to pay for two attributes, product quality and service quality. Our model assumes that all consumers agree that getting more of each attribute (service and quality) is always better but still vary in their willingness to pay for the attributes (see Vandenbosch and Weinberg (1995); Cattani et al. (2006) and Lauga and Ofek (2011)). This approach enables us to construct a more realistic representation of the market and, therefore, to identify the conditions under which a dual-channel supply chain benefits each channel.

To sum up, our contribution to the existing literature is threefold. First, we construct a two-dimensional vertical-differentiation model in which one attribute captures heterogeneity in consumer preferences for a given product quality (organic versus conventional) and another captures heterogeneity in consumer preferences for a given type of service experience (retail versus direct). Second, our model accounts for both channel competition and product competition by studying a dual-supply-chain market in which a single retailer offers two substitutable versions of a product—organic and conventional—and a direct channel offers only the organic version. Third, our model is the first to combine these unique features in the context of showrooming effects, which can have a major effect on the decisions and profits of suppliers and retailers.

3. Model

In our model, we consider a market in which a supplier (referred to as "he') offers his organic product directly to consumers and through a retailer (referred to as "she") while the retailer offers a conventional version of the product in addition to the organic version. Consumers who engage in showrooming behavior can use the retailer's physical store to research a product and then purchase the organic product through the direct channel. Each purchasing option results in different valuations for consumers as illustrated in Fig. 1.

3.1. Two-dimensional consumer choice model

A consumer's base valuation of the product is denoted by v. The consumer perceives the organic version of the product as higher quality (i.e., healthier and more environmentally friendly) than the conventional one. Let q denote the added value the consumer derives from the organic product. Similarly, let s denote the added value the consumer associates with the service experience provided by the retailer when purchasing the product, which includes the ability to see and touch the products under consideration.

To capture consumer heterogeneity, we denote by θ and ϕ the consumers' willingness to pay for quality and service, respectively. θ and ϕ are modeled as independent variables randomly drawn from a uniform distribution in the interval [0,1] (see, for example, Vandenbosch and Weinberg (1995), Cattani et al. (2006), Lauga and Ofek (2011), and Perlman et al. (2019)). Based on their joint distribution, we construct a two-dimensional consumer choice model.

As is common in the literature, the base utility v is assumed to be large enough that the market is fully covered and all consumers purchase a product at equilibrium (see, for example, Vandenbosch and Weinberg (1995), Dumrongsiri et al. (2008), and Lauga and Ofek (2011)). Each consumer purchases the product that provides the greatest utility: organic version from the retailer (*OR*), conventional version from the retailer (*CR*) or organic version directly from the farmer (*OD*).

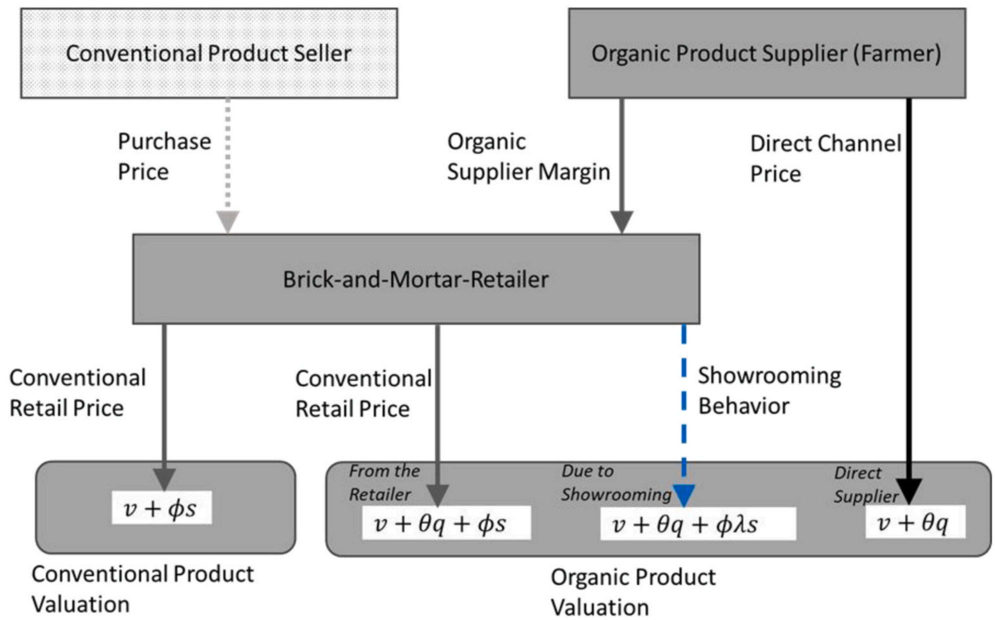


Fig. 1. Consumer choice model in a dual channel in the presence of showrooming.

When purchasing the organic product from the retailer at price P_{OR}, a consumer gains utility

$$U_{OR} = v + \theta q + \phi s - P_{OR}. \tag{1}$$

The utility gained by purchasing the conventional product from the retailer at price P_{CR} is

$$U_{CR} = v + \phi s - P_{CR}. \tag{2}$$

The valuation of the organic product purchased directly from the supplier (i.e., the value gained by consumers who prefer to shop through the farmer's direct channel and do not engage in showrooming) is $v + \theta q$. We further consider the possibility of a showrooming effect in which a consumer, not sure which purchase option is best, can visit the retailer and examine the products. This consumer can take advantage of the service provided by the retailer to find out about the organic product, thereby reducing uncertainty about its added quality. Thus, consumers who engage in showrooming and buy the product directly from the supplier after examining the product at the retailer receive an additional value, $\phi\lambda s$, where λ denotes the coefficient of the showrooming effect. It is assumed that $0 < \lambda < 1$ since showrooming offers only partial service (He et al., 2016). Thus, the value gained by consumers who engage in showrooming is $v + \theta q + \phi\lambda s$.

Similar showrooming coefficients have been used in the literature. He et al. (2016) argued that consumers who engage in showrooming are not necessarily able to take full advantage of the service the retailer provides (e.g., sales staff will serve consumers who visit only to examine the product out of courtesy but will not necessarily invest 100% effort). Li et al. (2019) argued that retail service can generate additional utility for consumers who buy directly from the supplier due to word-of-mouth (e.g., a recommendation from someone who purchased from the retailer). We assume that the showrooming coefficient is a product-specific characteristic that is exogenously determined (see also Li et al. (2019), Liu et al. (2019), and Basak et al., 2017, 2020)).

Let I_t denote the 0–1 random variable indicating (with consumer-dependent probability t) whether consumers engage in showrooming behavior. That is, $I_t = 0$ denotes a consumer who does not use showrooming while $I_t = 1$ denotes a consumer who does use showrooming. The utility gained by purchasing the organic version from the direct supplier (*OD*) is

$$U_{OD} = v + \theta q + \phi I_t \lambda s - P_{OD} \tag{3}$$

where P_{OD} is the price of the organic product offered by the direct supplier.

3.2. Duopolistic model

We start by modeling the duopolistic market to study the competition between a direct supplier who offers the organic product and a retailer who offers only the conventional product. The direct channel and retail channel offer different levels of service to consumers while the organic and conventional versions of the product offer different levels of quality. This duopoly competition serves as a baseline to evaluate whether suppliers and retailers can benefit from establishing a dual-channel supply chain under the influence of showrooming behavior.

3.2.1. Market configurations under duopoly

In the duopoly scenario, the supplier and retailer compete by offering separate versions of the product so the consumer has only two choices (*OD* or *CR*) and there is no showrooming behavior. When the utility a consumer derives from the direct channel is greater than the utility derived from the retail channel, $U_{OD} > U_{CR}$, the consumer buys from the supplier; otherwise, the consumer buys from the retailer. Consumers who are indifferent between the two options are represented by the indifference line between U_{OD} and U_{CR} given by

$$\phi = \frac{\theta q - P_{OD} + P_{CR}}{s}. \tag{4}$$

This indifference line is an increasing function in the (θ, ϕ) unit square. Analyzing the line given in equation (4), we identify the following four market configurations, which are also illustrated in Fig. 2:

(i) $q - s \le P_{OD} - P_{CR} \le 0$,
(ii) $-s \le P_{OD} - P_{CR} \le \min\{q - s, 0\}$,
(iii) $0 \le P_{OD} - P_{CR} \le q - s$, and
(iv) $\max\{q - s, 0\} \le P_{OD} - P_{CR} \le q$.

Fig. 2 depicts expected demand (market share) for the channels (Q_D for the direct supplier and Q_R for the retailer).

It follows that the values of demand (Q_D and Q_R) depend on whether $q \ge s$. When $q \ge s$, market configuration *i* does not exist; when $q \le s$ market configuration *iii* does not exist. By calculating the areas of the

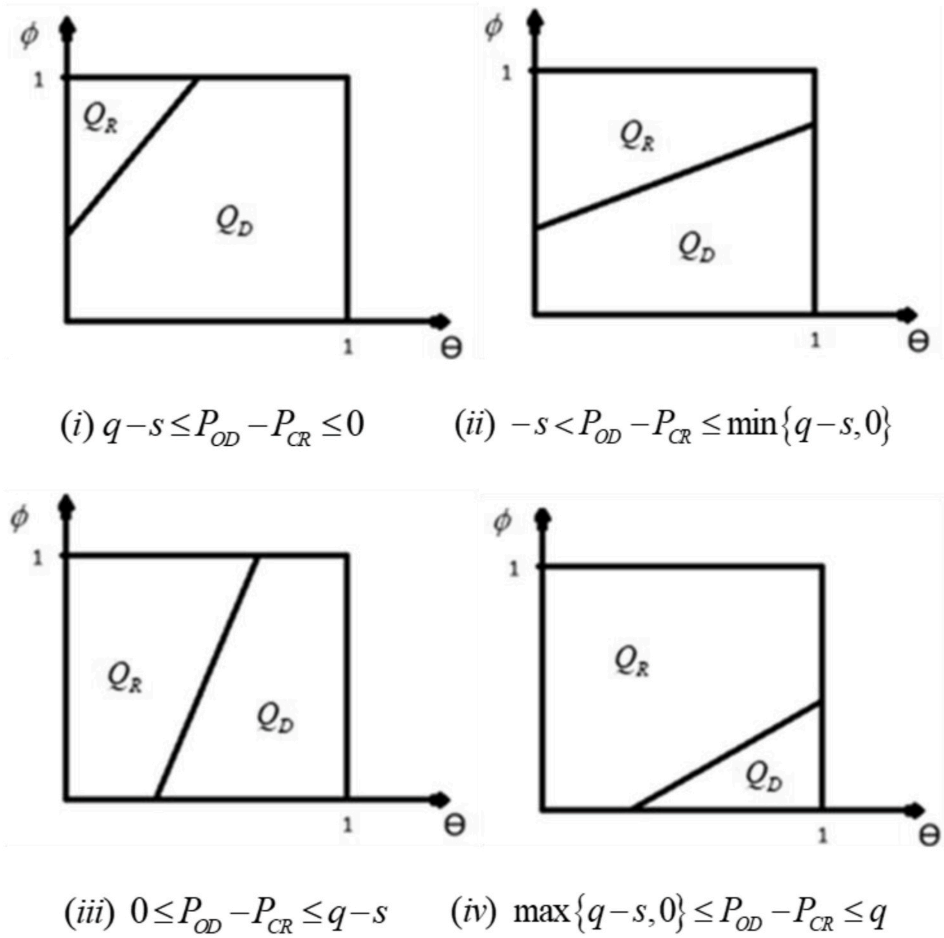


Fig. 2. Market configurations in a duopoly.

regions in Fig. 2, we specify the demand function of each channel in the following proposition.

