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Channel Performance and Incentives for Retail Cost Misrepresentation*

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Abstract

This paper investigates the price decision making and channel performance under cost misrepresentation at the retail stage. In the standard double marginalization game, we introduce a preliminary stage, where the retailer can misrepresent her constant marginal cost. We give respective sufficient conditions on the demand function for the retailer to misrepresent her marginal cost downwards and upwards. In contrast to the literature, we prove that the opportunistic behavior of the retailer does not necessarily lower channel performance and social welfare. Indeed, a downward misrepresentation of the retail cost, which one obtains when the price elasticity of demand is not very price elastic, increases channel performance and social welfare. Illustrative examples using common specifications of demand are provided.

Key words : Channel Cooperation, Channels of Distribution, Decision-Making, Distribution, Game Theory, Pricing Research, Retailing and Wholesaling, Signaling, Supply Chains.

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Résumé : Cet article étudie les décisions de fixation des prix et le bien-être social des acteurs du canal de distribution lorsque le distributeur exploite une information privée sur ses coûts. Nous introduisons dans le jeu standard de la double marginalisation une étape préliminaire, où le distributeur peut faire une fausse annonce sur son coût marginal. Nous établissons des conditions suffisantes sur la fonction de demande pour que le distributeur soit incité à sur-évaluer ou inversement à sous-évaluer son coût. Nous montrons ainsi, par opposition aux résultats standard de la littérature, que le comportement opportuniste du distributeur ne réduit pas nécessairement la performance du canal de distribution et le bien-être social. Plus précisément, le distributeur peut être incité à sous-évaluer son coût marginal. Ce comportement apparaît lorsque l'élasticité prix de la demande est peu élastique. De plus, il a pour effet d'accroître la performance du canal de distribution et le bien-être social. Nous donnons des exemples illustratifs de spécifications usuelles de la fonction de demande qui vérifient nos conditions.

Mots Clefs: fixation des prix; canal de distribution; coût de distribution; information privée; fonction de demande

1 Introduction

The advancement of new information technologies and the worldwide globalization of economies affect vertical market structures and subsequently alter the division of power between manufacturers and intermediaries. Universal product coding, combined with optical scanning techniques and development of integrated information systems tend to transform distribution outlets into observation posts. Nowadays, retailers do not just channel flows of goods and services, but, more significantly than ever, they also trade data (see e.g. Blattberg et al.(1994)). Consequently, intermediaries' privileged access to marketing and merchandising information may enable them to compete indirectly with each other via upstream trade pressures by increasing their own power vis-à-vis their suppliers, which may ultimately affect social welfare (Messinger and Narasimhan (1995)).

Yet as management textbooks point out, the road from observations of facts to the value adding use of relevant information reveals to be long and intricate. Quick updating and computer processing just do not suffice to enhance market intelligence or improve supply chain logistics. Data collected must be filtered, validated and "digested" through appropriate decision support systems elaborated by experts in specific entities of the organization.

The introduction of information flows, via, for example, Marketing Decision Support Systems (MDSS) introduced by Little (1979), has two opposite impacts on channel performance. First, information increases channel performance, since it ensures a better perception by a channel member of her environment. This better perception allows by itself to reduce channel costs. As an illustration, Cachon and Fisher (2000) show, in a simulation-based numerical study, how the supply chain costs can be reduced by using a better information-sharing policy. In addition, information allows the channel member to internalize the spillovers induced by her own decisions in the distribution channel. This internalization is a prerequisite to solving the well-known double marginalization problem uncovered by Spengler (1950). It can be achieved through a coordination mechanism, such as the quantity discount schedule discussed by Jeuland and Shugan (1983). An illustration of the crucial role of information is given by Chu and Messinger (1997), who show that improved information about demand always increases individual profits, as well as the share of channel profits claimed by the informed channel member.

Second, the opportunistic behavior of the informed channel member decreases channel performance. Nevertheless, this second negative impact might be avoided through type-revealing channel contracts. Chu (1992) studies how channel members deal with asymmetric information in the context of new product introduction. The manufacturer, with the private information that demand for her product will be high, can differentiate herself from the low-demand type through strong advertising and a high wholesale price. The retailer, in turn, can screen high-demand from low-demand products by stipulating a take-it-or-leave-it slotting allowance.

The main conclusion of the literature is that, for the information flow to increase channel performance, the information needs to be shared by all channel members. As an illustration, Desiraju and Moorthy (1997) study channel performance when the retailer is better informed about demand conditions than the manufacturer. They prove that channel profit is maximized when this information about demand is indirectly shared by the manufacturer through the observation of the retail price and service. For this purpose, the retailer and the manufacturer jointly invest in the information systems required to monitor the retailer's compliance with the requirements (on retail price and service).

In this paper, we study channel performance when the retailer is better informed about her own cost. This private information might come from merchandising cost accounting systems, so-called Direct Product Profitability (DPP) systems, which allows, despite the width and depth of assortments, to evaluate the true profitability of the thousands of wares that the retailer carries. We shall assume that this private information is not shared directly or indirectly by the manufacturer allowing for an opportunistic behavior on the part of the retailer. This issue was first mentioned by Jeuland and Shugan (1983): "... However in practice the constant ... may not be known because manufacturer and retailer do not know each other's costs. Furthermore, we expect that channel members have an incentive to provide biased information to each other about their respective operations when negotiating year agreement... ".

The purpose of this paper is to investigate the decisions and channel performance under cost misrepresentation at the retail stage. We ask the following questions :

1. What is the retailer incentive to misrepresent her marginal cost ?

2. Does this cost misrepresentation necessarily decrease channel performance and social welfare ?

3. How are these results related to the shape of the demand function ?

In order to focus on these issues we consider the simplest asymmetric information model where the manufacturer believes that the cost announced by the retailer is the true cost. This could be legitimized by the fact that the manufacturer does not possess any additional relevant information about the retail cost. In other words, we are implicitly assuming the manufacturer is rather naive in that he takes for granted the announcement of the retailer, although she ought to be aware, given the common knowledge structure of the game, that incentives for misrepresentation might be present. More precisely, we are not modeling the strategic interaction here as a Bayesian game where the retailer's cost is private information, with the manufacturer acting only on the basis of a prior belief about this cost.

We perform our investigation in the standard double marginalization game, in which we introduce a preliminary stage, where the retailer can misrepresent her constant marginal cost. We first prove that the retailer does not necessarily choose to misrepresent upwards her marginal cost. Indeed, the retailer's incentive to misrepresent her marginal cost crucially depends on how the manufacturer reacts to the reported retail cost. The latter reaction crucially depends, in turn, on the shape of the demand function. The intuition behind this result is the following. When the retail cost increases, the manufacturer knows that the retailer will increase the retail price. If the demand function is such that this strongly reduces market demand, the manufacturer might choose to reduce the wholesale price in order to stimulate market demand. This is obtained when the price-elasticity of demand is not very price elastic. This condition is fulfilled, for example, by the class of iso-price-elastic demands that is most frequently used to study channel performance. To conclude, we prove that when the price-elasticity of demand is not very high, the retailer chooses to misrepresent downwards her marginal cost, while when the price-elasticity of demand is high, the retailer chooses to misrepresent upwards her marginal cost. The latter condition is fulfilled, for example, by linear demand, the second most often adopted demand in the literature.

Our second important result deals with the implication on channel performance. Perhaps surprisingly, we prove that the opportunistic behavior of the retailer does not necessarily lower channel performance. Indeed, when demand is not very price elastic, the opportunistic behavior of the retailer increases channel performance. The latter would even be improved by a larger cost misrepresentation by the retailer. Hence, the result, taken for granted in the literature, that the opportunistic behavior of the retailer necessarily decreases channel performance is only valid when the price-elasticity of demand is significantly price elastic. Note that, by avoiding the problem of double marginalization, vertical integration still clearly ensures the best channel performance.

