Management Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

Supplier Encroachment Under Asymmetric Information

Zhuoxin Li, Stephen M. Gilbert, Guoming Lai

To cite this article:
Zhuoxin Li, Stephen M. Gilbert, Guoming Lai (2014) Supplier Encroachment Under Asymmetric Information. Management Science 60(2):449-462. http://dx.doi.org/10.1287/mnsc.2013.1780

MANAGEMENT SCIENCE
Vol. 60, No. 2, February 2014, pp. 449–462
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

http://dx.doi.org/10.1287/mnsc.2013.1780

Supplier Encroachment Under Asymmetric Information

Zhuoxin Li, Stephen M. Gilbert, Guoming Lai
McCombs School of Business, University of Texas at Austin, Austin, Texas 78712
{zhuoxin.li@phd.mccombs.utexas.edu, steve.gilbert@mccombs.utexas.edu, guoming.lai@mccombs.utexas.edu}

Prior literature has shown that, for a symmetric information setting, supplier encroachment into a reseller's market can mitigate double marginalization and benefit both the supplier and the reseller. This paper extends the investigation of supplier encroachment to the environment where the reseller might be better informed than the supplier. We find that the launch of the supplier's direct channel can result in costly signaling behavior on the part of the reseller, in which he reduces his order quantity when the market size is small. Such a downward order distortion can amplify double marginalization. As a result, in addition to the "win–win" and "win–lose" outcomes for the supplier and the reseller, supplier encroachment can also lead to "lose–lose" and "lose–win" outcomes, particularly when the reseller has a significant efficiency advantage in the selling process and the prior probability of a large market is low. We further explore the implications of those findings for information management in supply chains. Complementing the conventional understanding, we show that with the ability to encroach, the supplier may prefer to sell to either a better informed or an uninformed reseller in different scenarios. On the other hand, as a result of a supplier developing encroachment capability, a reseller either may choose not to develop an advanced informational capability or may become more willing to find a means of credibly sharing his information.

Keywords: direct and indirect channel; information asymmetry; supplier encroachment
History: Received March 13, 2012; accepted May 12, 2013, by Yossi Aviv, operations management. Published online in *Articles in Advance* November 4, 2013.

1. Introduction

Many upstream manufacturers have invested in direct channels such as online stores, catalog sales, and factory outlets (Nair and Pleasance 2005). With these established direct channels, manufacturers may sell their products directly as well as indirectly through the reselling channels (e.g., distributors, wholesalers, retailers). Consequently, competition can arise between the resellers and their suppliers, a phenomenon often referred to as "supplier encroachment."

Whereas retail competition (competition among resellers) has been extensively studied and well understood, supplier encroachment has received much less attention and has distinct features. A study by Arya et al. (2007) shows that supplier encroachment endows the supplier with a mechanism to control the selling price in the retail market, and consequently motivates her to reduce her wholesale price. The combination of these two effects mitigates double marginalization and can benefit both the supplier and the reseller when the latter has a significant efficiency advantage in the retail process. Whereas the existing literature has considered various elements that may influence the effects of supplier encroachment, the information structure is often assumed to be symmetric in the supply chain. In practice, resellers often have better knowledge of the market potential than the upstream suppliers, due to their expertise and superior forecasting ability in the selling process, as well as rich first-hand sales data. Although conventional wisdom holds that resellers necessarily benefit from having access to private market information, our results demonstrate that this is not always the case when the supplier has developed its own direct channel.

In this paper, we build upon the supplier encroachment framework based on Cournot competition from Arya et al. (2007) by incorporating an asymmetric information structure, where the reseller knows the realization of the market size but the encroaching supplier knows only the prior distribution of the market size. Credible information communication is not available. In the face of information disadvantage, the supplier wants to infer the true market size from the reseller's order quantity to more properly decide the direct selling quantity. Anticipating the supplier's strategy, the reseller may purposely distort his order quantity for his own benefit. The interaction between the supplier's and the reseller's incentives can result in an inefficient downstream signaling outcome. Regardless of which market size is observed by

the reseller, he would like the supplier to believe it is small. Consequently, when the reseller observes a small market, he may need to distort his order quantity downward in order to send a credible signal that the market size is small. This downward distortion, if it occurs, amplifies double marginalization and may hurt both the supplier and the reseller. As a result, we find that, in the presence of asymmetric information, the supplier's development of encroachment capability can lead to "lose–win" or "lose–lose" outcomes for the supplier and the reseller in addition to the "win–win" and "win–lose" outcomes that are reported in Arya et al. (2007).

We then explore the implications of supplier encroachment for information management in supply chains. Prior literature has shown that with a reselling channel alone, the supplier is indifferent between a reseller who is better informed or equally informed. However, we find that when the supplier has the ability to encroach, she strictly prefers to sell to a better-informed reseller when her efficiency disadvantage in the selling process is not large; otherwise, she prefers to sell to an equally informed reseller. On the other hand, prior literature shows that without the supplier's direct channel, the reseller always prefers to be better informed. Whereas, after the supplier launches her direct channel, the incumbent reseller can be discouraged from obtaining advanced information in a wide range of parameters. While this prevents downward distortion of the reseller's order quantity and benefits the supplier, it expands the range of parameters for which total supply chain profits are lower under encroachment. Our analysis also provides an interesting implication on information sharing. It is well known in the literature that, in standard bilateral monopoly settings in which production costs are linear, the supplier is restricted to setting a linear wholesale price, and the reseller determines the output quantity, the reseller benefits from having private information about demand. In contrast, we find that in the presence of the supplier's direct channel, the reseller may prefer that the supplier has access to the same information that he has over being privately informed.

The remainder of our paper is organized as follows. Section 2 reviews the related literature. In §3, we describe the model. We provide the analysis of the model in §4, and in §5, we discuss the implications for supply chain information management. Finally, in §6, we discuss the limitations of our analysis and directions for future research.