Proposition 1. *Demand functions of the channels under duopoly*

(i) Demand functions when $q \geq s$:

Demand for direct supplier's organic product

$$Q_D^q \equiv \begin{cases} \dfrac{2qs-(P_{OD}-P_{CR}+s)^2}{2qs} & -s \le P_{OD}-P_{CR} \le 0 \\ \dfrac{2q-s-2(P_{OD}-P_{CR})}{2q} & 0 \le P_{OD}-P_{CR} \le q-s \\ \dfrac{(P_{OD}-P_{CR}-q)^2}{2vs} & q-s \le P_{OD}-P_{CR} \le q \end{cases}.$$

Demand for retailer's conventional product

$$Q_R^q \equiv \begin{cases} \dfrac{(P_{OD}-P_{CR}+s)^2}{2qs} & -s \le P_{OD}-P_{CR} \le 0 \\ \dfrac{2(P_{OD}-P_{CR})+s}{2q} & 0 \le P_{OD}-P_{CR} \le q-s \\ \dfrac{2qs-(P_{OD}-P_{CR}-q)^2}{2qs} & q-s \le P_{OD}-P_{CR} \le q \end{cases}.$$

(ii) Demand functions when $q \leq s$:

Demand for direct supplier's organic product

$$Q_D^s \equiv \begin{cases} \dfrac{2qs-(P_{OD}-P_{CR}+s)^2}{2qs} & -s \le P_{OD}-P_{CR} \le q-s \\ \dfrac{q-2(P_{OD}-P_{CR})}{2s} & q-s \le P_{OD}-P_{CR} \le 0 \\ \dfrac{(P_{OD}-P_{CR}-q)^2}{2qs} & 0 \le P_{OD}-P_{CR} \le q \end{cases}.$$

Demand for retailer's conventional product

$$Q_R^s \equiv \begin{cases} \dfrac{(P_{OD}-P_{CR}+s)^2}{2qs} & -s \le P_{OD}-P_{CR} \le q-s \\ \dfrac{2s-q+2(P_{OD}-P_{CR})}{2s} & q-s \le P_{OD}-P_{CR} \le 0 \\ \dfrac{2qs-(P_{OD}-P_{CR}-q)^2}{2qs} & 0 \le P_{OD}-P_{CR} \le q \end{cases}.$$

3.2.2. *Pricing strategy under duopoly*

The direct supplier and the retailer compete in a Bertrand game by setting their product prices. The direct supplier is selling his own product and thus incurs no wholesale purchase price. He selects the price, P_{OD}, that maximizes his expected profit:

$$\Pi_D = Q_D\, P_{OD}. \tag{5}$$

Likewise, the retailer selects the price, P_{CR}, for the conventional product that maximizes her expected profit given the wholesale purchase price c paid to the conventional seller:

$$\Pi_R = Q_R(P_{CR}-c). \tag{6}$$

Clearly, at equilibrium, $P_{CR} \geq c$; otherwise, the retailer could not stay in business. Note that this asymmetric cost structure in which only the brick-and-mortar retailer incurs a purchase cost and the direct supplier's cost is normalized to zero is common in the literature (e.g., Shen et al., 2019; Tian et al., 2018; Zhang et al., 2019a).[1]

The Nash equilibrium pricing strategy is given in the following theorem.

Theorem 1. *A unique (pure strategy) Nash equilibrium in pricing strategy exists under duopoly. Equilibrium prices are given by*

$$P^*_{OD} = \begin{cases} \dfrac{4q - s + 2c}{6} & 0 \leq c \leq q - s \\ \dfrac{2s + q + 2c}{6} & 0 \leq c \leq 2(s - q) \\ \dfrac{5(c - s) + 3\sqrt{(c - s)^2 + 8qs}}{8} & otherwise \end{cases}$$

and

$$P^*_{CR} = \begin{cases} \dfrac{2q + s + 4c}{6} & 0 \leq c \leq q - s \\ \dfrac{4s + 4c - q}{6} & 0 \leq c \leq 2(s - q) \\ \dfrac{7c + s + \sqrt{(c - s)^2 + 8qs}}{8} & otherwise \end{cases}$$

Proof. See Appendix A.

Theorem 1 *allows us to characterize the market configurations at equilibrium. The market is configured as in i in* Fig. 2 *when* $0 \leq c \leq 2(s - q)$ *, as in iii when* $0 \leq c \leq q - s$ *, and as in ii when* $c \geq \max\{q - s, 2(s - q)\}$ *. Market configuration iv does not exist at equilibrium. The latter result follows from the fact that only the retailer incurs a wholesale purchase price.*[2]

Note that Theorem 1 *implies that there are settings in which the direct supplier's price will be higher than the retailer's price. This occurs in market configuration iii, where* $P^*_{OD} - P^*_{CR} \geq 0$ *. In other words, when (i) the value of the product-quality attribute is greater than the value of the service-quality attribute and (ii) the wholesale purchase price of the conventional product is less than the gap between the values of the product-quality and service-quality attributes* ($0 \leq c \leq q - s$)*, non-intuitively and despite the fact that the direct supplier incurs no purchasing cost, under duopoly he can claim a price higher than the retailer's price at equilibrium.*

By Theorem 1*, the expected profits of the supplier and retailer at equilibrium under duopoly are*

$$\Pi^*_D = \begin{cases} \dfrac{(2c - s + 4q)^2}{36q} & 0 \leq c \leq q - s \\ \dfrac{(2c + 2s + q)^2}{36s} & 0 \leq c \leq 2(s - q) \\ \dfrac{5\left((s - c)\sqrt{(s - c)^2 + 8qs} - 12qs + (s - c)^2\right)\left(s - c - 0.6\sqrt{(s - c)^2 + 8qs}\right)}{128qs} & otherwise \end{cases} \tag{7}$$

and

$$\Pi^*_R = \begin{cases} \dfrac{(-2c + s + 2q)^2}{36q} & 0 \leq c \leq q - s \\ \dfrac{(-2c + 4s - q)^2}{36s} & 0 \leq c \leq 2(s - q) \\ \dfrac{\left(s - c + \sqrt{(s - c)^2 + 8qs}\right)^3}{256qs} & otherwise \end{cases} \tag{8}$$

3.3. Dual channel model

In our model of the dual-channel market, the retailer offers both the conventional and the organic versions of the product. Thus, a consumer who purchases an organic product from the retailer receives both the extra service and higher quality attributes. To provide a more realistic representation of the factors that affect competition between direct suppliers and offline retailers, we assume that the retailer's existing brick and mortar physical store serves as a showrooming venue without incurring additional expense. Consumers who use showrooming can examine the products at the retailer and decide to purchase the organic version directly from the supplier; some consumers will choose to purchase the organic product directly from the supplier without engaging in showrooming behavior.

3.3.1. Market configurations under dual channel

We start by constructing the demand functions of consumers who use showrooming, that is, $I_t = 1$ in equation (3) (hereafter denoted by the superscript *Show*). As previously discussed, consumers in our model of a dual-channel supply chain (denoted by superscript *d*) choose to buy one of three products: organic from the retailer, organic direct from the supplier, or conventional from the retailer. Consumers who are indifferent in terms of the channel in which they purchase the organic product (i.e., indifferent between U_{OR} and U_{OD}) are represented by the indifference line (ϕ^{Show}_{RD}):

$$\phi^{Show}_{RD} \equiv \frac{P^d_{OR} - P^d_{OD}}{s(1 - \lambda)}, \tag{9}$$

which is a horizontal line in the (θ, ϕ) unit square. $0 \leq \phi^{Show}_{RD} \leq 1$ imposes the condition $0 \leq P^d_{OR} - P^d_{OD} \leq s(1 - \lambda)$.

Similarly, θ^{Show}_{OC} is a vertical line in the (θ, ϕ) unit square representing consumers who are indifferent between U_{OR} and U_{CR}:

$$\theta^{Show}_{OC} \equiv \frac{P^d_{OR} - P^d_{CR}}{q}. \tag{10}$$

$0 \leq \theta^{Show}_{OC} \leq 1$ imposes the condition $0 \leq P^d_{OR} - P^d_{CR} \leq q$.

The indifference line between U_{OD} and U_{CR}, denoted by $\phi^{Show}_{OD\backslash CR}$, is

[1] The opposite case in which the direct supplier incurs a higher marginal cost than the retailer (e.g., considering a case in which the organic farmer bears a higher cost due to strict production procedures to ensure that the product conforms to organic requirements) can be represented in this model by letting c be negative.

[2] If c is assumed to be negative—that is, the direct supplier incurs a higher marginal cost than the retailer—the Nash equilibrium pricing strategy can be derived in a similar manner. Note that, in that case, configuration *ii* does not exist at equilibrium.

given by

$$\phi^{Show}_{OD\backslash CR} \equiv \frac{\theta q - P^d_{OD} + P^d_{CR}}{s(1-\lambda)}. \tag{11}$$

This line of indifference is an increasing line in the (θ, ϕ) unit square that passes through the intersection point of the θ^{Show}_{OC} and ϕ^{Show}_{RD} indifference lines. It follows that, when the conditions $0 \leq P^d_{OR} - P^d_{OD} \leq s(1-\lambda)$ and $0 \leq P^d_{OR} - P^d_{CR} \leq q$ hold, both θ^{Show}_{OC} and ϕ^{Show}_{RD} are in the unit square and the line $\phi^{Show}_{OD\backslash CR}$ intersects the unit square. Analyzing the line given in equation (11), we identify the following two market configurations in the dual-channel model.

Configuration I. : $P^d_{OR} \geq P^d_{CR} \geq P^d_{OD}$ and $P^d_{OR} \leq \min\{P^d_{CR} + q, P^d_{OD} + s(1-\lambda)\}$

Configuration II. : $P^d_{OR} \geq P^d_{OD} \geq P^d_{CR}$ and $P^d_{OR} \leq \min\{P^d_{CR} + q, P^d_{OD} + s(1-\lambda)\}$

These market configurations are depicted in Fig. 3.

Note that, under both configurations in the dual-channel supply chain, the direct supplier offers the organic product at a lower price than the retailer ($P^d_{OR} \geq P^d_{OD}$). This suggests that consumers could be motivated to engage in showrooming—researching the product at the retail site and then taking advantage of the direct supplier's lower price when purchasing.

Let $\Delta = \frac{(P^d_{CR} - P^d_{OD})^2}{2s(1-\lambda)q}$. Calculating the areas of the regions in Fig. 3, the following proposition formulates the demand functions in a dual-channel market for consumers who use showrooming ($I_t = 1$).

Proposition 2. *Demand functions of consumers who use showrooming in the dual-channel market are*:

(i) *Demand for the organic product in the retail channel*:

$$Q^{Show}_{OR} \equiv \frac{\left(P^d_{OD} + s(1-\lambda) - P^d_{OR}\right)\left(P^d_{CR} + q - P^d_{OR}\right)}{s(1-\lambda)q}$$

(ii) *Demand for the organic product in the direct channel*:

$$Q^{Show}_{OD} \equiv \begin{cases} \dfrac{\left(2P^d_{CR} - P^d_{OR} - P^d_{OD} + 2q\right)\left(P^d_{OR} - P^d_{OD}\right)}{2s(1-\lambda)q} - \Delta & \min\{P^d_{CR} + q, P^d_{OD} + s(1-\lambda)\} \geq P^d_{OR} \geq P^d_{CR} \geq P^d_{OD} \\ \dfrac{\left(2P^d_{CR} - P^d_{OR} - P^d_{OD} + 2q\right)\left(P^d_{OR} - P^d_{OD}\right)}{2s(1-\lambda)q} & \min\{P^d_{CR} + q, P^d_{OD} + s(1-\lambda)\} \geq P^d_{OR} \geq P^d_{OD} \geq P^d_{CR} \end{cases}$$

(iii) *Demand for the conventional product in the retail channel*:

$$Q^{Show}_{CR} \equiv \begin{cases} \dfrac{\left(2P^d_{OD} - P^d_{OR} - P^d_{CR} + 2s(1-\lambda)\right)\left(P^d_{OR} - P^d_{CR}\right)}{2s(1-\lambda)q} & \min\{P^d_{CR} + q, P^d_{OD} + s(1-\lambda)\} \geq P^d_{OR} \geq P^d_{CR} \geq P^d_{OD} \\ \dfrac{\left(2P^d_{OD} - P^d_{OR} - P^d_{CR} + 2s(1-\lambda)\right)\left(P^d_{OR} - P^d_{CR}\right)}{2s(1-\lambda)q} - \Delta & \min\{P^d_{CR} + q, P^d_{OD} + s(1-\lambda)\} \geq P^d_{OR} \geq P^d_{OD} \geq P^d_{CR} \end{cases}$$

Next, the demand functions of consumers who do not use showrooming ($I_t = 0$, denoted by $Q^{No\text{-}Show}$) is derived by substituting $\lambda = 0$ in Proposition 2. *Since the market configuration conditions do not depend on λ, the demand function of these consumers is classified using the same market configurations.*

Finally, the expected demand function for the entire population under the dual channel is obtained by $Q^d = tQ^{Show} + (1-t)Q^{No\text{-}Show}$.