For what regards the retail price, we prove that whatever the shape of the demand function, the retail price increases with the reported retail cost. This obtains since we establish that the sum of the wholesale price and the reported retail cost increases with the reported retail cost. These results are not surprising, but the added generality is manifested in the absence of customary assumptions of restraints on the shape of the demand function and second order condition (i.e. some form of concavity of the profit function). To conclude, when it is optimal for the opportunistic retailer to misrepresent downwards (respectively upwards) her marginal cost in the decentralized channel, she also sets a lower (respectively higher) retail price.

The two previous results allow to deduce the implication on social welfare of the opportunistic behavior of the retailer. The counterintuitive result here is that, when the price elasticity of demand is not very price elastic, the opportunistic behavior of the retailer does not only increase channel performance but, it also increases social welfare, since, in this case, the retailer also sets a lower retail price. Social welfare would even be improved if the cost misrepresentation were larger. The more intuitive result that the opportunistic behavior of the retailer lowers social welfare and increases the retail price is only valid when price elasticity of demand is significantly price elastic. Naturally social welfare is still maximized under vertical integration.

Section 2 sets the model up and gives generalizations of existing results in the literature related to the reaction of the retail price to an increase in the sum of the wholesale price and the retail marginal cost and the reaction of the wholesale price to an increase in the retail marginal cost. Section 3 studies the retailer's incentive to misrepresent her marginal cost. Illustrative examples of demand models are provided. Section 4 studies the implications on channel performance, retail price and social welfare of the retailer's misrepresentation of her marginal cost. Section 5 contains a brief discussion. Section 6 contains a summary of the supermodularity notions used and proofs for all the results of the paper.

2 Set-up

In this section we define our set-up and give generalizations of existing results in the literature related to the reaction of the retail price to an increase in the sum of the wholesale price and the retail marginal cost and the reaction of the wholesale price to an increase in the retail marginal cost. The added generality is manifested in the absence of customary restrictive assumptions on the shape of the demand function (i.e. some form of concavity of the profit function).

Consider the following channel setting. An upstream manufacturer produces a product at a constant marginal cost c_1. She then sells the product through an independent retailer. Double marginalization occurs since the manufacturer and the retailer successively choose the wholesale price p_1 and the retail price p_2. This is a two-level monopoly since each agent has downstream monopoly power. The manufacturer has no direct control over the marketing policies of the retailer. Nevertheless, the manufacturer does have some influence on the final retail price. This derives from the assumptions that the manufacturer possesses sufficient channel power to set its own wholesale price and that she knows how much her retailer will order at any given wholesale price. This knowledge of the retailer's reaction function enables the manufacturer to set the wholesale price to maximize her own profit taking into consideration the retailer's reaction. These sequential decisions are traditionally formalized in a two-stage game: At stage 1 the manufacturer chooses the wholesale price ; at stage two, given this wholesale price, the retailer chooses the final retail price.

In this paper, we introduce a preliminary stage where the retailer reports, and thus can misrepresent, her constant marginal cost. We assume the manufacturer is rather naïve in that he takes at face value the announcement of the retailer, although she ought to be aware, given the common knowledge structure of the game, that incentives for misrepresentation might be present. In other words, we are not modeling the strategic interaction as a Bayesian game where the retailer's cost is private information, with the manufacturer acting only on the basis of a prior belief about this cost.

Hence, the sequential decisions are formalized in a three-stage game: At stage 0, the retailer announces the marginal cost $c_2 + \delta$, where $\delta \in [-c_2, +\infty)$ and c_2 is her true marginal cost, anticipating the manufacturer's reaction to this announcement and her own reaction to the wholesale price. At stage 1, the manufacturer chooses p_1 taking for granted $c_2 + \delta$ and knowing the retailer's reaction to p_1. As in the standard game of double marginalization, the manufacturer does have some influence on the final retail price: The manufacturer still possesses sufficient channel power to set the wholesale price. Nevertheless, this influence is now biased in the sense that the retailer's reaction expected by the manufacturer for any given wholesale price is conditional on the announced retailer's marginal cost . This biased knowledge of the retailer's reaction function allows the manufacturer to set the wholesale price to maximize her own profit taking into consideration the expected retailer's reaction (which differs from the true retailer's reaction). Finally, at stage two, the retailer chooses p_2 given $c_2 + \delta$ and p_1.

The (subgame perfect) equilibrium of this three-stage game can be computed through backward induction, where computations at stage 2 allow to define the retailer's reaction function expected by the manufacturer.

At stage 2, the manufacturer expects that the retailer chooses the retail price $p_2 \in [p_1 + c_2 + \delta, +\infty)$ in order to maximize her (announced) profit

$$\pi_2^A (p_2, p_1 + c_2 + \delta) = (p_2 - p_1 - c_2 - \delta) D(p_2),$$

given p_1. We introduce the following assumption.

Assumption 1 *The demand function is C^1 and such that $D(p_2) > 0$, for all $p_2 > 0$ in the price set, and $\lim_{p_2 \to +\infty} p_2 D(p_2) = 0$.*

Under Assumption 1, the solution $p_2 (p_1 + c_2 + \delta)$ is always interior[1], i.e. $p_1 + c_2 + \delta <$

[1] From Assumption (A1), it follows that there exists $\overline{p_2} \in (p_1 + c_2 + \delta, +\infty)$ such that

$p_2(p_1 + c_2 + \delta) < +\infty$, and it fulfills :

$$(p_2 - p_1 - c_2 - \delta) D'(p_2) + D(p_2) = 0. \quad (1)$$

We establish now that, whatever the shape of the demand function, the manufacturer knows that the retailer increases her price when the sum of the wholesale price and the retail marginal cost increases.

Proposition 1 *Under Assumption 1, $p_2(p_1 + c_2 + \delta)$ is strictly increasing in $(p_1 + c_2 + \delta)$.*

All proofs are in the appendix. Note that the proof of this proposition follows the line of arguments given by Amir et al. (2004), which uses lattice-theoretic techniques developed by Topkis (1978, 1998) in a study of monopoly pricing.[2]

At stage 1, the manufacturer chooses the wholesale price p_1 in order to maximize her profit.

$$\max_{p_1 \in [c_1, +\infty)} \pi_1(p_1, c_2 + \delta) = (p_1 - c_1) D(p_2(p_1 + c_2 + \delta))$$

Under Assumption (A1), the solution $p_1(c_2 + \delta)$ is always interior , i.e. $c_1 < p_1(c_2 + \delta) < +\infty$, and it fulfills :

$$D(p_2) + (p_1 - c_1) D'(p_2) p_2'(p_1 + c_2 + \delta) = 0. \quad (2)$$

Our second general result is that whatever the shape of the demand function, the sum of the wholesale price and reported retail marginal cost is strictly increasing with the reported retail marginal cost.

Proposition 2 *Under Assumption 1, $p_1(c_2 + \delta) + c_2 + \delta > 0$ is strictly increasing in $(c_2 + \delta) \in [0, +\infty)$.*

At stage 0, the retailer chooses to misrepresent her marginal cost by the amount $\delta \in [-c_2, +\infty)$ in order to maximize her (true) profit. The price rule the retailer takes into account is, of course, the announced price rule, $p_2(p_1(c_2 + \delta) + c_2 + \delta)$, if not the retailer's behavior would be incoherent, and the manufacturer would know she had cheated

$\pi_2^A(\overline{p_2}, p_1 + c_2 + \delta) > 0$ and $\lim_{p_2 \to +\infty} \pi_2^A(p_2, p_1 + c_2 + \delta) \leq 0$ for all $p_1 + c_2 + \delta$. Since, $\pi_2(p_1 + c_2 + \delta, p_1 + c_2 + \delta) = 0$, there is an interior price argmax for all $p_1 + c_2 + \delta \geq 0$.