2. Literature Review

The effects of supplier encroachment have been discussed in the literature. Empirical studies find that supplier encroachment can possibly lower a reseller's effort to sell a product (Fein and Anderson 1997) and it can also affect brand image (Frazier and Lassar 1996). However, several analytical studies have shown that supplier encroachment can mitigate double marginalization and thus benefit both the supplier and the reseller. For example, Chiang et al. (2003) demonstrate that a supplier's threat to sell through a direct channel causes the reseller to lower his selling price, which can benefit both parties. In another study, Tsay and Agrawal (2004) incorporate sales efforts that can be exerted by the supplier as well as the reseller, and show that in such a context, the launch of a supplier direct channel can still benefit both parties. The effect of mitigating double marginalization is also found by Cattani et al. (2006), based on a model with horizontal differentiation. They reveal that supplier encroachment can benefit both the supplier and the reseller if the supplier commits to the same selling price and the direct channel is not as convenient for consumers as is the existing reselling channel. Similarly, Arya et al. (2007) demonstrate based on a quantity competition model that the supplier's direct sale not only adds another source of revenue for her but also motivates her to offer a lower wholesale price to the reseller. Consequently, encroachment has the potential to benefit the supplier as well as the reseller, especially when the latter enjoys a significant cost advantage in the selling process. Our work complements this stream of research by allowing for the reseller to have private information about the market size, and this leads to results that are quite different from those found in the literature, including the fact that supplier encroachment can sometimes amplify double marginalization and hurt both the supplier and the reseller when the latter is privately informed about demand.

Our work is also related to the literature that investigates the incentives of information sharing in supply chains. Cachon and Lariviere (2001) explore contracts through which a downstream buyer can credibly share private demand information with a supplier. Li (2002) and Zhang (2002) investigate information sharing in a setting where a central supplier sells to multiple competing resellers and they show that without particular incentives, the resellers will withhold their private demand information instead of sharing it with the supplier in equilibrium. With a confidential agreement by which the supplier does not leak received information, competing resellers might be willing to share their private demand information with the supplier, which can drive down the wholesale price. Ha and Tong (2008) and Ha et al. (2011) study the incentives of information sharing within two competing supply chains, considering the effects of information accuracy, nonlinear production costs,

and a nonlinear pricing schedule. Two recent papers are similar to ours in considering how a reseller's concern over leaking his private demand information may affect how he orders from a supplier. Anand and Goyal (2009) and Kong et al. (2013) investigate a one supplier–two reseller setting where the supplier may leak the market information learned from the incumbent reseller's order quantity to an entrant reseller. Anand and Goyal (2009) show under an exogenous wholesale-price contract that the supplier always leaks information to stimulate downstream order quantity. Consequently, the incumbent reseller may purposely block information dissemination by ordering the same quantity for any market size. Kong et al. (2013) consider a similar setting, but demonstrate that a revenue-sharing scheme may prevent the supplier from leaking information, and consequently can result in Pareto gains for all parties. Similar to this latter paper, we allow for an endogenous wholesale price, but we consider a setting in which the supplier's own direct channel, rather than a second reseller, is the potential beneficiary of information gained from the informed reseller. In addition, we consider the effect that a supplier's development of a direct channel can have upon her own, as well as the reseller's, preferences among different information structures, and we find that encroachment may encourage the reseller to share his private information with the supplier. Consequently, our perspective of analyzing how supplier encroachment affects the flows of materials and information in a supply chain is quite different from either of these papers.

Finally, our work is related to the recent work of Jiang et al. (2011). In their study, an independent seller sells a product through a platform. The platform owner can also acquire the product and has monopolistic control over the access to the market. In particular, the platform owner can incur a fixed cost, to sell the independent seller's product and take away all of the demand from the latter if strong sales are revealed. They show a pooling outcome where the independent seller's incentive to hide the private demand information by exerting the same selling effort may hurt the platform owner, but benefit himself. In contrast, we assume that both firms have access to the market, but the supplier has full control over the access to the product (i.e., the reseller has no alternative source of supply). For this setting, we show that no pooling equilibrium can survive the intuitive criterion, and that in the resulting separating equilibria, supplier encroachment can either benefit or hurt the two firms.

3. The Model

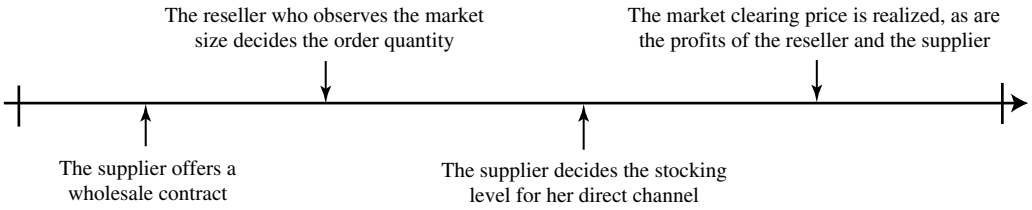
We consider a supplier (she) that sells a product through a reseller (he), but she also has her own direct channel and may sell the product directly to consumers. We normalize both the production cost of the supplier and the selling cost for the reseller to zero. To allow for the possibility that the supplier may be less efficient in retail operations than is the reseller, we assume that the supplier incurs a per-unit selling cost of c for each unit that she sells directly to consumers. Consumer demand follows a linear, downward-sloping demand function, $P = \mathbf{a} - Q$, where Q is the total number of the product deployed for sale, P is the market clearing price, and $\mathbf{a}$ represents the market size. Note that it is without further loss of generality that we have normalized the slope of this demand function to be -1.