3.3.2. Pricing strategy under dual channel

A dual-channel market changes the pricing power of the supplier and retailer; see Kuiper and Meulenberg (2004) for an empirical study of price leadership in agricultural product markets. Traditionally, price was decided by a wholesale price contract in which the upstream member was more powerful (e.g., Danone, Heinz, Kraft, Nestle´, and Unilever in the food sector discussed in Kuiper and Meulenberg (2004)). This supplier price leadership also exists in dual supply chains such as the one used by Cofco, a fresh product supplier, and retailer Bright Food Group (discussed in Yang and Tang (2019)). However, large global food retailers such as Wal-Mart in the United States, Carrefour in France, and Ahold in the Netherlands charge a margin on products from suppliers before the suppliers determine their wholesale prices.

In the dual-channel game studied herein, the retailer functions in a "dual channel" with the supplier of the substitutable organic product but also offers the conventional version of the product to consumers. Therefore, it is reasonable to assume that the relationship between the parties in the game is relatively symmetric, and we assume that the supplier and retailer are equally powerful and determine their prices simultaneously (see, e.g., Choi (1991), Kogan et al. (2008), Lu and Liu (2013), Zhao et al. (2017), Matsui (2019), and Taleizadeh and Sadeghi (2019)).

Specifically, in the dual-channel game, prices for the organic direct and conventional retail products, p^d_{OD} and P^d_{CR}, are determined by the supplier and retailer, respectively. The retail price for the organic product, p^d_{OR} , equals the sum of the margins, W^d_O and M^d_O, determined by the supplier and the retailer, respectively. That is, $P^d_{OR} = W^d_O + M^d_O$. Industry practices support the assumption that margins are viewed as control variables in a supply chain (Matsui, 2019). Empirical studies have shown that the strategic interaction between a supplier and a

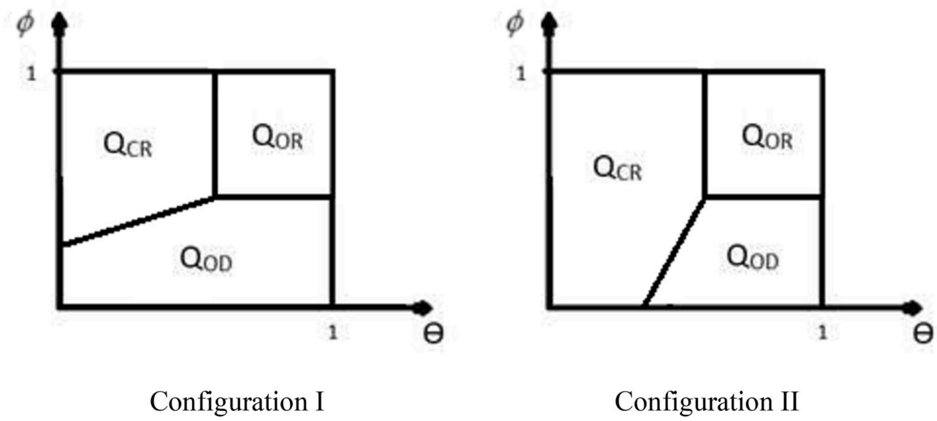


Fig. 3. Market configurations in the dual-channel supply chain.

retailer in several food categories, including coffee (Draganska et al., 2010) and milk, butter, bread, and margarine (Cotterill and Putsis (2001), can be modeled as a vertical Nash game.[3]

Thus, the supplier chooses his margin for the organic product sold by the retailer, W_O^d, and the direct sale price of the organic product, p_{OD}^d, to maximize his expected profit, Π_D^d :

$$\Pi_D^d = Q_{OD}^d P_{OD}^d + Q_{OR}^d W_O^d. \tag{12}$$

The retailer chooses her margin for the organic product, M_O^d (i.e., $P_{OR}^d = W_O^d + M_O^d$), and the price for the conventional product, P_{CR}^d, to maximize her expected profit, Π_R^d:

$$\Pi_R^d = Q_{OR}^d M_O^d + Q_{CR}^d \left(P_{CR}^d - c\right). \tag{13}$$

The Nash equilibrium pricing strategy is obtained using the following procedure.

3.3.2.1. Procedure 1. **Step 1.** Using the first order optimality conditions, obtain a system of four equations in four decision variables that are unknown stationary points.

Step 2. Solve the system determined by Step 1 to find all possible sets of values for the four unknowns. Each set represents a potential equilibrium; see Appendix B.

Step 3. Eliminate the sets that do not meet the feasibility requirements (configuration constraints).

Step 4. Eliminate the sets for which the Hessians corresponding to the two player decision variables are not negative definite; see Appendix C.

Step 5. Eliminate the sets for which at least one of the parties can increase profits by changing strategies (including not establishing the dual channel); see Appendix D. The remaining sets are Nash equilibria of the game.

If no solution remains, the parties do not establish the dual channel and the Nash equilibrium pricing strategy is the strategy in Theorem 1 (in duopolistic competition). We show numerically in the next section (based on an extensive numerical analysis) that at most one Nash equilibrium pricing strategy in the dual channel is obtained employing this procedure.

4. Impact of showrooming on decision to establish a dual channel

We now identify the conditions under which the supplier and/or retailer benefit from establishing a dual-channel market for the organic product in the presence of showrooming. The profits of the retailer and supplier at equilibrium in the dual-channel supply chain are compared with their profits in the baseline case of duopoly in which the retailer sells the conventional version and the supplier sells the organic version of the product.

While closed form expressions for the profits of the supplier and the retailer at equilibrium were derived (see equations (7) and (8)), we must resort to numerical analysis to obtain the parties' profits at equilibrium in the dual-channel market (employing Procedure 1). A full factorial analysis is performed with $q \neq s \in \{1, 3, 6, 10, 12, 20, 24, 30, 35, 40, 80, 100\}$, $c \in \{0, 1, 5, 10, 15, 35, 65, 80\}$ and $\lambda \in \{0, 0.25, 0.5, 0.95\}$.

We analyze the results of 2300 cases[4] and, based on those results, derive three conjectures. We find that there always exists a unique Nash equilibrium within the dual channel. The findings described in the sequel were obtained for all the numerical cases. Two numerical examples are presented to illustrate how the showrooming-effect coefficient influences the strategic decision of the retailer and the direct supplier regarding whether to establish the dual channel. The first is a representative example in which the value of the quality attribute is greater than the value of the service attribute, and the second is a representative example of the opposite conditions.

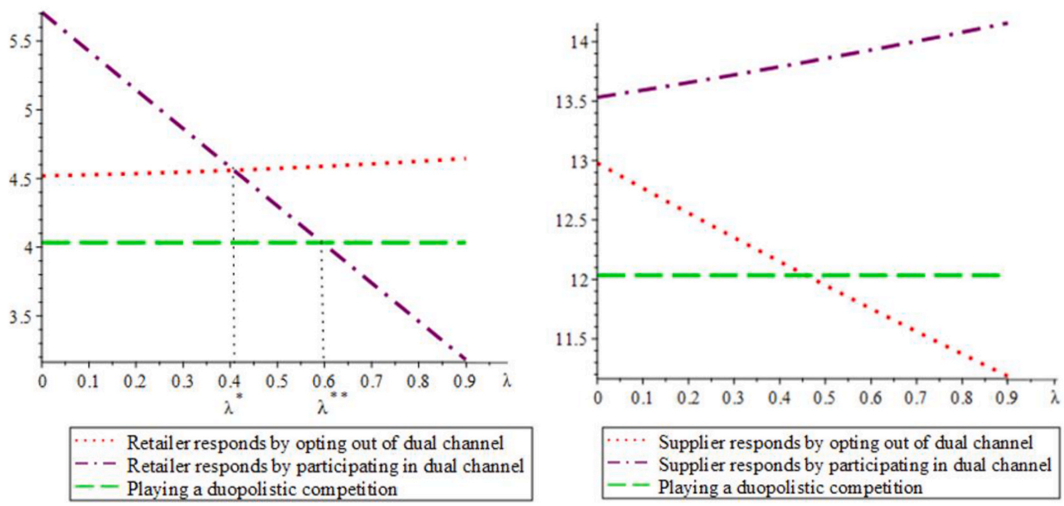
4.1. Main analysis

First, we compare the profits of each party in three scenarios:

(i) The supplier (retailer) plays according to the Nash equilibrium within the dual channel whereas the retailer (supplier) plays by opting out of the dual channel. Retailer's (supplier's) profit is represented by the dotted red line in Fig. 4a(b) and 5a(b).
(ii) The retailer and the supplier play according to the Nash equilibrium within the dual channel. Retailer's (supplier's) profit is

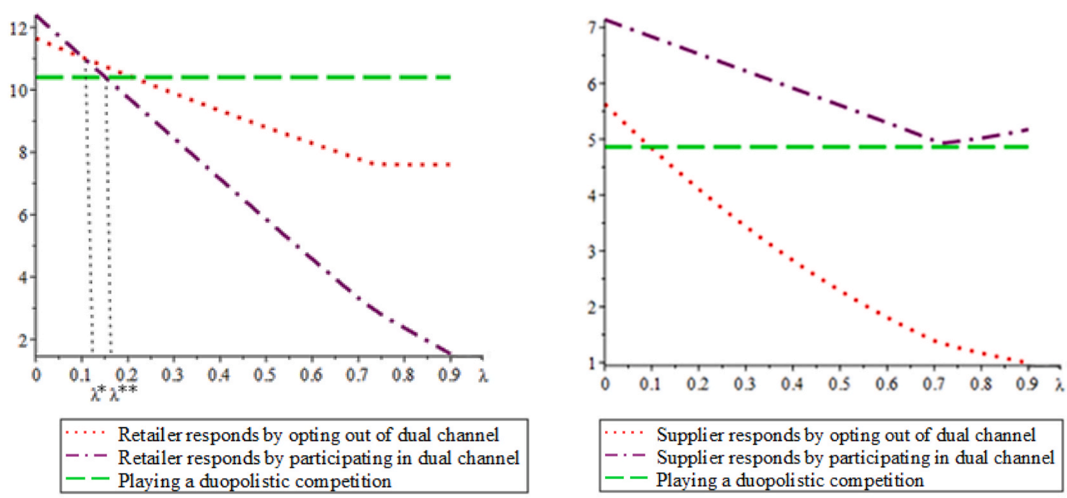
[3] The term *vertical Nash game* (or *Nash game*) was used in the seminal work of Choi (1991) to describe this game of vertical competition between upstream and downstream members of the supply chain.

[4] As the purchase price (c) of the conventional product increases, the conventional product's market share (sold by the retailer) decreases. Since the retailer can also offer the organic product in the dual supply chain, the market share of the conventional product in the dual-channel supply chain diminishes more quickly with c than it does in the duopolistic competition. Therefore, to avoid a degenerate case, we limited the experiment to combinations of values for which the market shares of the conventional product were positive.



(a) Retailer's profit **(b)** Supplier's profit

Fig. 4. Parties' profits under three scenarios for $q = 30$, $s = 10$, and $c = 2$ as a function of λ



(a) Retailer's profit **(b)** Supplier's profit

Fig. 5. Parties' profits under three scenarios for $q = 10$, $s = 30$, and $c = 2$ as a function of λ

represented by the purple dashed-dotted line in Fig. 4a(b) and 5a(b).