[2] Appendix 6.1 summarizes the relevant notions from this theory for the present paper.

on her retail cost.

$$\max_{\delta\in[-c_2,+\infty)} \pi_2(\delta) = (p_2(p_1(c_2+\delta)+c_2+\delta) - p_1(c_2+\delta) - c_2)\, D(p_2(p_1(c_2+\delta)+c_2+\delta)).$$

To simplify the analysis, we introduce another assumption on the demand function.

Assumption 2 *The demand function is C^3 and one has*

$$\begin{cases} D'(p_2) < 0 \ \ \textit{for any price } p_2, \\ 2(D'(p_2))^2 - D''(p_2)\, D(p_2) \neq 0 \ \ \textit{for any price } p_2 \textit{ that fulfills (1).} \end{cases}$$

This assumption essentially ensures that the optimal retail price $p_2(p_1+c_2+\delta)$ is a function of $(p_1+c_2+\delta)$ that is twice-continuously differentiable and that the optimal wholesale price $p_1(c_2+\delta)$ is a continuously differentiable function of $(c_2+\delta)$.[3] The marginal profit of the retailer with respect to δ can then be written

$$\begin{aligned} \frac{d\pi_2}{d\delta}(\delta) &= [p_2'(p_1'+1) - p_1']D(p_2) + (p_2 - p_1 - c_2)\, D'(p_2)\, p_2'(p_1'+1) \\ &= p_2'(p_1'+1)\left[D(p_2) + (p_2 - p_1 - c_2)\, D'(p_2)\right] - p_1' D(p_2). \end{aligned}$$

From (1), we deduce that

$$\frac{d\pi_2}{d\delta}(\delta) = -p_1' D(p_2) + p_2'(p_1'+1)\, \delta D'(p_2). \tag{3}$$

Hence, the retailer's incentive to misrepresent her marginal cost crucially depends on how the manufacturer reacts to the reported retail cost (i.e. on the sign of p_1'). Denote by δ^N the optimal level of δ.

3 The retailer's incentive to misrepresent her marginal cost

In this section we prove that under a broad set of demand models, the retailer will choose to misrepresent upwards her marginal cost. We also establish the counterintuitive result that under a rather restricted but nonetheless robust set of demand models, the retailer will choose to misrepresent downwards her marginal cost. We introduce the following notation

$$\Delta \equiv D^2\left(D'''D' - D''^2\right) - 2\left(DD'' - D'^2\right)^2.$$

[3] To be more rigorous, the latter property required an additionnal assumption introduced in Proposition 3 (see Appendix 8.4).

Proposition 3 *Under Assumptions 1 and 2*[4]*, at the subgame-perfect equilibrium of the three-stage game:*

(i) If the demand function is such that $\Delta > 0$*, for* $p_2 \geq p_2(p_1(c_2) + c_2)$*, then the retailer misrepresents downwards her marginal cost, i.e.* $\delta^N < 0$*.*

(ii) If the demand function is such that $\Delta < 0$*, for* $p_2 \leq p_2(p_1(c_2) + c_2)$*, then the retailer misrepresents upwards her marginal cost, i.e.* $\delta^N > 0$*.*

As the conditions $\Delta > 0$ and $\Delta < 0$ are rather unusual and opaque, we can provide respective sufficient conditions for $\Delta > 0$ that are more familiar and insightful. If $(-P')$ is log-concave, then clearly $\Delta > 0$. In turn, a sufficient condition for $(-P')$ to be log-concave is $P''' \leq 0$. On the other hand, sufficient conditions for $\Delta < 0$ are much more restrictive in view of the fact that the second term in Δ is negative due to the square term (more on this below).

The intuition behind this result is the following. An increase of the cost misrepresentation δ generates two effects on the retailer's profit. The first effect is induced by the increase of the retail price that the cost misrepresentation generates. Effectively, at stage one, we know (from Proposition 2) that the sum of the wholesale price and the reported marginal cost increases with the reported marginal cost. Consequently, the retailer increases the retail price (Proposition 1). This generates two opposite effects on the retailer's profit, a negative effect since demand decreases but also a positive effect since the retailer's mark-up increases. Nevertheless, thanks to (1), one can prove that the global effect induced by the increase of the retail price can be written $p_2'(p_1' + 1)\,\delta D'(p_2)$; it is positive for an upward initial misrepresentation of the retail cost, i.e. whenever $\delta > 0$, and it is negative for a downward initial misrepresentation of the retail cost, i.e. whenever $\delta < 0$.

In addition, there is a second mark-up effect induced by the change of the wholesale price that the cost misrepresentation generates. Formally, this effect can be written $-p_1' D(p_2)$. The sign of this effect crucially depends on whether the manufacturer chooses to increase the wholesale price. At stage 1, the manufacturer knows that the retailer will increase the retail price in stage 2 in reaction to an increase of the reported retail cost. If

[4] *Note that this proposition does not require that the demand function be strictly decreasing for any* p_2 *(but only for any* p_2 *that fulfills (1) and (2)).*

the demand function is such that this reduces strongly market demand (this is obtained when the price elasticity of demand is not very price elastic), the manufacturer might find it advisable to decrease the wholesale price in order to stimulate market demand. In this case, the retailer's mark-up increases and so does the retailer's profit. Inversely, if demand is not severely decreased by the increase of the retail price (this is obtained when the price elasticity of demand is very price elastic, so that for high price levels the price-elasticity of demand is smaller), the manufacturer increases the wholesale price. In this case, the retailer's mark-up decreases and so does the retailer's profit.

To conclude, according to (3), whenever the wholesale price reacts positively to an increase of the reported retail cost, for an upward initial misrepresentation of the retail cost, the retailer has an incentive to decrease her reported marginal cost, i.e. $\frac{d\pi_2}{d\delta}(\delta) < 0$ for all $\delta \geq 0$. In this case, the retailer always misrepresents downwards her marginal cost, i.e. $\delta^N < 0$.[5] Symmetrically, the retailer misrepresents upwards her marginal cost whenever the wholesale price reacts negatively to an increase in the retail marginal cost for a downward initial misrepresentation of the retail cost, so $\frac{d\pi_2}{d\delta}(\delta) > 0$ for all $\delta \leq 0$.

The condition $\Delta > 0$ is satisfied by demand functions that are weakly log-concave or log-convex with $-D'$ strongly log-convex . In particular, $\Delta > 0$ when $\left(DD'' - D'^2\right)$ is small and the price elasticity of demand is not very price-elastic. A class of demand models frequently used to study channel performance that fulfills this requirement is the class of iso-price-elastic demands (see example 2 below). The condition that $\Delta < 0$ is obtained for demand functions that are strongly log-concave or log-convex with $-D'$ weakly log-convex. In particular, $\Delta < 0$ when $\left(DD'' - D'^2\right)$ is large and the price elasticity of demand is very elastic. This is the case for the second class of demands most frequently used in the literature, namely the class of linear demands (see example 3 below). In addition, we give next an example of a class of demand functions parametrized by a constant $\alpha > 0$, which represents the elasticity of the price-elasticity of demand, such that for small values of α the condition $\Delta > 0$ is fulfilled, while for other large values of α, the condition $\Delta < 0$ is fulfilled.

[5] This is obtained as the choices in $[0, +\infty)$ are clearly dominated by any $\delta \in [-c_2, 0)$. In addition, the retailer's profit is continuous in δ over $[-c_2, 0]$, hence invoking Weierstrass's classical theorem it has a maximum value on this interval.