The above setup is nearly identical to that of Arya et al. (2007). However, to capture the notion that the reseller is closer to the market and may also have better expertise in forecasting the demand than the supplier, we assume that the market size $\mathbf{a}$ is, ex ante, random which can be either large ($\mathbf{a} = a_H$) with probability λ and small ($\mathbf{a} = a_L$) with probability $1-\lambda$, where $a_H > a_L > 0$; the reseller can observe the true market size privately, before ordering from the supplier, whereas the supplier knows only the prior distribution of the market size.[1] Let $\mu = \lambda a_H + (1-\lambda)a_L$, representing the expected market size, and $\sigma^2 = \lambda(a_H - \mu)^2 + (1-\lambda)(a_L - \mu)^2$ be the variance of the market size distribution. We restrict our attention to the cases in which $a_L > \mu/2$, so that, as we will show later, the reseller's equilibrium order quantity is strictly positive for both market sizes without supplier encroachment. Such an assumption will simplify the analysis and can also highlight the contrast between the cases with and without supplier encroachment. Finally, we assume that the supplier uses a linear wholesale-price-only contract. Linear pricing schemes are widely used in practice and also are commonly assumed in the literature that studies channel structure (e.g., McGuire and Staelin 1983, Lariviere and Porteus 2001, Cachon 2003, Arya et al. 2007). Similar results hold even if the supplier can implement nonlinear pricing through a menu of contracts.

Figure 1 details the timeline of the model. First, the supplier offers a wholesale contract to the reseller, which contains a unit wholesale price w. The reseller who has observed the true market size, $\mathbf{a} = a_H$ or $\mathbf{a} = a_L$, orders q_R units from the supplier. The supplier then decides the quantity q_S, which she sells through her direct channel. The market clearing price P is realized according to $P = a_i - (q_R + q_S)$ for $i \in \{H, L\}$, and

[1] For simplicity, we assume here that the reseller learns the market size perfectly, whereas the supplier only has the prior knowledge. The insights we reveal, however, will continue to hold, even if both of them receive noisy signals of the market size, as long as the reseller is more precisely informed about the demand than the supplier.

Figure 1 Timeline of the Model



the two parties obtain their final profits.[2] The assumption that the reseller orders before the supplier determines her order quantity is justified by the fact that the supplier has no way to credibly commit to refrain from revising her own order quantity after receiving the reseller's order.

4. Analysis

Before beginning our analysis of how the development of supplier encroachment capability (i.e., the launch of the direct channel) affects the interactions between a supplier and a reseller, we first present the benchmark in which the supplier lacks this capability and sells the product *only* through the reseller.

4.1. Benchmark Without Encroachment

When the supplier lacks the infrastructure of a direct channel, she has effectively provided a credible commitment that she will not encroach. Then, given the wholesale price w and the market size a_i, $i \in \{H, L\}$, the reseller determines his order quantity as the solution to

$$\max_{q_R}[a_i - q_R - w]q_R.$$

It is easy to obtain the optimal order quantity of the reseller for each market size a_i, $i \in \{H, L\}$:

$$q_R^N(w; a_i) = \frac{a_i - w}{2}.$$

Recall that the supplier does not observe the true market size, but anticipates the reseller's decision. Thus, the supplier chooses her wholesale price as the solution to

$$\max_{w} \mathbf{E}[q_R^N(w; \mathbf{a})w].$$

In equilibrium, the supplier's optimal wholesale price is $w^N = \mu/2$, and the expected profits of the reseller and the supplier are, respectively,

$$\pi_R = \frac{\mu^2 + 4\sigma^2}{16} \quad \text{and} \quad \pi_S = \frac{\mu^2}{8}, \tag{1}$$

where the lowercase π indicates that there is no encroachment.

[2] This inverse demand function implicitly assumes that consumers perceive the two channels to be perfect substitutes. Although allowing for partial substitutability would complicate the analysis, it would not provide additional insights.

4.2. Encroachment Analysis

Let us now enhance the model to allow for supplier encroachment, by which we mean the supplier has her direct channel in place and can choose to sell directly. Since the supplier does not observe the market demand directly, she will use the information revealed from the reseller's order quantity to make her decision on the direct sale quantity. Because the reseller anticipates the supplier's reaction to his order, a signaling game may arise in which the reseller may purposely alter his order quantity. In particular, as is often the case, there are two mutually exclusive types of equilibria that might arise. In the first, the reseller orders a distinct quantity for each market size, and his order perfectly reveals the market size to the supplier. In the second, he orders the same quantity for both market sizes, and his order is uninformative. The former case represents a separating outcome, whereas the latter corresponds to a pooling outcome. Typically, such signaling games can have multiple equilibria depending on the players' belief specification. However, this obstacle can be overcome by using the intuitive criterion, which is a classical equilibrium refinement developed by Cho and Kreps (1987). Because we can show (see Online Appendix D, available at http://ssrn.com/abstract_id=2340117) that pooling equilibrium cannot survive the intuitive criterion in our model, we focus directly on separating equilibrium. That is, all of the formulation and analysis presented below are based on the fact that the supplier can perfectly infer the market size from the reseller's order quantity. Furthermore, we confine our formulation and analysis to those cases (with respect to c, λ, a_H, and a_L) where the supplier optimally sells a positive quantity for each market size. (The boundary condition is provided when we characterize the equilibrium.) Displaying the full analysis for the cases where the supplier optimally chooses not to encroach would complicate the exposition without adding any interesting insights.