(iii) The retailer and the supplier play according to the Nash equilibrium within the duopoly and their profits are given by equations (7) and (8), respectively. Retailer's (supplier's) profit is represented by the green dashed line Fig. 4a(b) and 5a(b).

Establishing a dual channel is beneficial to the supplier since the market share of organic product can only increase relative to the duopoly. Moving to a dual channel becomes even more beneficial as showrooming behavior increases. This result is depicted in Fig. 4b where, for all values of λ, the purple dashed-dotted line is strictly above the red dotted and green dashed lines. Note that, when the service attribute is greater than the quality attribute, shopping at the retailer becomes more attractive and more consumers will prefer to purchase the conventional product offered by the retailer. Thus, in that case, increasing the showrooming coefficient can reduce the profit of the supplier. However, as depicted in Fig. 5b, even in cases in which $s > v$, for all values of λ the purple dashed-dotted line is strictly above the red dotted and green dashed lines. Thus, the supplier always benefits from participating in the dual channel regardless of the value of the showrooming-effect coefficient.

From the retailer's perspective, an increase in the showrooming coefficient means a greater number of consumers, after checking the product at the store, could choose to purchase the organic product from the direct supplier. Thus, since the retailer is supplying service but obtaining little or no sales in return, there are likely to be levels of showrooming behavior at which opting out of establishing a dual-channel market becomes the best option for the retailer.

Let λ^* be the intersection point between the retailer's profit when she plays by opting out of the dual channel and the retailer's profit when both parties play according to the Nash equilibrium within the dual channel (the intersection of the red dotted and purple dashed-dotted lines in Figs. 4a and 5a). Hence, a Nash equilibrium in the dual channel does not exists when $\lambda \geq \lambda^*$ since the retailer can increase her profit by choosing to opt out of the dual channel.

When $\lambda \leq \lambda^*$ there exists a unique Nash equilibrium in which a dual channel is established (since neither can improve their profits by choosing an action other than establishing a duopoly). These results are summarized in the following conjecture.

Conjecture 1

I. For all values of λ, the supplier prefers to participate in the dual-channel supply chain.
II. There exists a showrooming-effect coefficient λ^* such that the retailer will choose not to establish the dual channel for all $\lambda > \lambda^*$.
III. When $\lambda \leq \lambda^*$ there exists a unique Nash equilibrium in which a dual channel is established.

From a managerial perspective, Conjecture 1-I likely explains the growing number of online suppliers engaging in dual-channel operations and opening physical stores as “showrooms” (see examples of such sellers in Gu and Tayi (2017) and Shi and Liu (2018)).

Let λ^{**} denote the intersection point between the retailer’s profit when she plays according to the Nash equilibrium within the dual channel and the retailer’s profit when both parties play according to the Nash equilibrium within the duopoly (the purple dashed-dotted and green dashed lines in Figs. 4a and 5a). In other words, λ^{**} is the value of the showrooming effect, which leads to the retailer’s profit when the parties establish a dual channel to be equal to her profit obtained under duopoly.

These numerical examples illustrate an important managerial implication. In the dual-channel game, there are values of $\lambda > \lambda^*$ at which the retailer chooses to opt out of the dual channel despite the fact that, once back under duopolistic competition (the green dashed line in Figs. 4a and 5a), she ultimately earns less profit than if she stayed under the Nash equilibrium in the dual channel.

Accordingly, we put forward the following conjecture.

Conjecture 2

A prisoner’s-dilemma-type outcome arises under the dual-channel-game Nash equilibrium when the coefficient of the showrooming effect satisfies $\lambda^* < \lambda < \lambda^{**}$ in which the decision to opt out of the dual-channel market is detrimental to both parties.

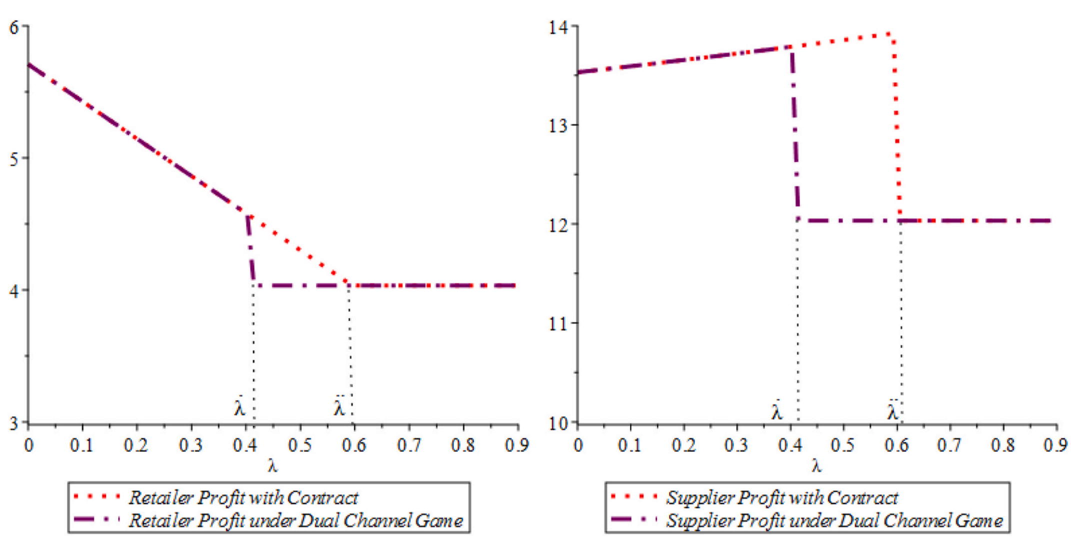
Contracts have been shown to be effective in coordinating dual channel supply chains and increasing the profits of their members (Tsay and Agrawal, 2004; Xu et al., 2018); they also can improve the environment and overall social welfare (Peng et al., 2020). Recently, two papers suggested use of a contract to address the negative effects caused by showrooming and arrive at a win-win situation for the supplier and the brick-and-mortar retailer. Zhang et al. (2019b) suggested a service compensation contract; Basak et al. (2020) derived a contract initiated by the supplier that enabled the retailer to expend adequate sales effort and therefore was beneficial for both parties.

Building on this notion, we propose an innovative contract that resolves the prisoner’s-dilemma-type outcome when the retailer and supplier first strategically decide whether to establish the dual-channel market. That is, the parties create a contract in which they commit to establishing the dual channel and cannot opt out of it (because, for example, the cost of opting out is so high that it is never worthwhile to do so). Given that the supplier always prefers to participate in the dual channel, the two parties will establish such a contract only when the retailer stands to benefit from the dual channel—when $\lambda < \lambda^{**}$. At the same time, because of the contract, the dual channel will remain open even when $\lambda^* < \lambda < \lambda^{**}$ despite the fact that, according to Procedure 1, the retailer would opt out for values of λ in this range. Thus, use of the contract leads both parties to earn greater profits when $\lambda^* < \lambda < \lambda^{**}$, providing win-win benefits to the supplier and the retailer.

Figs. 6 and 7 demonstrate the differences in the parties’ profits with and without such a contract. The dotted red lines represent profits under the contract, and the dashed-dotted lines represent profits under the dual-channel game’s Nash equilibrium pricing strategy. The additional profits gained under the contract are represented by the differences between the two corresponding lines when $\lambda^* < \lambda < \lambda^{**}$. Note that the contract allows the retailer to establish the dual channel for higher levels of showrooming effect, providing both the retailer and the supplier with a greater profit.

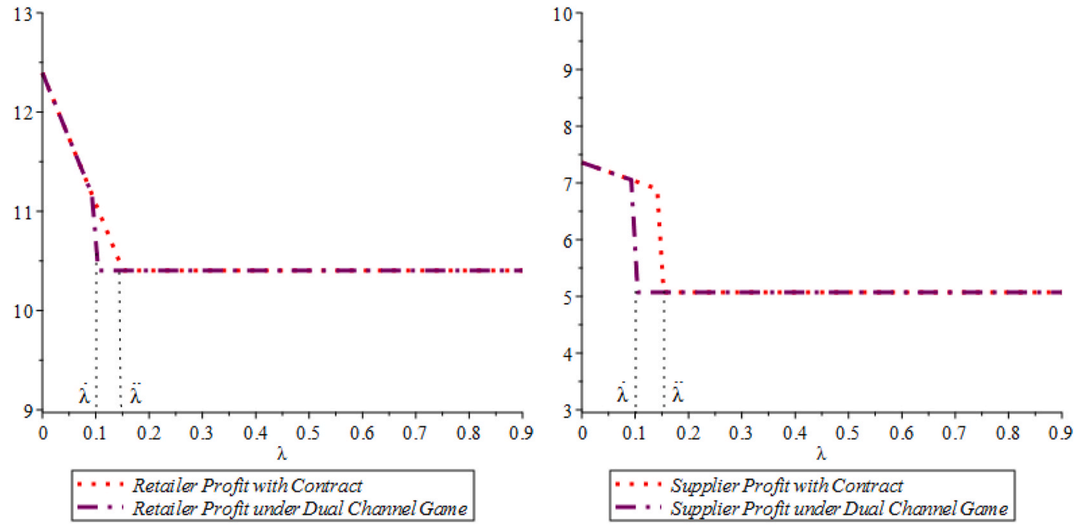
This analysis provides an interesting managerial result. Under a dual-channel supply chain, an increase in the showrooming coefficient always harms the retailer by reducing her profit and, as expected, the retailer is better off in a dual-channel market when there is no showrooming effect (i.e., $\lambda = 0$). Non-intuitively, the supplier also can prefer no showrooming because the impact of showrooming on his profit depends on the quality (q) and service (s) attribute values (Figs. 6b and 7b). Specifically, if the service value (the retailer’s competitive attribute) is much greater than the quality value (the supplier’s competitive attribute) and the wholesale purchasing price of the conventional product is relatively low, showrooming can induce consumers to switch to the conventional product, reducing the supplier’s sales and profit.

We turn now to the effect of showrooming on the share of total profit obtained by each channel under the contract. Under the dual channel



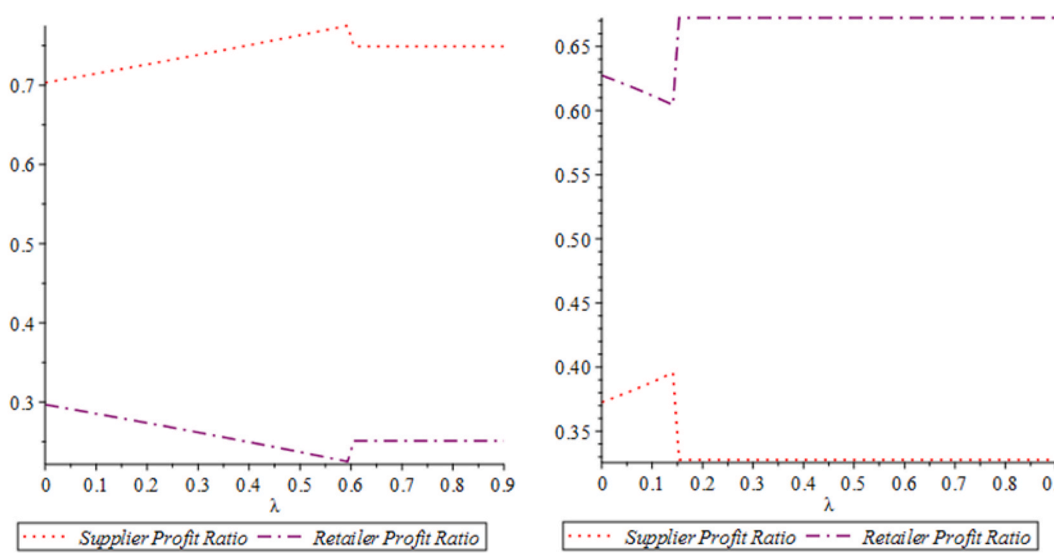
(a) Retailer’s profit **(b)** Supplier’s profit

Fig. 6. Parties’ profits with and without a contract for $q = 30$, $s = 10$, and $c = 2$ as a function of λ