Example 1

Consider the class of demand functions $D(p_2) = e^{-(p_2)^\alpha}$ with $\alpha > 0$. Note that the price-elasticity of the demand D is given by $\varepsilon(p_2) = -\frac{D' p_2}{D} = \alpha p_2^\alpha$. Therefore α is the price-elasticity of the price-elasticity of demand, i.e. $\alpha = \frac{p_2 \varepsilon'(p_2)}{\varepsilon(p_2)}$ for all p_2.

One easily checks that $D(\cdot)$ fulfills Assumptions 1 to 3 for all $\alpha > 0$. In addition, standard computations yield

$$\Delta = -e^{-4p_2^\alpha}\alpha^2 \frac{-3p_2^{2\alpha}\alpha + p_2^{3\alpha}\alpha^2 + p_2^{2\alpha} - \alpha p_2^{3\alpha} + 2p_2^{2\alpha}\alpha^2}{p_2^4}$$

For $\frac{1}{2} \leq \alpha < 1$, D and $-D'$ are log-convex, and one easily checks that $\Delta > 0$ for all p_2, so $\delta^N < 0$. In other words, $\Delta > 0$ when the price-elasticity of demand is not very price elastic.

For $\alpha = 1$, a standard calculation yields $\Delta = 0$ for all p_2 and

$$\begin{cases} p_2(p_1 + c_2 + \delta) = p_1 + c_2 + \delta + 1 \\ p_1(c_2 + \delta) = 1 + c_1 \\ p_2'(p_1' + 1)\delta D'(p_2) = 0 \end{cases}.$$

The solution of this system is

$$\begin{cases} p_2^N = p_1 + c_2 + 1 \\ p_1^N = 1 + c_1 \\ \delta^N = 0 \end{cases}.$$

For $\alpha > 1$, D and $-D'$ are log-concave and one can easily check that $\Delta < 0$, therefore $\delta^N > 0$. In other words, $\Delta < 0$ when the price-elasticity of demand is very price elastic.

Example 2

Consider the class of iso-price-elastic demand models that is most frequently used to study channel performance:

$$D(p_2) = a(p_2)^{-b} \text{ where } a > 0,\ b > 1.$$

Here, the parameter b is the price-elasticity of demand. The larger b is, the more sensitive demand is to a change in price. We focus on price-elastic products by assuming $b > 1$. (This restraint follows from Assumption (A1). Indeed, if $b < 1$, the optimal price for the retailer's optimization problem would go to infinity.)

Any iso-price-elastic demand with $b > 1$ fulfills Assumptions 1 to 3.

A standard computation yields

$$\Delta = p_2^{-4b-4} a^4 b^2 \left((b+1)^2 - 2 \right)$$

Hence, $\Delta > 0$ for all p_2, therefore $\delta^N < 0$. More precisely, a standard computation yields

$$\begin{cases} p_2 \left(p_1 + c_2 + \delta \right) = b \frac{(p_1 + c_2 + \delta)}{(b-1)} \\ p_1 \left(c_2 + \delta \right) = \frac{bc_1 + c_2 + \delta}{b-1} \\ \frac{\partial \pi_2}{\partial \delta} \left(\delta \right) = -p_1' D \left(p_2 \right) + p_2' \left(p_1' + 1 \right) \delta D' \left(p_2 \right) = -\frac{1}{(b-1)} a \left(p_2 \right)^{-b-1} \left(p_2 + \frac{b^3}{b-1} \delta \right) \end{cases}.$$

Solving,

$$\begin{cases} \delta^N = -\frac{(c_1 + c_2)}{b(b-1)+1} \\ p_1^N = \frac{\left(b^2+1\right) c_1 + bc_2}{b(b-1)+1} \\ p_2^N = b^3 \frac{(c_1 + c_2)}{(b(b-1)+1)(b-1)} \\ \frac{\pi_2^N}{(\pi_1 + \pi_2)^N} = \frac{((b(b-1)+1)(b-1))^b}{(b-1)^b \left(b(b-1)(b^2-b+1)^{b-1} + (b^2-b+1) \right)} \end{cases}.$$

Example 3

Consider the second class of demand functions most often adopted in the literature, namely the class of linear demand models. We let $D(p_2)$ take the form $D(p_2) = a - bp_2$ where $a, b > 0$ are two constants. In this formulation, the price-elasticity of demand is given by $\varepsilon(p_2) = \frac{-bp_2}{(a - bp_2)}$, thus the price-elasticity of demand increases with b and decreases with a, and the product is price-elastic if $p_2 \leq \frac{a}{2b}$ and inelastic otherwise.

$D(p_2)$ fulfills Assumptions 2 and 3, Assumption 1 implies that the retail price belongs to $[c_2, \frac{a}{b})$, thus $p_2 < \frac{a}{b} \Leftrightarrow b(c_1 + c_2) < a$.

A standard computation yields

$$\Delta = -2b^4 < 0.$$

Hence, $\Delta < 0$ for all p_2, therefore $\delta^N > 0$. More precisely, a standard computation yields

$$\begin{cases} p_2 \left(p_1 + c_2 + \delta \right) = \frac{a + b(p_1 + c_2 + \delta)}{2b} \\ p_1 \left(c_2 + \delta \right) = \frac{a + bc_1 - b(c_2 + \delta)}{2b} \\ \frac{\partial \pi_2}{\partial \delta} \left(\delta \right) = -p_1' D \left(p_2 \right) + p_2' \left(p_1' + 1 \right) \delta D' \left(p_2 \right) = \frac{1}{8} a - \frac{1}{8} bc_1 - \frac{1}{8} bc_2 - \frac{3}{8} b\delta \end{cases}$$

Thus,

$$\begin{cases} \delta^N = \frac{a-b(c_1+c_2)}{3b} \\ p_1^N = \frac{1}{3b}\left(a+2bc_1-bc_2\right) \\ p_2^N = \frac{1}{6b}\left(5a+b\left(c_1+c_2\right)\right) \\ \varepsilon\left(p_2^N\right) = \frac{D'\left(p_2^N\right)p_2^N}{D\left(p_2^N\right)} = -\frac{5a+b(c_1+c_2)}{a-b(c_1+c_2)} \\ \frac{\pi_2^N}{(\pi_1+\pi_2)^N} = \frac{3}{5} \end{cases}$$

4 Channel Performance and Social Welfare

We shall now study the channel performance and social welfare implications of the previous misrepresentation of the retail cost in the decentralized channel. We compare the channel performance and social welfare under four different scenarios. The first scenario is our three-stage game, that is the double marginalization game with retail cost reporting in a preliminary stage 0. Denote by N this scenario (where N stands for Non-cooperation at stage 0). The second scenario is identical to scenario N except for the stage 0 where the retail cost misrepresentation is chosen cooperatively by the retailer and the manufacturer in order to maximize the channel profit. Denote by C this scenario (where C stands for Cooperation at stage 0). The third scenario is the standard game of double marginalization that we shall denote by S. Finally the fourth scenario is the vertical integration that is well known in the literature to yield the highest channel profit and social welfare. Denote by V this last scenario.