We first formulate the supplier's belief. We use $a_{j(q_R)}$ to indicate the market size that the supplier believes after receiving an order quantity q_R from the reseller. It is intuitive that the reseller will order more when the true market size is large than when the market size is small. Thus, we apply the following belief

structure depending on a threshold order quantity $\hat{q}_R(w)$ for a given wholesale price w. (Other belief formulations exist that can lead to the same equilibrium result.)

$$j(q_R) = \begin{cases} H & \text{if } q_R > \hat{q}_R(w), \\ L & \text{otherwise.} \end{cases}$$

That is, the supplier believes that the market size is large if the reseller's order quantity $q_R > \hat{q}_R(w)$ and small otherwise. Then, after observing the reseller's order quantity q_R, the supplier determines her direct selling quantity by solving

$$\max_{q_S}[a_{j(q_R)} - q_R - q_S - c]q_S,$$

which yields the optimal direct selling quantity:

$$q_S(q_R) = \frac{a_{j(q_R)} - q_R - c}{2}.$$

In anticipation of the supplier's belief and reaction, the reseller, who knows the true market size a_i, $i \in \{H, L\}$, solves

$$\max_{q_R}[a_i - q_R - q_S(q_R) - w]q_R. \tag{2}$$

Let $q_R(w; a_i)$ denote the optimal solution of (2). Notice that for a given order quantity, the reseller would be better off if the supplier believed the market size were small than if she believed it were large. Thus, the reseller may purposely order a lower quantity to induce the supplier to believe the market size is small. The supplier will adjust $\hat{q}_R(w)$ taking the reseller's incentive into account. To solve this problem, we define the following equilibrium concept.

Definition 1. Given any wholesale price w, a perfect Bayesian separating equilibrium is reached if $a_{j(q_R(w;\, a_i))} = a_i$ for each market size a_i, $i \in \{H, L\}$; that is, there exists a $\hat{q}_R(w)$ such that $q_R(w; a_H) > \hat{q}_R(w)$ while $q_R(w; a_L) \le \hat{q}_R(w)$.

To facilitate the characterization of the equilibrium, we define the following functions:

$$V_{ij}(q_R) = \left[a_i - q_R - \frac{a_j - q_R - c}{2} - w\right]q_R, \quad \forall\, i,\ j \in \{H, L\},$$

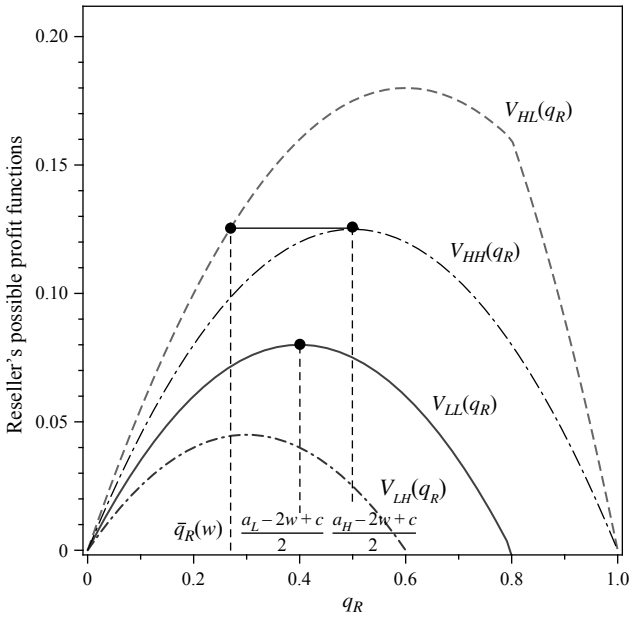
where $V_{ij}(q_R)$ is the reseller's profit if the true market size is a_i, while, given the reseller's order quantity q_R, the supplier believes that the market size is a_j.

Lemma 1. *The function $V_{ij}(q_R)$ is concave in q_R for any i, $j \in \{H, L\}$, and there is a unique maximizer of $V_{ii}(q_R)$; that is, $q_R = ((a_i - 2w + c)/2)^+$, for each $i \in \{H, L\}$.*

All proofs are provided in Online Appendix A.

Figure 2 illustrates the reseller's possible profit functions, $V_{ij}(q_R)$. From Lemma 1, we can clearly see that if the supplier could also observe the market size,

Figure 2 **Demonstration of the Reseller's Possible Profit Functions and the Threshold $\bar{q}_R(w)$**



Notes. The parameters are $\lambda = 0.3$, $a_H = 1.2$, $a_L = 1$, $w = 0.2$, and $c = 0.2$. In this example, $w < \bar{w} = 0.55$.

then the reseller would order $q_R = ((a_i - 2w + c)/2)^+$ for each market size a_i. When the supplier does not have complete information, the reseller may have an incentive to place an order lower than $((a_i - 2w + c)/2)^+$. It is easy to see that the supplier would never benefit from setting a wholesale price, $w \ge (a_H + c)/2$, since this would prevent the reseller from ordering anything for each market size. Therefore, we implicitly assume $w < (a_H + c)/2$ for all the analysis below.

Lemma 2. *For any $q_R > 0$, $V_{HL}(q_R) > V_{HH}(q_R)$, and there exists*

$$\begin{aligned} &\bar{q}_R(w) \\ &= \frac{2a_H - a_L - 2w + c - \sqrt{(a_H - a_L)(3a_H - a_L - 4w + 2c)}}{2} \\ &< \frac{a_H - 2w + c}{2} \end{aligned}$$

such that $V_{HL}(\bar{q}_R(w)) = V_{HH}((a_H - 2w + c)/2)$, $V_{HL}(q_R) < V_{HH}((a_H - 2w + c)/2)$ when $q_R < \bar{q}_R(w)$, and $V_{HL}(q_R) > V_{HH}((a_H - 2w + c)/2)$ when $\bar{q}_R(w) < q_R < (a_H - 2w + c)/2$. Furthermore, let $\bar{w} = (3a_L - a_H + 2c)/4$. Then, $\bar{q}_R(w) \lessgtr ((a_L - 2w + c)/2)^+$ when $w \lessgtr \bar{w}$.