(a) Retailer's profit **(b)** Supplier's profit

Fig. 7. Parties' profits with and without a contract for $q = 10$, $s = 30$, and $c = 2$ as a function of λ



(a) $q = 30$, $s = 10$, and $c = 2$ **(b)** $q = 10$, $s = 30$, and $c = 2$

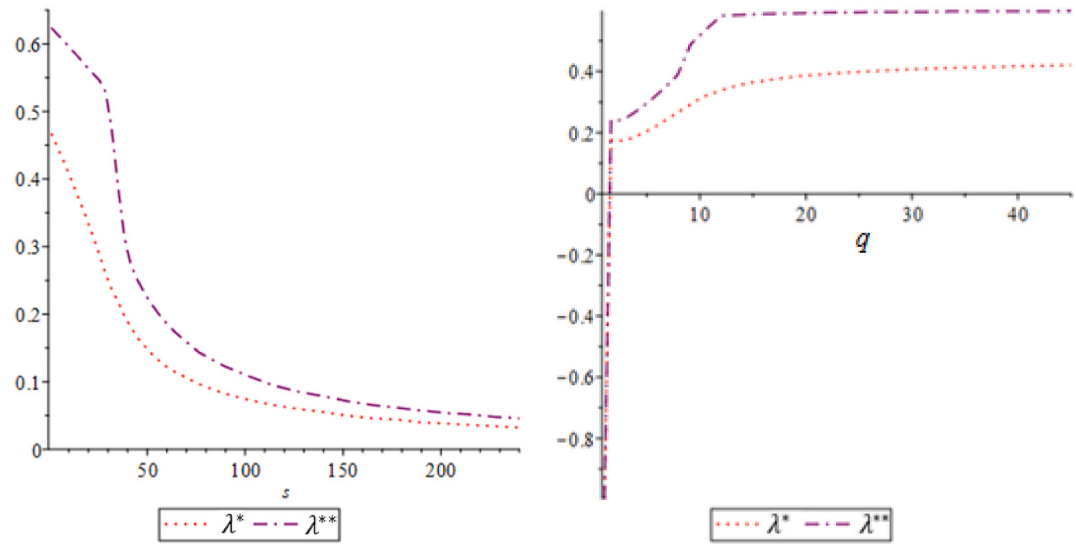
Fig. 8. Parties' profit shares under the contract as a function of λ

(that is, for $\lambda < \lambda^{**} = 0.6$ in Fig. 8a and $\lambda < \lambda^{**} = 0.15$ in Fig. 8b), the supplier's share of the total profit increases as consumers who visit the retailer buy his organic product rather than the conventional one. The retailer's share of the market's total profit decreases as the showrooming coefficient (λ) increases because she loses sales of the organic product to the supplier. As depicted in Fig. 8, this observation holds regardless of which attribute level (quality or service) is greater. Note that, for $\lambda > \lambda^{**}$, the dual channel ceases to exist so the supply chain members compete (moving to duopolistic competition). Interestingly, closing the dual channel always results in a jump discontinuity in the profit ratios, reducing the supplier's share of profits and increasing the retailer's share. This follows because the supplier benefits more than the retailer from establishing the dual channel. Thus, moving to duopolistic competition always reduces the supplier's share of total profit.

4.2. Sensitivity analysis

We conducted a sensitivity analysis to study how a change in the values of the service and quality levels affect the values of the λ^* and λ^{**} thresholds. As expected, the analysis shows that increasing the value of the retailer's service attribute decreases the values of the showrooming thresholds (see Fig. 9a). As the retailer's service level increases, the retailer has more to lose from showrooming. Non-intuitively, the extent to which the threshold values increase from an increase in the quality level of the organic product is bounded by a value strictly less than 1 (Fig. 9b). That is, beyond a certain point, increasing the quality value has no effect on the decision to establish the dual-channel market (as expressed by the values of the thresholds λ^* and λ^{**}). At that point, the decision depends entirely on the coefficient of the showrooming effect.

From a managerial point of view, when the quality level of the



(a) As a function of *s* **(b)** As a function of *q*

Fig. 9. Thresholds λ* and λ** for $q = 30$, $s = 10$, and $c = 2$

organic product is only fair (i.e., above a certain threshold level), the retailer's decision on whether to establish the dual channel depends mostly on the value of the retailer service attribute. When that service level is relatively low, she is more likely to participate in the dual channel. However, when the quality of the direct supplier's product is poor (the supplier's attribute), the retailer will choose not to participate in the dual channel regardless of the showrooming effect. This insight is important to direct farmers who must ensure that they in fact provide higher quality.

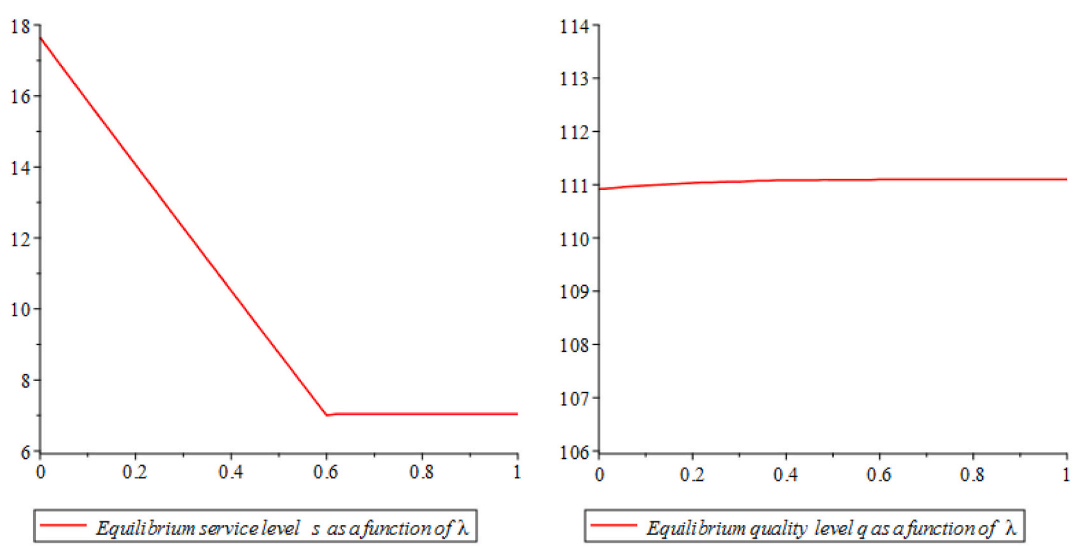
4.3. Gains from a dual channel under a contract

We analyze the dual-channel game under a contract to determine which party benefits most from establishing the dual-channel market in terms of the shares of total market profit obtained and the percent increases in profit relative to profits obtained under duopolistic competition. Based on the average results for the 2300 cases of the factorial experiment, we state:

Conjecture 3

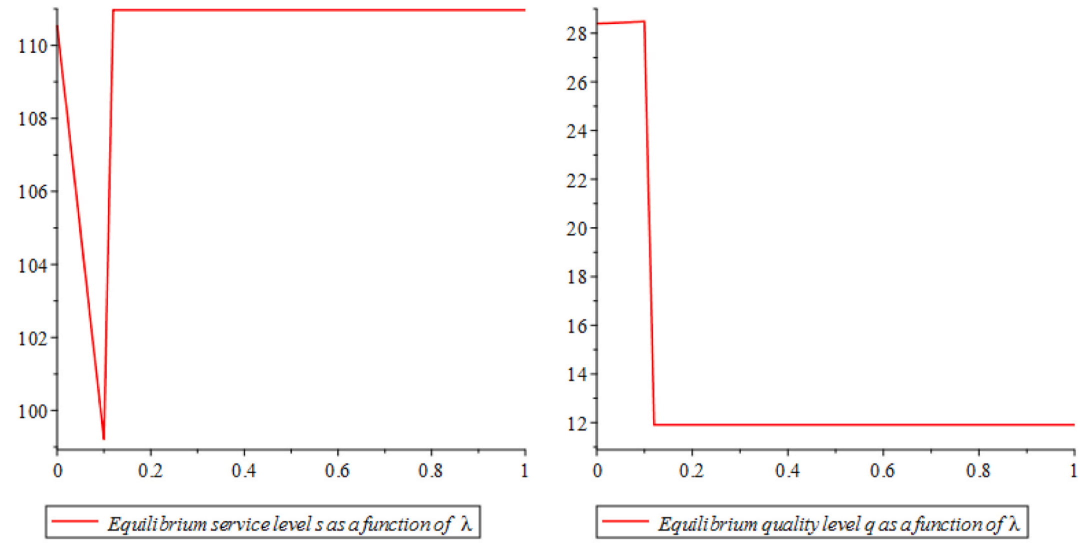
I. In a dual-channel supply chain, on average, the retailer obtains 36% of the market's total profit and the supplier obtains the remaining 64%.
II. When the supplier moves from the duopolistic competition to the dual-channel supply chain, his profit grows by 76% at most (the maximal ratio is 1.76).

This conjecture sheds some light on the comparative benefits for the supplier and retailer from establishing the dual-channel market (opening a retail channel for the organic product) in the absence of the



(a) Equilibrium service level **(b)** Equilibrium quality level

Fig. 10. Equilibrium service and quality for $h_s = 0.08$, $h_q = 0.02$ and $c = 2$ as a function of.λ



(a) Equilibrium service level **(b)** Equilibrium quality level

Fig. 11. Equilibrium service and quality for $h_s = 0.02$, $h_q = 0.05$ and $c = 2$ as a function of λ

showrooming effect. If the primary motivation for establishing the dual channel is to increase profit without regard to market share, the retailer is likely to benefit more than the supplier. This is so because the retailer's profit under duopolistic competition can approach zero when the purchasing price of the conventional product is too high. The retailer can increase her profit to an infinite degree by moving to the dual-channel supply chain. The potential increase in profit for the supplier is limited (see examples in Appendix E). However, if the primary motivation for establishing the dual channel is to increase a party's share of the market's total profit, the supplier benefits more than the retailer from establishing the dual channel.

5. Equilibrium choice of service and quality levels

As in Cattani et al. (2006) and Dumrongsiri et al. (2008), our initial model assumed that the values of the quality and service attributes were exogenous such that only a pricing game was studied. We now extend our model by allowing the retailer and supplier to choose the level of service and quality, respectively, by constructing a two-stage game.

In the first stage, the supplier and retailer simultaneously choose the level of their respective competitive attributes (the retailer chooses her optimal service level, and the supplier chooses his optimal quality level) under the common assumption that the cost of their investment is quadratic in the specific attribute each party controls (see e.g., Perlman, 2013). In the second stage, the supplier and retailer observe each other's choice of attribute level (quality and service) and choose pricing strategies. The game is solved via backward induction starting with the pricing strategy obtained by employing Procedure 1 and then determining the choice of attribute levels. The supplier chooses the level of quality that maximizes his objective function,

$$\Pi_D^d = Q_{OD}^d P_{OD}^{d*} + Q_{OR}^d W_O^{d*} - h_q q^2, \tag{14}$$

which is derived by substituting the equilibrium-pricing strategy in equation (12) and subtracting the supplier's investment cost, when h_q is a cost-scaling factor. The retailer chooses the level of service that maximizes her objective function,

$$\Pi_R^d = Q_{OR}^d M_O^{d*} + Q_{CR}^d \left(P_{CR}^{d*} - c\right) - h_S s^2, \tag{15}$$

which is derived by substituting the equilibrium-pricing strategy in equation (13) and subtracting the retailer's investment cost when h_s is a cost-scaling factor. It can be shown numerically (based on the extensive analysis described in the previous section) that a unique Nash equilibrium exists for this game.

We further study the impact of showrooming on the attribute values at equilibrium using representative examples in which h_s is higher than h_q and vice versa. We find that the equilibrium service level decreases with λ (see Fig. 10a for $0 \le \lambda \le \lambda^{**} = 0.6$ and Fig. 11a for $0 \le \lambda \le \lambda^{**} = 0.1$). This result follows since, as the showrooming effect increases, more consumers benefit from the service offered by the retailer but buy the product directly from the supplier. Thus, the retailer cannot obtain the full benefit from her investment and reduces her service level. Non-intuitively, we find that the equilibrium quality level is steady, changing only slightly as a function of λ (see Fig. 10b for $0 \le \lambda \le \lambda^{**} = 0.6$ and 11b for $0 \le \lambda \le \lambda^{**} = 0.1$). In other words, showrooming has no impact on the quality decision, which is the supplier's competitive attribute.