Let us write formally these four scenarios. Under all these scenarios, the channel profit can be written as a function of the final retail price

$$(\pi_1+\pi_2)(p_2) = \left[p_2-(c_1+c_2)\right] D(p_2).$$

Formally, scenarios N and C only diverge at stage 0, where the channel profit can be written, in both cases, as a function of the retail cost misrepresentation (given the manufacturer's reaction at stage 1, $p_1(c_2+\delta)$, and the retailer's reaction at stage 2, $p_2(p_1+c_2+\delta)$).

$$\widetilde{(\pi_1+\pi_2)}(\delta) = (\pi_1+\pi_2)\left(p_2\left(p_1\left(c_2+\delta\right)+c_2+\delta\right)\right) \tag{4}$$

In scenario C, the cost misrepresentation, δ^C, is chosen cooperatively by the two firms in order to maximize the channel profit

$$\delta^C \in \arg \max_{\delta \in [-c_2, +\infty)} \widetilde{(\pi_1 + \pi_2)} (\delta) .$$

Hence, δ^C fulfills

$$p_2' \left(p_1' + 1\right) \left(D + (p_2 - c_1 - c_2) D'\right) \leq 0$$

From (1), we deduce that

$$p_2' \left(p_1' + 1\right) \left(p_1 + \delta^C - c_1\right) D' \leq 0.$$

From the Propositions 1 and 2, we know that $p_2' (p_1' + 1) D' < 0$, thus one can easily checks that δ^C is necessarily unique and[6]

$$\begin{cases} \text{if } p_1(0) \geq c_1 + c_2 \text{ then } \delta^C = -c_2 \text{ and } p_1\left(c_2 + \delta^C\right) + \delta^C \geq c_1, \\ \text{if } p_1(0) < c_1 + c_2 \text{ then } \delta^C > -c_2 \text{ and } p_1\left(c_2 + \delta^C\right) + \delta^C = c_1. \end{cases} \tag{5}$$

The manufacturer then reacts in stage 1 following the function $p_1(c_2 + \delta)$ and the retailer reacts in stage 2 following the function $p_2(p_1 + c_2 + \delta)$. Therefore, under scenario C the wholesale price and the retail price are

$$\begin{cases} p_1^C = p_1\left(c_2 + \delta^C\right) \\ p_2^C = p_2\left(p_1\left(c_2 + \delta^C\right) + c_2 + \delta^C\right) \end{cases}.$$

Scenario S matches the two last stages of scenario N with the cost misrepresentation, at stage 0, set to 0. Hence, the equilibrium values in the double marginalization game are such that

$$\begin{cases} p_1^S = p_1(c_2) \\ p_2^S = p_2(p_1(c_2) + c_2) \\ (\pi_1 + \pi_2)^S = \widetilde{(\pi_1 + \pi_2)}(0) \end{cases}$$

Finally, scenario V is the one-stage game where the integrated firm chooses the retail price p_2^V in order to maximize the channel profit, i.e.

$$p_2^V \in \arg \max_{p_2 \in [(c_1 + c_2), +\infty)} (\pi_1 + \pi_2)(p_2) \tag{6}$$

[6]If $p_1(0) \geq c_1 + c_2$, one can check (see (8) below) that $\widetilde{(\pi_1 + \pi_2)}(\delta)$ is strictly decreasing in δ over $(-c_2, +\infty)$.

If $p_1(0) < c_1 + c_2$, one can check (see (8) below) that $\widetilde{(\pi_1 + \pi_2)}(\delta)$ is strictly increasing in δ on $(-c_2, \delta^C)$ and strictly decreasing in δ on $(\delta^C, +\infty)$, where δ^C is the unique solution in δ of $p_1\left(c_2 + \delta^C\right) + \delta^C = c_1$.

It is interesting to note that $(\pi_1 + \pi_2)(p_2) = \pi_2^A(p_2, c_1 + c_2)$, therefore

$$p_2^V = p_2(c_1 + c_2). \tag{7}$$

This means that the retail price under vertical integration would correspond to the retail price under scenario N if $p_1\left(c_2 + \delta^N\right) + \delta^N$ was equal to c_1.

We shall first study the channel profit under these four scenarios. From (6), we deduce that vertical integration that avoids the problem of double marginalization still ensures the best channel performance. More precisely, the channel performance under vertical integration, $(\pi_1 + \pi_2)^V$, is such that $(\pi_1 + \pi_2)^V = (\pi_1 + \pi_2)\left(p_2^V\right) \geq (\pi_1 + \pi_2)(p_2)$ for all $p_2 \in [c_2, +\infty)$. In particular, $(\pi_1 + \pi_2)^V \geq (\widetilde{\pi_1 + \pi_2})(\delta)$ for all $\delta \in [-c_2, +\infty)$. It is also important to note that the channel profit under vertical integration, $(\pi_1 + \pi_2)^{VI}$, corresponds to the channel profit under scenario C, $(\pi_1 + \pi_2)^C$, when $\delta^C > -c_2$, that is when $p_1(0) < c_1 + c_2$. Effectively, the channel profit under scenario C, when $\delta^C > -c_2$, is given by

$$(\pi_1 + \pi_2)^C = \left[p_2\left(p_1\left(c_2 + \delta^C\right) + c_2 + \delta^C\right) - (c_1 + c_2)\right] D\left(p_2\left(p_1\left(c_2 + \delta^C\right) + c_2 + \delta^C\right)\right)$$

From (5), we deduce that

$$\begin{aligned}(\pi_1 + \pi_2)^C &= [p_2(c_1 + c_2) - (c_1 + c_2)] D(p_2(c_1 + c_2)) \\ &= (\pi_1 + \pi_2)(p_2(c_1 + c_2)),\end{aligned}$$

and from (7), we deduce that

$$(\pi_1 + \pi_2)^C = (\pi_1 + \pi_2)^V.$$

In scenarios N and C, we deduce from (4) that the channel marginal profit induced by a misrepresentation of the retail cost at stage 0 is given by

$$\frac{d(\widetilde{\pi_1 + \pi_2})(\delta)}{d\delta} = p_2'\left(p_1' + 1\right)\left[D + (p_2 - (c_1 + c_2)) D'\right].$$

From (1), we deduce that

$$\frac{d(\widetilde{\pi_1 + \pi_2})(\delta)}{d\delta} = p_2'\left(p_1' + 1\right)(p_1(c_2 + \delta) + \delta - c_1) D'. \tag{8}$$

From Proposition 1 and Proposition 2, we deduce that the sign of the derivative $\frac{d(\widetilde{\pi_1+\pi_2})(\delta)}{d\delta}$ is the sign of $(c_1 - p_1(c_2 + \delta) - \delta)$. For $\delta \geq 0$, since the manufacturer always chooses a wholesale price larger than her marginal cost, one has $p_1(c_2+\delta)+\delta > c_1$. Therefore, $\frac{d\widetilde{(\pi_1+\pi_2)}(\delta)}{d\delta} < 0$ for all $\delta \geq 0$, and the channel profit is necessarily maximized for a downward misrepresentation of the retail marginal cost. In other word, the misrepresentation level of the retail cost chosen cooperatively by the two firms in scenario C is such that $\delta^C < 0$. Hence, while an upward misrepresentation of the retail marginal cost clearly decreases the channel performance, a downward misrepresentation will on the contrary increase the channel performance. This proves that the opportunist behavior of the retailer that emerges in scenario N does not necessarily decrease channel performance. Hence, the result, taken for granted in the literature, that the opportunist behavior of the retailer necessarily decreases channel performance is only valid when the price-elasticity of demand is significantly price elastic (since, in this case, according to Proposition 3, $\delta^N > 0$). In the appendix, we prove in addition that $\delta^C < \delta^N$ for $\delta^N < 0$. In other words, when the retailer chooses a downward misrepresentation of her marginal cost, the channel performance would even be improved by a larger downward misrepresentation. This is essentially explained by the fact that the manufacturer's profit is strictly decreasing in the retailer's annoucement δ.

These results are rigorously stated in the following proposition.