Figure 2 provides an illustration of the results of Lemma 2 and the threshold $\bar{q}_R(w)$. Lemma 2 implies that if the threshold $\hat{q}_R(w)$ in the supplier's belief structure is above $\bar{q}_R(w)$, then if the reseller observes a large market he would order less than $(a_H - 2w + c)/2$, to induce the supplier to believe that

the market size is small. Therefore, for a separating equilibrium to exist, $\hat{q}_R(w)$ cannot be greater than $\bar{q}_R(w)$. With this intuition, the following proposition characterizes a unique separating equilibrium that survives the intuitive criterion.

Proposition 1. *There exists a unique perfect Bayesian separating equilibrium that survives the intuitive criterion, in which the reseller's order quantity satisfies* $q_R(w; a_H) = (a_H - 2w + c)/2$ *and* $q_R(w; a_L) = \hat{q}_R(w) = \min\{((a_L - 2w + c)/2)^+, \bar{q}_R(w)\}$, *and the supplier's direct selling quantity is* $q_S(q_R(w; a_i)) = (a_i - q_R(w; a_i) - c)/2$, $\forall\, i \in \{H, L\}$.

In this equilibrium, the reseller orders $(a_H - 2w + c)/2$ when the market size is large, which coincides with the optimal quantity he would order if the supplier also observes the market size. In other words, for the large market size, the reseller's order quantity will not be distorted as the information of the market size becomes private to the reseller. However, when the market size is small, distortion of the reseller's order quantity can arise due to information asymmetry. We can observe from Lemma 2 that only when $w \geq \bar{w}$ would $q_R(w; a_L)$ coincide with $((a_L - 2w + c)/2)^+$, and when $w < \bar{w}$, $q_R(w; a_L) < ((a_L - 2w + c)/2)^+$. That is, if the wholesale price $w < \bar{w}$, then for the small market size, the reseller will order less in the presence of asymmetric information than he would if the market size were observable to the supplier. To credibly signal that the market size is small, the reseller needs to downward distort the order quantity to such a level that he would have no incentive to mimic when observing the large market size, even if that would allow him to deceive the supplier. Consequently, in equilibrium, the supplier can always learn the market size from the reseller's order quantity and determine her direct selling quantity accordingly.

Recall from Arya et al. (2007) that the potential for mutual benefit from encroachment arises because the supplier lowers the wholesale price at the same time that she stimulates the volume of sales through the reseller with the threat of her own direct sales. However, in the presence of asymmetric information, the reseller's propensity to downward distort his order quantity when the wholesale price is low can dampen the supplier's willingness to reduce her wholesale price. Consequently, informational asymmetry can reduce or eliminate the potential for mutual benefit from encroachment.

A deeper investigation of the reseller's order quantity for the small market size can draw the following conclusion.

Lemma 3. *The reseller's equilibrium order quantity for the small market size satisfies* $|(dq_R(w; a_L))/dw| = 1$ *when* $\bar{w} \leq w < (a_L + c)/2$ *and* $|(dq_R(w; a_L))/dw| < 1$ *when* $w < \bar{w}$.

Lemma 3 asserts that the reseller's equilibrium order quantity under a small market size, $q_R(w; a_L)$, will be less responsive to the wholesale price (i.e., the order quantity increases at a slower rate as the wholesale price decreases) in the region with a distortion than in a region without. As we will see later (at Proposition 2), the point where w drops below $\bar{w}$ corresponds to a discontinuous drop in the price elasticity of the reseller's order quantity and can drive up the supplier's wholesale price and thus amplify double marginalization.

The supplier's wholesale pricing decision, in anticipation of the subsequent subgames, can be expressed as

$$\max_w \mathbf{E}\big[q_R(w; \mathbf{a})w + (\mathbf{a} - q_R(w; \mathbf{a}) - q_S(q_R(w; \mathbf{a})) - c) \cdot q_S(q_R(w; \mathbf{a}))\big]. \tag{3}$$

Proposition 2 provides the solution to (3) and the corresponding subgame equilibrium for the cases where the supplier encroaches for both market sizes.

Proposition 2. *Given* a_H *and* a_L, *for any* $\lambda \in (0, 1)$, *there exists a threshold* $\bar{c}(\lambda)$ *such that in equilibrium,*[3]

(1) *the supplier's optimal wholesale price and the reseller's order quantity follow*:

(i) *if* $c \in (0, (3\sqrt{\lambda}(a_H - a_L))/4]$, *then* $w^* = (3a_H - c)/6$, $q_R(w^*; a_H) = (a_H - 2w^* + c)/2$, *and* $q_R(w^*; a_L) = 0$;

(ii) *if* $c \in ((3\sqrt{\lambda}(a_H - a_L))/4, \min\{(3(1 + 2\lambda)(a_H - a_L))/8, \bar{c}(\lambda)\}]$, *then* $w^* = (3\mu - c)/6$, $q_R(w^*; a_H) = (a_H - 2w^* + c)/2$, *and* $q_R(w^*; a_L) = (a_L - 2w^* + c)/2$;

(iii) *if* $c \in (\min\{(3(1+2\lambda)(a_H - a_L))/8, \bar{c}(\lambda)\}, \bar{c}(\lambda))$, *then* $w^* = \min\{\bar{w}, w_f\}$, *where* $w_f > (3\mu - c)/6$ *is the smallest solution of the first-order condition of* (3),[4] $q_R(w^*; a_H) = (a_H - 2w^* + c)/2$ *and* $q_R(w^*; a_L) = \bar{q}_R(w^*)$;

(2) *the supplier's direct selling quantity follows* $q_S(q_R(w^*; a_i)) = (a_i - q_R(w^*; a_i) - c)/2$, $\forall\, i \in \{H, L\}$, *which is positive for* $c \in (0, \bar{c}(\lambda))$.