6. Conclusions

Our research addresses an increasingly important question for direct farmers (suppliers) offering organic food and brick-and mortar retailers in the agro-food sector: whether to compete or collaborate by establishing a dual channel supply chain in which consumers can purchase products either from the retailer or directly from the farmer, usually at a lower price. We assumed that each channel offers a competing benefit; specifically, the quality of the farmer's organic product is superior to the quality of the conventional product (i.e., healthier and more environmentally friendly) whereas the retailer provides a higher service level (tailored information and the ability to see and touch the products). We further assumed that consumers are heterogeneous in their valuations of these benefits and constructed a unique two-dimensional vertical differentiation consumer choice model.

The effects of "showrooming" in which consumers use a retail store's service of displaying products to evaluate the different versions of the product is further embedded in the models. Engaging in showrooming behavior can enable customers to gain information and reduce uncertainty regarding the organic product attributes when choosing to buy the organic product directly. Two game theoretic models were constructed to compare the retailer's and supplier's performance in the presence of showrooming with their performance in a duopolistic competition in which they offered different, competing versions of a product. We find closed form expressions for the optimal prices of the organic and conventional products under duopoly and developed a procedure by which the parties can determine the prices of their products in a dual supply chain. The study was then extended to allow each channel to also determine the level of the competitive attributes offered (the retailer chooses her optimal service level, and the supplier chooses the optimal quality level for the organic product). A two-stage game was constructed. First, the parties chose the level of their respective competitive attributes and then determined the optimal pricing strategy.

Our findings have important managerial implications for supply chain members. At the strategic level, it is critical for direct farmers and brick-and-mortar retailers to identify the conditions under which establishing a dual supply chain will benefit them. As expected, the direct supplier always benefits from offering his product both directly and through a retail channel. The retailer, however, only benefits from participating in the dual-channel supply chain when consumer showrooming remains below a certain threshold. Thus, there is a range of values of the showrooming coefficient for which, according to the game between the supplier and retailer, the retailer will choose to discontinue the dual channel even though doing so (moving to duopolistic competition) ultimately results in a loss of potential profit for the supplier. Surprisingly, by opting out of the dual channel, the retailer also could suffer a loss of potential profit. A contract is suggested to address the negative effects caused by showrooming and to arrive at a win-win situation for the direct supplier and retailer. Clearly, such contracts can be established only when the value of the coefficient of the showrooming effect makes the dual channel more profitable than competition for both parties.

At the tactical level, as the showrooming effect increases, more consumers benefit from the service offered by the retailer but some buy the product directly from the supplier. Thus, the retailer cannot obtain the full benefit from her investment and reduces her service level. When the quality of the organic product is poor (the product of the direct farmer), the retailer will choose not to participate in the dual channel regardless of the showrooming effect. Thus, direct farmers must ensure that they are in fact providing a high-quality product. This result is likely to explain the growing number of direct organic farmers engaging in dual-channel operations. Their organic outputs contribute to sustainable development and are safer for both the environment and customers than conventional substitutes.

At the operational level, we show that the price of an organic product offered directly is always lower than the price of the organic product at the retailer. Thus, indeed, consumers who engage in showrooming have an incentive to buy the product from the direct farmer at a lower price. Non-intuitively, we identify conditions under which the direct farmer in a duopoly claims a price higher than the retailer's price at equilibrium, despite the fact that he incurs no purchasing price selling his own products. This result holds when the value of the organic product is perceived by consumers as greater than the value of the service quality offered by the brick-and-mortar retailer and the purchase price of the conventional product is less than the gap between the values of the product-quality and service-quality attributes.

Because we consider a heterogeneous consumer base and provide detailed characterizations of market configurations for different scenarios in the presence of showrooming, our model can be used as a practical decision tool for supply chain members considering establishing a dual channel. Although the motivation was based on agro-food supply chains, our model is useful for brick-and-mortar retailers in diverse domains considering competing with online sellers and desiring to avoid being excessively vulnerable to showrooming.

This study can be extended in several directions in future research. In our scenario, the supplier and retailer have equal market power and thus set their prices simultaneously. Future research could explore other types of power structures between them. While the current model accounts only for some costs (purchasing costs and attribute-investment costs), additional costs are relevant in the context of managing showrooming in a supply chain of organic products. One such cost would be associated with production; organic products typically involve additional costs associated with strict production procedures required to ensure that the product conforms to organic standards. Others include the inconvenience cost incurred by consumers for shopping online and a cost incurred by consumers to travel to and from brick-and-mortar stores. In addition, there are cases in which the retailer needs to invest to create a showroom for competing versions of a product. Since a dual-channel market always benefits the supplier in the presence of showrooming, it also would be interesting to study a "coopetition" strategy in which the supplier and retailer share the cost of the retailer's showroom. Finally, we assume that the showrooming coefficient is a product-specific characteristic that is exogenously determined. Considering the showrooming effect as an endogenous coefficient is another interesting topic for future study.

Credit author statement

Yael Perlman: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendices.

Appendix A

Lemma 1. *Let* $q \geq s$

(i) The best-response price of the direct supplier for a given retailer price is:

$$P_{OD}^{q^*}(P_{CR}) = \begin{cases} \dfrac{P_{CR}+q}{3} & c \leq P_{CR} \leq 1.5s-q \\[2ex] \dfrac{q}{2}-\dfrac{s}{4}+\dfrac{P_{CR}}{2} & 1.5s-q \leq P_{CR} \leq q-0.5s \\[2ex] \dfrac{2(P_{CR}-s)+\sqrt{(P_{CR}-s)^2+6qs}}{3} & q-0.5s \leq P_{CR} \end{cases}$$

(ii) The best-response price of the retailer for a given supplier price is

$$P_{CR}^{q*}(P_{OD})=\begin{cases}\dfrac{P_{OD}+s+2c}{3} & c-s\le P_{OD}\le c+0.5s\\ \dfrac{P_{OD}+2s+2c}{4} & c+0.5s\le P_{OD}\le c+2q-1.5s\\ \dfrac{c+2(P_{OD}-q)+\sqrt{(P_{OD}-q-c)^2+6qs}}{3} & c+2q-1.5s\le P_{OD}\end{cases}$$

Proof of Lemma 1

(i) Solving the first-order condition by equating the first derivative of the direct supplier's profit with respect to his decision variable to zero and applying the conditions that define the corresponding market configuration, we obtain the best response for each configuration.

Denote by$P_{OD}^{q(ii)}(P_{CR})$the best response of the direct supplier when $P_{CR}-s\le P_{OD}\le P_{CR}$ (configuration *ii* in Fig. 1); then

$$P_{OD}^{q(ii)}(P_{CR})=\begin{cases}P_{CR} & c\le P_{CR}\le v-0.5s\\ \dfrac{2(P_{CR}-s)+\sqrt{(P_{CR}-s)^2+6qs}}{3} & q-0.5s\le P_{CR}\end{cases}.$$

Denote by$P_{OD}^{q(iii)}(P_{CR})$the best response of the direct supplier when$P_{CR}\le P_{OD}\le P_{CR}+q-s$ (configuration *iii* in Fig. 1); then

$$P_{OD}^{q(iii)}(P_{CR})=\begin{cases}P_{CR}+q-s & c\le P_{CR}\le 1.5s-q\\ \dfrac{v}{2}-\dfrac{s}{4}+\dfrac{P_{CR}}{2} & 1.5s-q\le P_{CR}\le q-0.5s\\ P_{CR} & q-0.5s\le P_{CR}\end{cases}.$$

Denote by$P_{OD}^{q(iv)}(P_{CR})$the best response of the direct supplier when$P_{CR}+q-s\le P_{OD}\le P_{CR}+q$ (configuration *iv* in Fig. 1); then

$$P_{OD}^{q(iv)}(P_{CR})=\begin{cases}\dfrac{P_{CR}+q}{3} & c\le P_{CR}\le 1.5s-q\\ P_{CR}+q-s & 1.5s-q\le P_{CR}\end{cases}.$$

The best response is obtained by selecting the price that maximizes the direct supplier's expected profit, $\underset{j=ii,iii,iv}{Max}\,\Pi_D^q(P_{OD}^{q(j)}(P_{CR}),P_{CR})$. By algebraic manipulation, when $c\le P_{CR}\le 1.5s-q$, the solution is $P_{OD}^{q(iv)}(P_{CR})$; when $1.5s-q\le P_{CR}\le q-0.5s$, the solution is $P_{OD}^{q(iii)}(P_{CR})$; and when $q-0.5s\le P_{CR}$, the solution is $P_{OD}^{q(ii)}(P_{CR})$.□.

(ii) Denote by $P_{CR}^{v(ii)}(P_{OD})$the best response of the direct supplier when $P_{OD}\le P_{CR}\le P_{OD}+s$ (config. *ii* in Fig. 1); then

$$P_{CR}^{v(ii)}(P_{OD})=\begin{cases}\dfrac{2c+P_{OD}+s}{3} & c-s\le P_{OD}\le c+0.5s\\ P_{OD} & c+0.5s\le P_{OD}\end{cases}.$$

Denote by $P_{CR}^{v(iii)}(P_{OD})$the best response of the direct supplier when $P_{OD}-(q-s)\le P_{CR}\le P_{OD}$ (config. *iii* in Fig. 1); then

$$P_{CR}^{v(iii)}(P_{OD})=\begin{cases}P_{OD} & c\le P_{OD}\le c+0.5s\\ \dfrac{c}{2}+\dfrac{s}{4}+\dfrac{P_{OD}}{2} & c+0.5s\le P_{OD}\le c+2q-1.5s\\ P_{OD}-q+s & c+2q-1.5s\le P_{OD}\end{cases}$$

Denote by $P_{CR}^{v(iv)}(P_{OD})$the best response of the direct supplier when$P_{OD}-v\le P_{CR}\le P_{OD}-(v-s)$ (config. *iv* in Fig. 1); then

$$P_{CR}^{v(iv)}(P_{OD})=\begin{cases}P_{OD}-q+s & c+q-s\le P_{OD}\le c+2q-1.5s\\ \dfrac{c+2(P_{OD}-q)+\sqrt{(P_{OD}-q-c)^2+6qs}}{3} & c+2q-1.5s\le P_{OD}\end{cases}.$$

The best response is obtained by selecting the price that maximizes the direct supplier's expected profit, . $\underset{j=ii,iii,iv}{Max}\,\Pi_{CR}^v(P_{CR}^{v(j)}(P_{OD}),P_{OD})$. By algebraic manipulation, when $c-s\le P_{OD}\le c+0.5s$, the solution is $P_{CR}^{v(ii)}(P_{OD})$; when $c+0.5s\le P_{OD}\le c+2q-1.5s$, the solution is $P_{CR}^{v(iii)}(P_{OD})$; and when $c+2q-1.5s\le P_{OD}$, the solution is $P_{CR}^{v(iv)}(P_{OD})$. □.

Lemma 2. *Le t*$q\le s$.

(i) The best-response price of the direct supplier for a given retailer price is

$$P_{CR}^{s*}(P_{OD})=\begin{cases}\dfrac{P_{OD}+s+2c}{3} & c-s\le P_{OD}\le c-s+1.5q\\ \dfrac{2P_{OD}+2s-q+2c}{4} & c-s+1.5q\le P_{OD}\le c+s-0.5q\\ \dfrac{c+2(P_{OD}-q)+\sqrt{(P_{OD}-q-c)^2+6qs}}{3} & c+s-0.5q\le P_{OD}\end{cases}.$$

$$P_{OD}^{s*}(P_{CR})=\begin{cases}\dfrac{P_{CR}+q}{3} & c\le P_{CR}\le 0.5q\\ \dfrac{q}{4}+\dfrac{P_{CR}}{2} & 0.5q\le P_{CR}\le 2s-1.5q\\ \dfrac{2(P_{CR}-s)+\sqrt{(P_{CR}-s)^2+6qs}}{3} & 2s-1.5q\le P_{CR}\end{cases}.$$

(ii) The best response price of the retailer for a given supplier price

Proof of Lemma 2

(i) Solving the first-order condition by equating the first derivative of the direct supplier's profit with respect to his decision variable to zero and applying the conditions that define the corresponding market configuration, we obtain the best response for each configuration.