Proposition 4 *Under Assumptions 1 and 2,*

(i) if $\Delta > 0$ for $p_2 \geq p_2(p_1(c_2)+c_2)$, one has $-c_2 \leq \delta^C < \delta^N < 0$ and

$$(\pi_1+\pi_2)^S < (\pi_1+\pi_2)^N < (\pi_1+\pi_2)^C \leq (\pi_1+\pi_2)^V,$$

where the last inequality holds with equality whenever $p_1(0) < c_1+c_2$, in this case $\delta^C > -c_2$. In particular,

$$\pi_1^S < \pi_1^N < \pi_1^C.$$

(ii) If $\Delta < 0$ for $p_2 \leq p_2(p_1(c_2)+c_2)$, one has $-c_2 \leq \delta^C < 0 < \delta^N$ and

$$(\pi_1+\pi_2)^N < (\pi_1+\pi_2)^S < (\pi_1+\pi_2)^C \leq (\pi_1+\pi_2)^V,$$

where the last inequality holds with equality whenever $p_1(0) < c_1+c_2$, in this case $\delta^C > -c_2$. In particular,

$$\pi_1^N < \pi_1^S < \pi_1^C.$$

We shall now compare the retail price under the four scenarios. Since $p_1(c_2+\delta) + (c_2+\delta)$ is strictly increasing in $(c_2+\delta)$ and $p_2(p_1+c_2+\delta)$ is strictly increasing in $(p_1+c_2+\delta)$, the retail price strictly increases with the misrepresentation level of the retail cost. In particular, a downward misrepresentation of the retail cost ($\delta^C < \delta^N < 0$) clearly induces a decrease of the retail price in the decentralized channel, more precisely, $p_2^C < p_2^N < p_2^S$. Symmetrically, an upward misrepresentation of the retail cost ($\delta^C < 0 < \delta^N$) clearly induces an increase of the retail price in the decentralized channel, more precisely $p_2^C < p_2^S < p_2^N$. For the comparison with vertical integration, we recall that the retail price under vertical integration would correspond to the retail price under scenario C if $p_1\left(c_2+\delta^C\right)+\delta^C$ was equal to c_1, i.e. $p_2^V = p_2(c_1+c_2)$, and by definition $p_2^C = p_2\left(p_1\left(c_2+\delta^C\right)+\delta^C+c_2\right)$. In addition, we know from (5) that $p_1\left(c_2+\delta^C\right)+\delta^C \geq c_1$ with an equality whenever $p_1(0) < c_1+c_2$. Since p_2 is strictly increasing, this implies that the retail price is always larger in the decentralized channel with misrepresentation of the retail cost than under vertical integration (and is identical whenever $p_1(0) < c_1+c_2$). These results are summarized in the following proposition.

Proposition 5 *Under Assumptions 1 and 2,*

(i) if $\Delta > 0$ for $p_2 \geq p_2(p_1(c_2)+c_2)$, one has $p_2^V \leq p_2^C < p_2^N < p_2^S$, where the first inequality holds with equality whenever $p_1(0) < c_1+c_2$,

(ii) if $\Delta < 0$ for $p_2 \leq p_2(p_1(c_2)+c_2)$, one has $p_2^V \leq p_2^C < p_2^S < p_2^N$, where the first inequality holds with equality whenever $p_1(0) < c_1+c_2$.

Finally, we compare consumer surplus and social welfare under the four scenarios. Note, that when the retailer increases the misrepresentation level of her marginal cost she also chooses a larger retail price. In this case, consumption decreases and so does consumer surplus. Symmetrically, when it is optimal for the retailer to decreases the misrepresentation level of her marginal cost, it is also optimal for her to decrease the retail price. In this case, consumption increases and so does consumer surplus. Since vertical integration leads to the lowest retail price it also leads to the larger consumer surplus. Hence, consumer surplus and channel performance follow the same classification and so does social welfare. The important, and rather counterintuitive result here, is that a downward misrepresentation of the retail cost in the decentralized channel allows to increase the channel performance, to decrease the retail price and therefore to increase consumer surplus and social welfare.

Proposition 6 *Under Assumptions 1 and 2, (i) if* $\Delta > 0$ *for* $p_2 \geq p_2(p_1(c_2) + c_2)$*, one has*

$$\begin{cases} CS^S < CS^N < CS^C \leq CS^V \\ (\pi_1 + \pi_2)^S < (\pi_1 + \pi_2)^N < (\pi_1 + \pi_2)^C \leq (\pi_1 + \pi_2)^V \\ SW^S < SW^N < SW^C \leq SW^V \end{cases},$$

where the last inequality of each line holds with an equality whenever $p_1(0) < c_1 + c_2$*, (ii) if* $\Delta < 0$ *for* $p_2 \leq p_2(p_1(c_2) + c_2)$*, one has*

$$\begin{cases} CS^N < CS^S < CS^C \leq CS^V \\ (\pi_1 + \pi_2)^N < (\pi_1 + \pi_2)^S < (\pi_1 + \pi_2)^C \leq (\pi_1 + \pi_2)^V \\ SW^N < SW^S < SW^C \leq SW^V \end{cases}.$$

where the last inequality of each line holds with an equality whenever $p_1(0) < c_1 + c_2$*.*

5 Discussion

Our results point out that the channel and social benefits of the use of information on retail cost in the distribution channel crucially depends on the shape of the demand function. Hence, when studying the impact of information sharing policies, the focus on specific shape of demand (generally adopted in the literature) might be quite misleading.

In one case, including the class of linear demand functions, an intuitive result, taken for granted in the literature, is confirmed. That is, for the information flow to increase channel performance, the information needs to be shared by all channel members (see, for example, Desiraju and Moorthy (1997)). Hence, when allowed to misrepresent her marginal cost, the retailer chooses an upward misrepresentation and therefore increases the retail price (with respect to the standard double marginalization game). As a consequence, the retailer's opportunistic behavior does not only decrease channel performance, but it also decreases consumer surplus and social welfare. In other words, the well known social benefit of vertical integration is reinforced with the introduction of retail cost misrepresentation in the decentralized channel.

In a second case, including the class of demand functions most frequently used to study channel performance, that is the class of iso-price-elastic demands, a more counterintuitive result is obtained. Effectively, in this case the retailer chooses to misrepresent downwards her marginal cost and therefore she sets a lower retail price (than under the standard double marginalization game). In contrast to the literature, this opportunistic behavior of the retailer increases channel performance, consumer surplus and social welfare. In other words, the well known social benefit of vertical integration is tempered with the introduction of the retail cost misrepresentation in the decentralized channel. Note that this result does not rely on the naive version of the game studied in this paper. Indeed, we conjecture that this qualitative result remains valid in the Bayesian game whenever the mean expected retail cost, according to the retailers's prior beliefs, is larger than the true cost and this mean increases with the reported retail cost for an upward initial misrepresentation of the retail cost.

6 Appendix

Here, we first present a concise summary of the relevent supermodularity notions used in this paper, and then provide the proofs of our results.

6.1 Mathematical Preliminaries

Consider a parametrized family of optimization problems, where $S \subset R$ is a parameter set, $A_s \subset A \subset R$ (for some action set A) is the set of feasible actions when the parameter is s, and $F : S \times A \to R$ is the objective function:

$$a^*(s) = \arg\max\{F(s,a) : a \in A_s\}. \tag{9}$$

The aim is to derive sufficient conditions on the objective and constraint set that yield monotone optimal argmax's.

A function $F : S \times A \to R$ is (strictly) supermodular[7] in (s,a) if $\forall a' > a, s' > s$

$$F(s',a') - F(s',a)(>) \geq F(s,a') - F(s,a) \tag{10}$$

[7] This is really the notion of increasing differences, which in R^2 is equivalent to supermodularity.

or in other words if the difference $F(\cdot, a') - F(\cdot, a)$ is an increasing function[8].
For smooth functions, supermodularity admits a convenient test (Topkis, 1978)[9]

Lemma 1 *If F is twice continuously differentiable, supermodularity is equivalent to $\partial^2 F(s,a)/\partial a \partial s \geq 0$, for all a and s.*

Supermodularity formalizes the usual notion of complementarity: Having more of one variable increases the marginal returns to having more of the other variable.