Proposition 2 shows that when the supplier's selling cost is relatively small, i.e., $0 < c \leq (3\sqrt{\lambda}(a_H - a_L))/4$, she chooses the wholesale price at a level such that the reseller orders a positive quantity only if the market size is large. With an intermediate selling cost, $(3\sqrt{\lambda}(a_H - a_L))/4 < c \leq \min\{(3(1 + 2\lambda) \cdot (a_H - a_L))/8, \bar{c}(\lambda)\}$, the supplier's optimal wholesale price induces the reseller to order a positive quantity for each market size. Furthermore, the reseller who observes high demand will have no incentive to attempt to mimic even the undistorted quantity that he would order with a small market size.

[3] The threshold, $\bar{c}(\lambda)$, is the selling cost above which the supplier's direct selling quantity under at least one market size reaches zero in equilibrium.

[4] The first-order condition of (3) is $\lambda(3a_H - c - 6w) + (1 - \lambda)(a_H + 2a_L - c - 6w)(1 - \sqrt{(a_H - a_L)/(3a_H - a_L + 2c - 4w)}) = 0$.

Consequently, when the supplier's selling cost is intermediate, we will see a natural separating equilibrium in which there is no distortion of the reseller's order quantity when the true market size is small. However, when the supplier's selling cost is relatively large, $\min\{(3(1+2\lambda)(a_H-a_L))/8, \bar{c}(\lambda)\} < c < \bar{c}(\lambda)$, the reseller who observes a large market size would have an incentive to mimic an undistorted small order quantity to deceive the supplier. As a result, the reseller will have to distort his order quantity downward when he truly observes a small market size, to credibly reveal the information to the supplier. In anticipation of this quantity distortion, the supplier's optimal wholesale price will exceed the $(3\mu - c)/6$ that she would otherwise offer in the absence of quantity distortion. Note that this is a direct outcome of the discontinuous reduction in the price elasticity of the reseller's order quantity as discussed after Lemma 3. Finally, note that we have restricted our analysis to the cases where $c < \bar{c}(\lambda)$ for which the supplier will sell a positive quantity through her direct channel for each market size. For $c \geq \bar{c}(\lambda)$, the analysis becomes quite complex because there may be cases in which the supplier sells nothing through her direct channel for either the small or the large market size. Because further analysis of these cases is unlikely to yield additional insights, we have restricted our attention to those cases for which the supplier always encroaches.

With Proposition 2, we can assess the impact of supplier encroachment on the supplier's as well as the reseller's profitability. Let us denote by uppercase Π_R and Π_S the equilibrium profits of the reseller and the supplier under encroachment when only the reseller knows the true realization of market size. We first focus on the cases with small and intermediate direct selling costs, i.e., $c \in (0, \min\{(3(1+2\lambda)\cdot(a_H-a_L))/8, \bar{c}(\lambda)\}]$.

Proposition 3. *The supplier is always better off in expectation by encroachment* (*i.e.*, $\Pi_S > \pi_S$) *when* $c \in (0, \min\{(3(1+2\lambda)(a_H-a_L))/8, \bar{c}(\lambda)\})$.

Proposition 3 shows that when the supplier's selling cost is relatively small or intermediate, encroachment always increases the supplier's profit. In particular, when the direct selling cost is small, $0 < c \leq (3\sqrt{\lambda}(a_H-a_L))/4$, by encroachment, the supplier can set a wholesale price, $w^* = (3a_H - c)/6$, more appropriately targeting the large market size than what she would offer without encroachment; on the other hand, having the ability to sell the product directly with a small cost limits the potential loss if the reseller does not order when the market size is small. When the direct selling cost is intermediate, $(3\sqrt{\lambda}(a_H-a_L))/4 < c < \min\{(3(1+2\lambda)(a_H-a_L))/8, \bar{c}(\lambda)\}$, the situation faced by the supplier in our model is the most similar to what has been explored in Arya et al. (2007). In particular, the reseller is induced to order a positive but distinct quantity for each market size without any intentional distortion. Supplier encroachment not only introduces another stream of revenues to the supplier but also endows the supplier with a mechanism to control the selling price in the retail market, which mitigates double marginalization.

For the reseller, although supplier encroachment causes him to lose the monopoly power in his market, it may also lead to a lower wholesale price. As revealed in Arya et al. (2007), with symmetric and full demand information, supplier encroachment can benefit or hurt the reseller depending on the supplier's direct selling cost. We find a similar result with asymmetric information.

Proposition 4. *Given* a_H *and* a_L, *for any* $\lambda \in (0,1)$, *there exists a threshold* $\hat{c}_R(\lambda)$ *such that the reseller is worse off in expectation by supplier encroachment* (*i.e.*, $\Pi_R < \pi_R$) *when* $c \in (0, \hat{c}_R(\lambda))$ *and better off* (*i.e.*, $\Pi_R > \pi_R$) *when* $c \in (\hat{c}_R(\lambda), \min\{(3(1+2\lambda)(a_H-a_L))/8, \bar{c}(\lambda)\}]$.

Proposition 4 shows the existence of a threshold, $\hat{c}_R(\lambda)$, with respect to the supplier's direct selling cost. When the supplier's direct selling cost, c, is lower than this threshold, the reseller is made worse off from losing the monopoly position in the downstream market as the supplier encroaches. In contrast, when the supplier's selling cost exceeds this threshold, the reseller enjoys a large efficiency advantage in the selling process, which helps him to gain more profit with a lower wholesale price offered by an encroaching supplier. The benefit from the reduction of the wholesale price outweighs the loss of demand due to the supplier's direct competition under encroachment. In particular, it can be shown that when $\lambda \to 0$, $\hat{c}_R(\lambda) \to (3\sqrt{2}a_L)/8$, and when $\lambda \to 1$, $\hat{c}_R(\lambda) \to (3\sqrt{2}a_H)/8$, which coincides with the threshold characterized in Arya et al. (2007) (with the market size a defined in their study being equal to either a_L or a_H). Therefore, supplier encroachment can still lead to a win–win outcome for the supplier and the reseller, even under the setting with asymmetric market information in the channel.