Denote by$P_{OD}^{s(ii)}(P_{OR})$ the best response of the direct supplier when$P_{CR}-s\le P_{OD}\le P_{CR}+q-s$ (configuration *ii* in Fig. 1); then

$$P_{OD}^{s(ii)}(P_{CR})=\begin{cases}q-s+P_{CR} & c\le P_{CR}\le 2s-1.5q\\ \dfrac{2(P_{CR}-s)+\sqrt{(P_{CR}-s)^2+6qs}}{3} & 2s-1.5q\le P_{CR}\end{cases}.$$

Denote by$P_{OD}^{s(i)}(P_{CR})$the best response of the direct supplier when$v-s+P_{CR}\le P_{OD}\le P_{CR}$ (configuration *i* in Fig. 1); then

$$P_{OD}^{s(i)}(P_{CR})=\begin{cases}P_{CR} & c\le P_{CR}\le 0.5q\\ \dfrac{q}{4}+\dfrac{P_{CR}}{2} & 0.5q\le P_{CR}\le 2s-1.5q\\ q-s+P_{CR} & 2s-1.5q\le P_{CR}\end{cases}.$$

Denote by$P_{OD}^{s(iv)}(P_{CR})$the best response of the direct supplier when$P_{CR}\le P_{OD}\le P_{CR}+q$ (configuration *iv* in Fig. 1); then

$$P_{OD}^{s(iv)}(P_{CR})=\begin{cases}\dfrac{P_{CR}+q}{3} & c\le P_{CR}\le 0.5q\\ P_{CR} & 0.5q\le P_{CR}\end{cases}.$$

The best response is obtained by selecting the price that maximizes the direct supplier's expected profit, $\underset{j=ii,i,iv}{Max}\Pi_D^s(P_{OD}^{s(j)}(P_{CR}),P_{CR})$. By algebraic manipulation, when $c\le P_{CR}\le 0.5q$, the solution is $P_{OD}^{s(iv)}(P_{CR})$; when $0.5q\le P_{CR}\le 2s-1.5q$, the solution is $P_{OD}^{s(i)}(P_{CR})$; and when $2s-1.5q\le P_{CR}$, the solution is $P_{OD}^{s(ii)}(P_{CR})$. □.

(ii) Denote by $P_{CR}^{s(ii)}(P_{OD})$ the best response of the direct supplier when $P_{OD}+s-q\le P_{CR}\le P_{OD}+s$ (configuration *ii* in Fig. 1); then

$$P_{CR}^{s(ii)}(P_{OD})=\begin{cases}\dfrac{2c+P_{OD}+s}{3} & c-s\le P_{OD}\le c-s+1.5q\\ P_{OD}+s-q & c-s+1.5q\le P_{OD}\end{cases}.$$

Denote by $P_{CR}^{s(i)}(P_{OD})$ the best response of the direct supplier when $P_{OD}\le P_{CR}\le P_{OD}+s-q$ (config. *i* in Fig. 1); then

$$P_{CR}^{s(i)}(P_{OD})=\begin{cases}c+s-0.5q & c+q-s\le P_D\le c-s+1.5q\\ \dfrac{c}{2}+\dfrac{s}{2}-\dfrac{q}{4}+\dfrac{P_{OD}}{2} & c-s+1.5q\le P_{OD}\le c+s-0.5q\\ P_D & c+s-0.5q\le P_D\end{cases}.$$

Denote by $P_{CR}^{s(iv)}(P_{OD})$ the best response of the direct supplier when $P_{OD}-q\le P_{CR}\le P_{OD}$ (config. *iv* in Fig. 1):

$$P_{CR}^{s(iv)}(P_{OD}) = \begin{cases} P_{OD} & c \le P_{OD} \le s - 0.5q + c \\ \dfrac{c + 2(P_{OD} - q) + \sqrt{(P_{OD} - q - c)^2 + 6qs}}{3} & s - 0.5q + c \le P_{OD} \end{cases}.$$

The best response is obtained by selecting the price that maximizes the direct supplier's expected profit, $\underset{j=ii,i,iv}{Max}\Pi_R^s(P_{CR}^{s(j)}(P_{OD}), P_{OD})$. By algebraic manipulation, when $c - s \le P_{OD} \le c - s + 1.5q$, the solution is $P_{CR}^{s(ii)}(P_{OD})$; when $c - s + 1.5q \le P_{OD} \le c + s - 0.5q$, the solution is $P_{CR}^{s(i)}(P_{OD})$; and when $s - 0.5q + c \le P_{OD}$, the solution is $P_{CR}^{s(iv)}(P_{OD})$. $\square$.

Proof of Theorem 1. When $q \ge s$, the theorem is proved by solving $P_{OD}^{v*}(P_{CR}^{v*}(P_{OD})) = P_{OD}$ and $P_{CR}^{v*}(P_{OD}^{v*}(P_{CR})) = P_{CR}$ given in Lemma 1 for the cases in which the market is in the same configuration. Similarly, when $q \le s$, solving $P_{OD}^{s*}(P_{CR}^{s*}(P_{OD})) = P_{OD}$ and $P_{CR}^{s*}(P_{OD}^{s*}(P_{CR})) = P_{CR}$ given in Lemma 2 for the cases in which the market is in the same configuration completes the proof. $\square$.

Appendix B

Denote by Π_D^{dI} and Π_D^{dII} the supplier's profits under market configurations I and II, respectively. Denote by Π_R^{dI} and Π_R^{dII} the retailer's profits under market configurations I and II, respectively. For each configuration, the respective necessary optimality conditions for the four unknowns: P_{OD}, W_O, P_{CR}, and M_O. For configuration I: solve $\frac{\partial \Pi_D^{dI}}{\partial P_{OD}} = 0,\ \frac{\partial \Pi_D^{dI}}{\partial W_O} = 0\ \frac{\partial \Pi_R^{dI}}{\partial P_{CR}} = 0,\ \frac{\partial \Pi_R^{dI}}{\partial M_O} = 0$. For configuration II: solve $\frac{\partial \Pi_D^{dII}}{\partial P_{OD}} = 0,\ \frac{\partial \Pi_D^{dII}}{\partial W_O} = 0\ \frac{\partial \Pi_R^{dII}}{\partial P_{CR}} = 0,\ \frac{\partial \Pi_R^{dII}}{\partial M_O} = 0$.

Solve the set of equations. Denote these solutions by the superscripts *dI* and *dII* , For configuration I:

$$P_{OD}^{dI} = \frac{2\left(q - 2W_{OD}^{dI} + P_{CR}^{dI}\right)M_O^{dI} - \left(M_O^{dI}\right)^2 - 3\left(W_O^{dI}\right)^2 + 4\left(q + P_{CR}^{dI}\right)W_O^{dI} - \left(P_{CR}^{dI}\right)^2}{4q};\ M_O^{dI} = \frac{a_2\left(W_O^{dI}\right)^2 + a_1 W_O^{dI} + a_0}{b_2\left(W_O^{dI}\right)^2 + b_1 W_O^{dI} + b_0}$$

$$P_{OR}^{dI} = M_O^{dI} + W_{OD}^{dI};\ P_{OR}^{dI} \ge P_{CR}^{dI} \ge P_{OD}^{dI}$$

where W_O^{dI} is the positive real root of the cubic polynomial function:

$$\begin{aligned} f(z) &= z^3\left(576q^2 - (384c + 576s(1-\lambda))q + 64c^2\right) - z^2\left(216q^3 + (792c - 888s(1-\lambda))q^2 - \left(600c^2 + 1192cs(1-\lambda)\right)q + 104c^3\right) + \\ &z\left((270c - 774s(1-\lambda))q^3 + \left(234c^2 - 390cs(1-\lambda) + 1210s^2(1-\lambda)^2\right)q^2 - \left(246c^3 + 904c^2 s(1-\lambda)\right)q + 46c^4\right) - 6(c+q)\cdot \\ &\left(c^4 + \left(9c^2 + 24cs(1-\lambda) + 121s^2(1-\lambda)^2\right)q^2 - \left(6c^3 + 28c^2 s(1-\lambda)\right)q - 40.5s(1-\lambda)q^3\right) \end{aligned}$$

and P_{CR}^{dI} is the positive real root of the cubic polynomial function:

$$\begin{aligned} f(z) &= 2z^3 - z^2\left(6M_O^{dI} + 9W_O^{dI} + c - 6q\right) + \\ &z\left(6\left(M_O^{dI}\right)^2 + 2\left(c - 2q + 9W_O^{dI}\right)M_O^{dI} + 10\left(W_O^{dI}\right)^2 + 4(c - 2q)W_O^{dI} - 4q(c + 2s(1-\lambda))\right) - \\ &2\left(M_O^{dI}\right)\left(M_O^{dI}\right)^3 + \left(c + 2q + 9W_O^{dI}\right)\left(M_O^{dI}\right)\left(M_O^{dI}\right)^2 - \left(10\left(W_O^{dI}\right)^2 + 2(2c - q)W_O^{dI} - 2q(c + 4s(1-\lambda))\right)M_O^{dI} - 3 \\ &\left(W_O^{dI}\right)^3 - (3c - 2q)\left(W_O^{dI}\right)^2 + 4q(c + s(1-\lambda))W_O^{dI} + 4cs(1-\lambda)q \end{aligned}$$

For configuration II:

$$P_{CR}^{dII} = \frac{4\left(s(1-\lambda) - W_{OD}^{dII} + P_{OD}^{dII}\right)M_O^{dII} - 3\left(M_O^{dII}\right)^2 - \left(W_O^{dII}\right)^2 + 2\left(s(1-\lambda) + P_{OD}^{dII}\right)W_O^{dI} + 2cs(1-\lambda) - \left(P_{OD}^{dII}\right)^2}{4s(1-\lambda)};$$

$$P_{OD}^{dII} = \frac{n_2\left(M_O^{dII}\right)^2 + n_1 M_O^{dII} + n_0}{m_2\left(M_O^{dII}\right)^2 + m_1 M_O^{dII} + m_0};\ P_{OR}^{dII} = M_O^{dII} + W_{OD}^{dII}; P_{OR}^{dII} \ge P_{OD}^{dII} \ge P_{CR}^{dII}.$$

where M_O^{dII} is the positive real root of the cubic polynomial function:

$$\begin{aligned} f(z) &= z^3\left(576q^2 - (384c + 576s(1-\lambda))q + 64c^2\right) - 24z^2\left(37q^2 - (6c - 9s(1-\lambda))q + c^2\right) - \\ &2s(1-\lambda)z\left(605q^3 + (11c - 387s(1-\lambda))q^2 - \left(17c^2 + 63cs(1-\lambda)\right)q + c^3\right) + 3qs^2(1-\lambda)^2\left(242q^2 - (44c + 81s(1-\lambda))q + 2c^2\right) \end{aligned}$$

and W_O^{dII} is the positive real root of the cubic polynomial function:

$$\begin{aligned} f(z) &= z^3\left(576q^2 - (384c + 576s(1-\lambda))q + 64c^2\right) - 24z^2\left(37q^2 - (6c - 9s(1-\lambda))q + c^2\right) - \\ &2s(1-\lambda)z\left(605q^3 + (11c - 387s(1-\lambda))q^2 - \left(17c^2 + 63cs(1-\lambda)\right)q + c^3\right) + 3qs^2(1-\lambda)^2\left(242q^2 - (44c + 81s(1-\lambda))q + 2c^2\right) \end{aligned}$$