A simplified version of Topkis's (1978) Monotonicity Theorem is now given. It is assumed throughout that F is continuous (or even just upper semi-continuous) in a for each s, so that the max in (1) is attained. Furthermore, the correspondence $a^*(s)$ then admits maximal and minimal selections, denoted $\overline{a}(s)$ and $\underline{a}(s)$ respectively.

Theorem 1 *Assume that*

(i) F is supermodular in (s, a), and

(ii) $A_s = [g(s), h(s)]$ where $h, g : S \to R$ are increasing functions with $g \leq h$.

Then the maximal and minimal selections of $a^*(s), \overline{a}(s)$ and $\underline{a}(s)$, are increasing functions. Furthermore, if (i) is strict, then every selection of $a^*(s)$ is increasing.

Sometimes, one might be interested in having a strictly increasing argmax.

Theorem 2 *Assume F is continuously differentiable, $\partial F/\partial a$ is strictly increasing in s and the argmax is interior. Then every selection of $a^*(s)$ is strictly increasing.*

Since supermodularity is equivalent to $\partial F/\partial a$ being increasing in s, the assumption in Theorem 3 is a minor strengthening of the supermodularity of F (see Amir, 1996 or Topkis, 1998 p.71 for a proof and further details.)

There are order-dual versions to all the above results. We state just the main one, giving obvious dual conditions under which an argmax is decreasing in the parameter. A function $F : S \times A \to R$ is (strictly) submodular if $-F$ is supermodular, i.e. if (2) holds with the inequality reversed.

[8]Throughout, a function $f : S \to R$ is increasing (decreasing) if $x \geq y \Rightarrow f(x) \geq (\leq) f(y)$. It is strictly increasing (decreasing) if $x > y \Rightarrow f(x) > (<) f(y)$.

[9]Furthermore, if $\partial^2 f(a,s)/\partial a \partial s > 0$ then F is strictly supermodular. On the other hand, the reverse implication need not hold.

Theorem 3 *Assume that*

(i) F is submodular in (s, a), and

(ii) $A_s = [g(s), h(s)]$ where $h, g : S \to R$ are decreasing functions with $g \leq h$.

Then the maximal and minimal selections of $a^*(s)$ are decreasing functions. Furthermore, if (i) is strict, then every selection of $a^*(s)$ is decreasing.

We say that a function $G : R_+ \longrightarrow R_+$ is log-concave (log-convex) if $\log G$ is concave (convex). The corresponding strict notions are defined in the obvious way. The following is a common way for supermodularity to arise.

Lemma 2 *A function $G : R_+ \longrightarrow R_+$ is log-concave (log-convex) if and only if $G(x+y)$ is log-submodular (log-supermodular) in (x, y).*

For a smooth function $G : R_+ \longrightarrow R_+$, log-concavity (log-convexity) is easily checked to be equivalent to

$$G(x)G''(x) - [G'(x)]^2 \leq (\geq) 0 \text{ for all non isolated } x. \tag{11}$$

The corresponding strict notions are given by (3) with a strict inequality.

6.2 Proof of Proposition 1

Under Assumption (A1), there is an interior price argmax for all $p_1 + c_2 + \delta \geq 0$. In addition, as the optimal price is invariant under a monotonic transformation, we may equivalently consider the objective

$$\log \pi_2^A (p_2, p_1 + c_2 + \delta) = \log (p_2 - (p_1 + c_2 + \delta)) + \log D (p_2) .$$

Since $\log \pi_2^A (p_2, p_1 + c_2 + \delta)$ has the property that $\frac{\partial^2 \log \pi_2^A (p_2, p_1 + c_2 + \delta)}{\partial p_2 \partial (p_1 + c_2 + \delta)} = \frac{p_1 + c_2 + \delta}{(p_2 - (p_1 + c_2 + \delta))^2} > 0$, the conclusion follows from Theorem 2.

6.3 Proof of Proposition 2

A convenient change of variable will allow a very simple proof of the proposition. Define $\widetilde{p_1}$ as $\widetilde{p_1} \triangleq p_1 + c_2 + \delta$, and write the equivalent manufacturer's objective with this change of variable as

$$\begin{aligned}\widetilde{\pi}_1\left(\widetilde{p_1}, c_2+\delta\right) &= \left(\widetilde{p_1}-\left(c_2+\delta\right)-c_1\right) D\left(p_2\left(\widetilde{p_1}\right)\right) \\ &= \left(\widetilde{p_1}-\left(c_1+c_2+\delta\right)\right) D\left(p_2\left(\widetilde{p_1}\right)\right), \text{ with } \widetilde{p_1}=p_1+c_2+\delta .\end{aligned}$$

As before, we will also need to consider the alternative objective

$$\log \widetilde{\pi}_1\left(\widetilde{p_1}, c_2+\delta\right)=\log \left(\widetilde{p_1}-\left(c_1+c_2+\delta\right)\right)+\log D\left(p_2\left(\widetilde{p_1}\right)\right).$$

We have

$$\frac{\partial^2 \log \widetilde{\pi}_1\left(\widetilde{p_1}, c_2+\delta\right)}{\partial \widetilde{p_1} \partial\left(c_2+\delta\right)}=\frac{1}{\left(\widetilde{p_1}-\left(c_1+c_2+\delta\right)\right)^2}>0.$$

Hence, $\log \widetilde{\pi}_1$ is strictly supermodular in $\left(\widetilde{p_1}, c_2+\delta\right)$. Since the solution $\widetilde{p_1}\left(c_2+\delta\right)$ is interior, i.e. $c_1+c_2+\delta<\widetilde{p_1}\left(c_2+\delta\right)<+\infty$, we deduce from Theorem 2 that $\widetilde{p_1}\left(c_2+\delta\right)$ is strictly increasing in $\left(c_2+\delta\right)$ and the conclusion follows.

6.4 Proof of Proposition 3

First note that, under the assumptions of the proposition, for any price pair (p_1, p_2) that fulfills (1) and (2), one has

$$\left\{\begin{array}{c} D'\left(p_2\right) \neq 0 \\ 2\left[D'\left(p_2\right)^2-D\left(p_2\right) D''\left(p_2\right)\right]^2-\left(D\left(p_2\right)\right)^2\left(D'\left(p_2\right) D'''\left(p_2\right)-\left(D''\left(p_2\right)\right)^2\right) \neq 0 \end{array}\right.$$

Hence, one can deduce from (2) and the implicit function theorem that the optimal wholesale price $p_1\left(c_2+\delta\right)$ is a continuously differentiable function of $\left(c_2+\delta\right)$. Therefore, the retailer profit function π_2 is a continuously differentiable function of δ and its first derivative is given by (3).