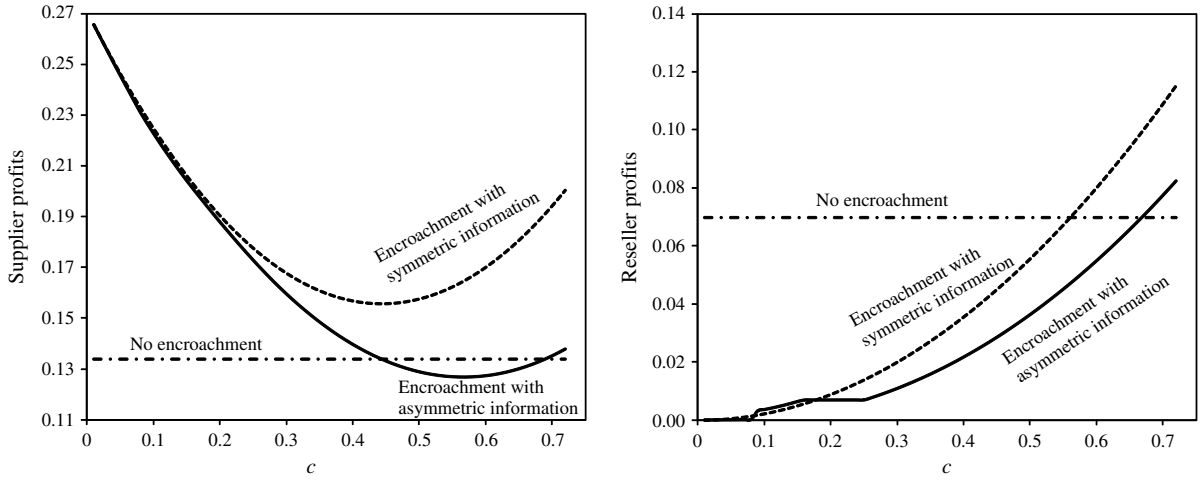
The above analysis focuses on the cases where the supplier has a relatively small or intermediate selling cost. In such cases, the reseller has no incentive to purposely distort his order quantity under the supplier's optimal wholesale price. However, as we observe from Proposition 2, when the supplier's selling cost is relatively large, the supplier will set a wholesale price under which the reseller will downward distort his order quantity if the market size is small. Such a distortion can take a toll on both the supplier and the reseller.

Remark 1. There exist a_H, a_L, λ, and $c \in (\min\{(3(1+2\lambda)(a_H-a_L))/8, \bar{c}(\lambda)\}, \bar{c}(\lambda))$ such that both the supplier and the reseller are worse off in expectation by supplier encroachment.

Although it is challenging to derive the sufficient and necessary condition under which having the ability to encroach hurts the supplier herself as well as the reseller, as a consequence of the fact that the supplier's optimal wholesale price takes a complex implicit form when $c \in (\min\{(3(1+2\lambda)(a_H-a_L))/8, \bar{c}(\lambda)\}, \bar{c}(\lambda))$, Remark 1 asserts the existence of such scenarios. With information asymmetry, the reseller observing a large market size has the incentive to order less to pretend to have observed a small market to induce the supplier to sell less in her direct channel. For a sufficiently small wholesale price, this incentive can cause the reseller to lower his order quantity to credibly signal his information when the market size is truly small. Recall from Lemma 3 that in the range of w for which distortion occurs, there is a reduction in the magnitude of the price elasticity of the reseller's order quantity. As a result, the anticipation of the reseller's potential distortion can cause the supplier to offer a higher wholesale price, which consequently amplifies double marginalization in the indirect channel. In contrast to the win–win outcome revealed in the earlier discussion, a lose–lose outcome can also arise if the supplier possesses the ability to encroach while she has an intermediate selling cost and the probability of a large market is low. This result does not occur in the analysis of Arya et al. (2007) because it is driven by the information asymmetry between the reseller and the supplier. It sounds an alarm over upstream encroachment when the downstream is better informed. Supplier encroachment can create downstream ordering distortion amid information dissemination, which harms channel efficiency.