Appendix C

The Hessian of the supplier's profit for Configuration I (denoted by Π_D^{dI}) is:

$$\begin{bmatrix} -\frac{2}{s(1-\lambda)} & \frac{2\left(P_{CR}^{d}-M_{O}^{d}-W_{O}^{d}+q\right)-W_{O}^{d}}{s(1-\lambda)q} \\ \frac{2\left(P_{CR}^{d}-M_{O}^{d}-W_{O}^{d}+q\right)-W_{O}^{d}}{s(1-\lambda)q} & -\frac{2P_{CR}^{d}+3P_{OD}^{d}-4M_{O}^{d}-6W_{O}^{d}+2q+2s(1-\lambda)}{s(1-\lambda)q} \end{bmatrix}$$

The Hessian of the supplier's profit for Configuration II (denoted by Π_{D}^{dII}) is:

$$\begin{bmatrix} -\frac{2\left(P_{CR}^{d}-P_{OD}^{d}+q\right)-P_{OD}^{d}}{s(1-\lambda)q} & \frac{2\left(P_{CR}^{d}-M_{O}^{d}-W_{O}^{d}+q\right)-W_{O}^{d}}{s(1-\lambda)q} \\ \frac{2\left(P_{CR}^{d}-M_{O}^{d}-W_{O}^{d}+q\right)-W_{O}^{d}}{s(1-\lambda)q} & -\frac{2P_{CR}^{d}+3P_{OD}^{d}-4M_{O}^{d}-6W_{O}^{d}+2q+2s(1-\lambda)}{s(1-\lambda)q} \end{bmatrix}.$$

The Hessian of the retailer's profit for Configuration I (denoted by Π_{R}^{dI}) is:

$$\begin{bmatrix} -\frac{2P_{OD}^{d}-3P_{CR}^{d}+c+2s(1-\lambda)}{s(1-\lambda)q} & \frac{2\left(P_{OD}^{d}-M_{O}^{d}-W_{O}^{d}+s(1-\lambda)\right)-M_{O}^{d}}{s(1-\lambda)q} \\ \frac{2\left(P_{OD}^{d}-M_{O}^{d}-W_{O}^{d}+s(1-\lambda)\right)-M_{O}^{d}}{s(1-\lambda)q} & -\frac{2P_{OD}^{d}+3P_{CR}^{d}-c-6M_{O}^{d}-4W_{O}^{d}+2q+2s(1-\lambda)}{s(1-\lambda)q} \end{bmatrix}$$

The Hessian of the retailer's profit for Configuration II (denoted by Π_{R}^{dII}) is:

$$\begin{bmatrix} -\frac{2}{q} & \frac{2\left(P_{OD}^{d}-M_{O}^{d}-W_{O}^{d}+s(1-\lambda)\right)-M_{O}^{d}}{s(1-\lambda)q} \\ \frac{2\left(P_{OD}^{d}-M_{O}^{d}-W_{O}^{d}+s(1-\lambda)\right)-M_{O}^{d}}{s(1-\lambda)q} & -\frac{2P_{OD}^{d}+3P_{CR}^{d}-c-6M_{O}^{d}-4W_{O}^{d}+2q+2s(1-\lambda)}{s(1-\lambda)q} \end{bmatrix}.$$

Appendix D

To obtain the supplier's best response solve the set of two first-order conditions with respect to his decision variables (P_{OD}^{d}, W_{O}^{d}) for each configuration.

The solution under configuration I (denoted by superscript RI):

$$P_{OD}^{RI}\left(M_{O}^{dI},P_{CR}^{dI}\right)=\frac{-\left(M_{O}^{dI}\right)^{2}+2\left(P_{CR}^{dI}+q-2W_{O}^{RI}\right)M_{O}^{dI}-3\left(W_{O}^{RI}\right)^{2}+4\left(P_{CR}^{dI}+q\right)W_{O}^{RI}-\left(P_{CR}^{dI}\right)^{2}}{4q}$$

where W_{O}^{RI} is the root of the cubic polynomial function.

$$f(z)=9z^{3}+6\left(3M_{O}^{dI}-3P_{CR}^{dI}-q\right)z^{2}+\left(11\left(M_{O}^{dI}\right)^{2}-22M_{O}^{dI}P_{CR}^{dI}-6M_{O}^{dI}q+11\left(P_{CR}^{dI}\right)^{2}+8P_{CR}^{dI}q-8qs(1-\lambda)\right)z$$
$$+2\left(M_{O}^{dI}-P_{CR}^{dI}-q\right)\left(\left(M_{O}^{dI}\right)^{2}-2\left(M_{O}^{dI}\right)^{2}P_{CR}^{dI}+\left(P_{CR}^{dI}\right)^{2}-2qs(1-\lambda)\right).$$

The solution under configuration II (denoted by superscript RII):

$$P_{OD}^{RII}\left(M_{O}^{dII},P_{CR}^{dII}\right)=\frac{\left(M_{O}^{dII}\right)^{2}+4M_{O}^{II}W_{O}^{RII}-M_{O}^{dII}\left(P_{CR}^{dII}-q\right)+3\left(W_{O}^{RII}\right)^{2}-2W_{O}^{RII}\left(P_{CR}^{dII}+q\right)}{2M_{O}^{dII}+3W_{O}^{RII}-2P_{CR}^{dII}-2q}$$

where W_{O}^{RII} is the root of the cubic polynomial function.

$$f(z)=36s(1-\lambda)z^{3}+3\left(\left(M_{O}^{dII}\right)^{2}+22s(1-\lambda)\left(M_{O}^{dII}-P_{CR}^{dII}-q\right)-4s^{2}(1-\lambda)^{2}\right)z^{2}-4\left(M_{O}^{dII}-P_{CR}^{dII}-q\right)\left(3s^{2}(1-\lambda)^{2}+\left(10q-9M_{O}^{dII}+10P_{CR}^{dII}\right)s(1-\lambda)-\left(M_{O}^{dII}\right)^{2}\right)z$$
$$+\left(M_{O}^{dII}-P_{CR}^{dII}-q\right)^{2}-3s^{2}(1-\lambda)^{2}+\left(-8q+6M_{O}^{dII}-8P_{CR}^{dII}\right)s\left(1-\lambda\right)+\left(M_{O}^{dII}\right)^{2}\Big)$$

The solution under duopolistic competition (for the possible best response) is given in Lemma 1 for $q \geq s$ and in Lemma 2 for. $q \leq s$.

Each boundary defines a path for the decision variables (P_{OD}^{d}, W_{O}^{d}) so in order to find the possible best responses on the boundary we find the stationary points on the boundary path and take the path edges.

Out of all the possible best responses above we find the one that maximizes the supplier's profit Π_{D}.

To obtain the retailer's best response solve the set of first-order conditions with respect to her decision variables (P_{CR}^{d}, M_{O}^{d}) for each configuration.

The solution under configuration I (denoted by superscript RI):

$$P_{CR}^{RI}\left(W_{O}^{dI},P_{OD}^{dI}\right)=\frac{3\left(M_{O}^{RI}\right)^{2}-2\left(P_{OD}^{dI}+s(1-\lambda)+q-0.5c-2W_{O}^{dI}\right)M_{O}^{RI}+\left(W_{O}^{dI}-P_{OD}^{dI}-s(1-\lambda)\right)\left(c-q+W_{O}^{dI}\right)}{3M_{O}^{RI}+2\left(W_{O}^{dI}-P_{OD}^{dI}-s(1-\lambda)\right)}$$

where M_{O}^{RI} is the root of the cubic polynomial function.

$$f(z)=36s(1-\lambda)z^3+3\left(\left(W_O^{dI}-c\right)^2+22q\left(W_O^{dI}-P_{OD}^{dI}-s(1-\lambda)\right)-4q^2\right)z^2-4\left(W_O^{dI}-P_{OD}^{dI}-s(1-\lambda)\right)\left(3q^2+\left(10s-9W_O^{dI}+10P_{OD}^{dI}-c\right)s(1-\lambda)-\left(W_O^{dI}-c\right)^2\right)z$$
$$2^{\left(-3q^2+\left(2c-8s(1-\lambda)+6W_O^{dI}-8P_{OD}^{dI}\right)q+\left(W_O^{dI}-c\right)^2\right)}.$$

The solution under configuration II (denoted by superscript RII):

$$P_{CR}^{RII}\left(W_O^{dII},P_{OD}^{dII}\right)=\frac{-3\left(M_O^{RII}\right)^2-4\left(W_O^{dII}-P_{OD}^{dII}-s(1-\lambda)\right)M_O^{RII}-\left(W_O^{dII}\right)^2+2\left(s(1-\lambda)+P_{OD}^{dII}\right)W_O^{dII}+2cs(1-\lambda)+\left(P_{OD}^{dII}\right)^2}{4s(1-\lambda)}.$$

where M_O^{RII} is the root of the cubic polynomial function.

$$f\left(z\right)=9z^3+6\left(3W_O^{dII}-3P_{OD}^{dII}-s\left(1-\lambda\right)\right)z^2+\left(11\left(W_O^{dII}\right)^2-22W_O^{dII}P_{OD}^{dII}-6W_O^{dII}s\left(1-\lambda\right)+11\left(P_{OD}^{dII}\right)^2+8P_{OD}s\right.$$

$$\left.\left(1-\lambda\right)-8qs-2cs\left(1-\lambda\right)\right)z+2\left(W_O^{dII}-P_{OD}-s\left(1-\lambda\right)\right)\left(\left(W_O^{dII}\right)^2-2W_O^{dII}P_{OD}^{dII}+\left(P_{OD}^{dII}\right)^2-2qs\left(1-\lambda\right)\right)$$

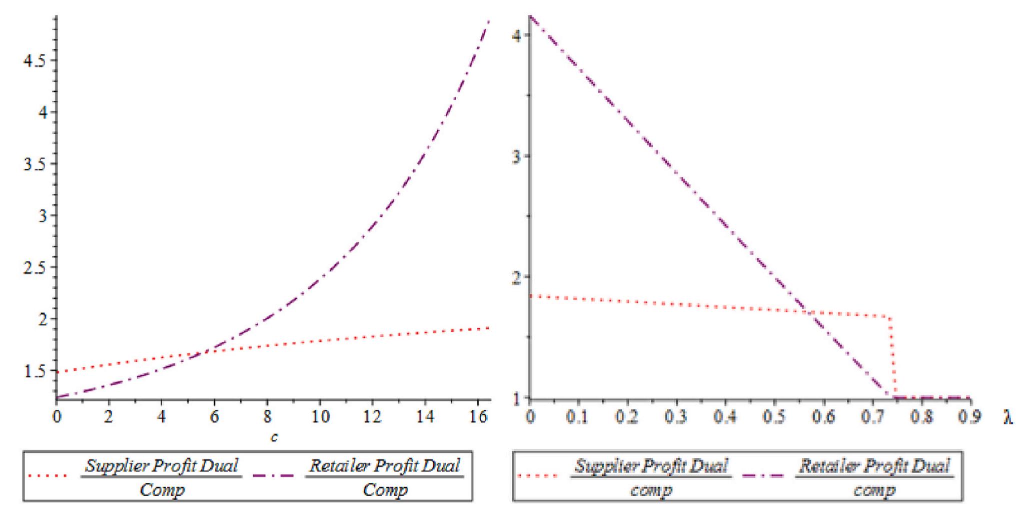
The solution under duopolistic competition (for the possible best response) is given in Lemma 1 for $q \geq s$ and in Lemma 2 for. $q \leq s$.

Each boundary defines a path for the decision variables (P_{CR}^d, M_O^d) so in order to find the possible best responses on the boundary find the stationary points on the boundary path and take the path edges.

Out of all the possible best responses above find the one that maximizes the retailer's profit Π_R.

Appendix E

As depicted in Figure E1, the supplier's profit growth obtained from opening a dual supply chain is bounded by 1.76. This maximal ratio is obtained when $\lambda = 0$.



(a) $q=12$ $s=20$ and $\lambda=0$ as a function of c **(b)** $q=30$ $s=10$ and $c=2$ as a function of λ

Figure E1. Retailer's and supplier's profit growth obtained from opening a dual supply chain.

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