The second important remark is that under the assumptions of Proposition 3, we can deduce from Proposition 1 and Proposition 2 and (3), that $\frac{d\pi_2}{d\delta}(\delta)<0$ for all $\delta \geq 0$, if $p_1'\left(c_2+\delta\right)>0$ for $\delta \geq 0$. In this case, the value that maximizes the retailer's profit is necessarily strictly negative, i.e. $\delta^N<0$. In other words, to prove (i), it is sufficient to prove that $p_1'\left(c_2+\delta\right)>0$ for $\delta \geq 0$. From Theorem 2, we know that $p_1\left(c_1+\delta\right)$ is strictly increasing in $\left(c_1+\delta\right)$ if $\pi_1\left(p_1, c_2+\delta\right)$ is strictly logsupermodular in $\left(p_1, c_2+\delta\right)$. In addition,

$$\pi_1\left(p_1, c_2+\delta\right)=\left(p_1-c_1\right) D\left(p_2\left(p_1+c_2+\delta\right)\right).$$

Hence,

$$\log \pi_1 \left(p_1, c_2 + \delta\right) = \log \left(p_1 - c_1\right) + \log D \left(p_2 \left(p_1 + c_2 + \delta\right)\right).$$

Therefore, $\pi_1 \left(p_1, c_2 + \delta\right)$ is strictly logsupermodular in $\left(p_1, c_2 + \delta\right)$ if and only if $D \circ p_2$ is strictly logconvex. The latter condition, according to (11), is obtained if and only if

$$\begin{aligned} \left(D \circ p_2\right) \left(D \circ p_2\right)'' - \left(D \circ p_2\right)'^2 &> 0 \\ \Leftrightarrow DD'' p_2'^2 + DD' p_2'' - D'^2 p'^2 &> 0 \\ \Leftrightarrow \left(DD'' - D'^2\right) p_2'^2 + DD' p_2'' &> 0 \end{aligned} \tag{12}$$

Note that, under Assumption (A2), one can deduce from (1) and the implicit function theorem that the optimal retail price $p_2 \left(p_1 + c_2 + \delta\right)$ is a continuously differentiable function of $\left(p_1 + c_2 + \delta\right)$ with

$$p_2' = \frac{\left(D'\right)^2}{2 \left(D'\right)^2 - D'' D}. \tag{13}$$

This implies, in particular, that $p_2 (\cdot)$ is also C^2 with

$$p_2'' = \frac{D'^3 \left[D'^2 D'' + D \left(D' D''' - 2 D''^2\right)\right]}{\left(2 D'^2 - D D''\right)^3}. \tag{14}$$

When substituting p_2' and p_2'' by their expressions in (12), we get after simplification

$$\left(D'\right)^4 \frac{-2 \left(DD'' - (D')^2\right)^2 + D^2 \left(D' D''' - (D'')^2\right)}{\left(2 (D')^2 - D'' D\right)^3} > 0$$

Since $\left(2 (D')^2 - D'' D\right) > 0$ from Proposition 13, result (i) follows.

Symmetrically, to prove (ii) it is sufficient to prove that $p_1' < 0$ for $\delta \leq 0$. By using the same line of argument, one can prove that this is true if

$$-2 \left(DD'' - (D')^2\right)^2 + D^2 \left(D' D''' - (D'')^2\right) < 0,$$

result (ii) follows.

6.5 Proof of Proposition 4

Let us first establish that the manufacturer's profit decreases with the retailer's annoucement δ. The manufacturer's profit can be written

$$\pi_1 \left(p_1, c_2 + \delta\right) = \left(p_1 - c_1\right) D \left(p_2 \left(p_1 + c_2 + \delta\right)\right).$$

For $p_1 = p_1(c_2+\delta)$, it can be rewritten

$$\widetilde{\pi_1}(\delta) = (p_1(c_2+\delta) - c_1) D (p_2(p_1(c_2+\delta) + c_2 + \delta)).$$

Hence,

$$\frac{d\widetilde{\pi_1}}{d\delta}(\delta) = p_1' D + (p_1 - c_1)\left(p_1' + 1\right) p_2' D'.$$

From (2), we deduce that

$$\frac{d\widetilde{\pi_1}}{d\delta}(\delta) = p_1' D - D\left(p_1' + 1\right) = -D < 0.$$

Therefore, $\widetilde{\pi_1}$ is strictly decreasing in δ.

(i) If $\Delta > 0$, we already know that $\delta^N < 0$. In addition, the retailer chooses the cost misrepresentation δ^N such that

$$\delta^N \in \arg\max_{\delta\in[-c_2,+\infty)} \pi_2(\delta).$$

From the first order maximization conditions of this program, we deduce that

$$\frac{d\pi_2}{d\delta}\left(\delta^N\right) = -p_1' D + p_2'\left(p_1'+1\right)\delta^N D' \leq 0.$$

With the use of (2), this implies that

$$-\left(p_1\left(c_2+\delta^N\right) - c_1 + \delta^N\right) p_1' D \leq \delta^N D < 0, \text{ for any } \delta^N < 0$$

Hence, one has

$$\begin{aligned} \left(p_1\left(c_2+\delta^N\right) - c_1 + \delta^N\right) &> 0 \\ \Leftrightarrow p_1\left(c_2+\delta^N\right) + \delta^N &> c_1 \geq p_1\left(c_2+\delta^C\right) + \delta^C. \end{aligned}$$

Thus,

$$p_1\left(c_2+\delta^N\right) + \delta^N > p_1\left(c_2+\delta^C\right) + \delta^C, \text{ if } \Delta > 0.$$

Since $(p_1'(c_2+\delta)+1) > 0$, this implies that $\delta^C < \delta^N < 0$. Therefore $\frac{d\widetilde{(\pi_1+\pi_2)}}{d\delta} < 0$ for $\delta \geq \delta^C$, hence

$$\begin{aligned} \widetilde{(\pi_1+\pi_2)}(0) &< \widetilde{(\pi_1+\pi_2)}\left(\delta^N\right) < \widetilde{(\pi_1+\pi_2)}\left(\delta^C\right) \\ \Leftrightarrow (\pi_1+\pi_2)^S &< (\pi_1+\pi_2)^N < (\pi_1+\pi_2)^C \end{aligned}$$

Since, $\widetilde{\pi_1}$ is strictly decreasing in δ, it is also true that

$$\begin{aligned} \widetilde{\pi_1}(0) &< \widetilde{\pi_1}\left(\delta^N\right) < \widetilde{\pi_1}\left(\delta^C\right) \\ &\Leftrightarrow \pi_1^S < \pi_1^N < \pi_1^C. \end{aligned}$$

For the comparison with vertical integration, we already know that $(\pi_1+\pi_2)^{VI} \geq (\pi_1+\pi_2)(p_2)$ for all $p_2 \in [c_2, +\infty)$. Hence, in particular, $(\pi_1+\pi_2)^{VI} \geq (\pi_1+\pi_2)^C$. In addition, we know that $(\pi_1+\pi_2)^{VI} = (\pi_1+\pi_2)^C$ whenever $\delta^C > -c_2$, that is if $p_1(0) < c_1 + c_2$. Point (i) follows.

(ii) If $\Delta < 0$, we already know that $\delta^N > 0$. In addition, we have already established that $\frac{d\widetilde{(\pi_1+\pi_2)}}{d\delta}(\delta) < 0$ for all $\delta \geq 0$ and that $\delta^C < 0$. Hence, it follows that, if $\Delta < 0$, one has

$$\begin{aligned} \widetilde{(\pi_1+\pi_2)}\left(\delta^N\right) &< \widetilde{(\pi_1+\pi_2)}(0) < \widetilde{(\pi_1+\pi_2)}\left(\delta^C\right) \\ \Leftrightarrow (\pi_1+\pi_2)^N &< (\pi_1+\pi_2)^S < (\pi_1+\pi_2)^C \end{aligned}$$

Since, $\widetilde{\pi_1}$ is strictly decreasing in δ, it is also true that

$$\begin{aligned} \widetilde{\pi_1}\left(\delta^N\right) &< \widetilde{\pi_1}(0) < \widetilde{\pi_1}\left(\delta^C\right) \\ &\Leftrightarrow \pi_1^N < \pi_1^S < \pi_1^C. \end{aligned}$$

The comparison with vertical integration remains valid and point (ii) follows.

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