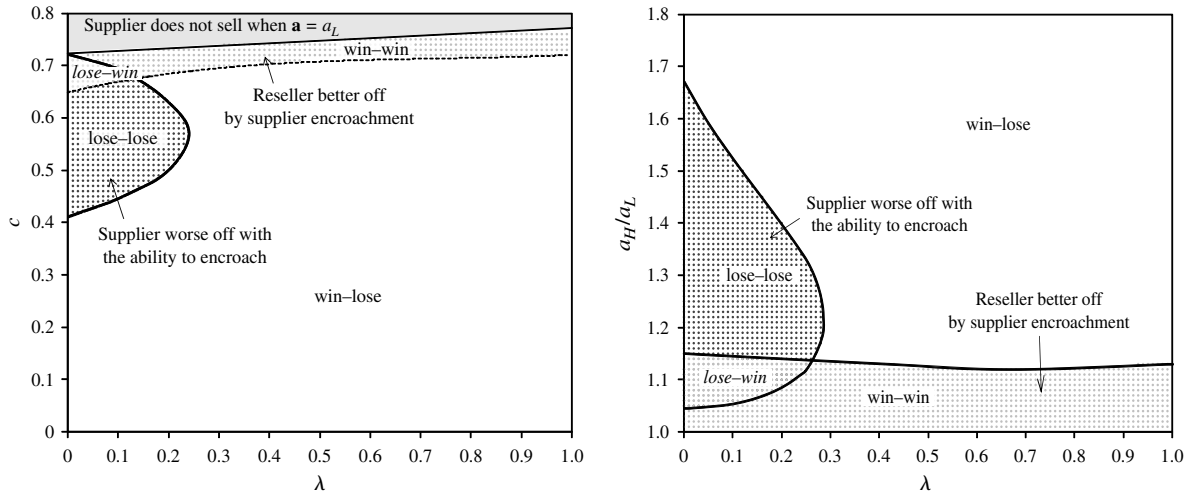
To gain a deeper intuition, we further conduct a numerical analysis to reveal all possible outcomes. First, we find that the presence of information asymmetry can have a significant impact on the benefits of encroachment for both the supplier and the reseller, and in general, this impact is stronger when the supplier's direct selling cost c becomes larger (see Figure 3). However, for some range of c, the presence of information asymmetry can also make supplier encroachment benefit the reseller more compared to the corresponding case with symmetric information. This is because an uninformed supplier cannot tailor her optimal wholesale price to the realized market size. Second, and more interestingly, we can observe from Figure 4 that in the presence of information asymmetry, supplier encroachment can still lead to either a win–win or a win–lose outcome for the supplier and reseller, respectively, but a lose–win or a lose–lose outcome is also possible. Recall from Arya et al. (2007) that neither of these latter two outcomes arises as a result of the development of encroachment capability under symmetric information. Specifically, even though the supplier benefits from having encroachment capability for a relatively wide range of parameters, she can still be worse off with a relatively small λ (the prior probability of the large market size) when her direct selling cost is intermediate (see the left subplot of Figure 4) or the ratio of the two market sizes is neither very large nor very small (see the right subplot of Figure 4). For the reseller, he will benefit from the supplier's ability to encroach only if he enjoys a relatively large advantage in the selling process while the ratio of the two market sizes is small. Note that the equilibrium result in our

Figure 3 Demonstration of the Impacts of Supplier Encroachment on the Supplier's and the Reseller's Profits with Symmetric and Asymmetric Information Settings



Note. In this example, $a_H = 1.35$, $a_L = 1$, and $\lambda = 0.10$.

Figure 4 Demonstration of the Impacts of Supplier Encroachment on the Supplier's and the Reseller's Profitability



Notes. In this example, $a_L = 1.0$. In the left plot, $a_H = 1.35$; in the right plot, $c = 0.6$.

study converges to that in Arya et al. (2007) as a_H/a_L approaches 1 so that there is no information asymmetry and the signaling game does not occur. Although our results also converge perfectly to their results as λ approaches 1, we will not have similar convergence as λ becomes arbitrarily small, since the signaling game will always arise and there will be a discontinuity between the equilibrium result in our study and that in Arya et al. (2007). Such a discontinuity is common among signaling games and is not unique to our model.

5. Implications for Information Management

Throughout the previous analysis, we have assumed that the reseller is endowed with a better knowledge of the market scenario than that of the supplier. In this subsection, we explore how the supplier's development of encroachment capability alters the extent to which the supplier and the reseller benefit from the possession of information. We explore this issue from three different perspectives. First, we take the perspective of a supplier that may be able to choose among several resellers with which to do business, and we address the issue of whether the supplier should prefer to interact with a more or less informationally capable reseller (i.e., who can be better informed than the supplier or just equally informed). Second, we take the perspective of a supplier who is in a bilateral monopoly relationship with a single reseller, in which the reseller's decision to develop infrastructure to enhance his informational capability is an endogenous decision. Here, we address the question of how such an endogenized informational strategy affects the equilibrium profits of the supplier and the reseller. Finally, we consider the possibility that the reseller can share demand information with the supplier, and we address the question of whether encroachment impedes or facilitates information sharing.

5.1. Preliminaries

To address the questions above, we must first perform some preliminary analysis to characterize the profits of the supplier and the reseller with and without encroachment capability under two additional information structures: one in which neither firm knows the realized market size, and another in which both firms know the realized market size. As before, we use π_R and π_S (Π_R and Π_S) to denote the profits of the reseller and the supplier without (with) supplier encroachment capability.

In the absence of encroachment, it is straightforward to show that when neither the supplier nor the reseller knows the realization of the market size, their equilibrium expected profits can be characterized as

$$\pi_R^{NI} = \frac{\mu^2}{16} \quad \text{and} \quad \pi_S^{NI} = \frac{\mu^2}{8}, \tag{4}$$

where NI indicates no information. Similarly, if both the reseller and the supplier can observe the realization of the market size, presumably through some credible information-sharing mechanism, then their expected profits can be expressed as

$$\pi_R^{SI} = \frac{\mu^2 + \sigma^2}{16} \quad \text{and} \quad \pi_S^{SI} = \frac{\mu^2 + \sigma^2}{8}, \tag{5}$$

where SI indicates shared information. Recall from §4.1 that when the reseller has private information, the profits of the reseller and the supplier are $\pi_R = (\mu^2 + 4\sigma^2)/16$ and $\pi_S = \mu^2/8$, respectively. Therefore, in the absence of supplier encroachment, we have

that $\pi_R \geq \pi_R^{SI} \geq \pi_R^{NI}$ while $\pi_S^{SI} \geq \pi_S = \pi_S^{NI}$, where the inequalities are strict if and only if $\sigma > 0$. That is, the reseller prefers to be privately informed to having shared information, and prefers shared information to no information. Although the supplier prefers having shared information to either no information or having a privately informed reseller, she is indifferent between the latter two. This finding has also been established in the literature (Li and Zhang 2002).

We now provide the profits of the firms for the case where the supplier has encroachment capability. (The detailed derivation is provided in Online Appendix B.) In particular, if neither firm has information about the realization of demand, then the reseller's and the supplier's expected profits follow:

$$\Pi_R^{NI} = \frac{2c^2}{9} \quad \text{and} \quad \Pi_S^{NI} = \frac{3\mu^2 - 6\mu c + 7c^2}{12}.$$

In contrast, if they both have information about the true market size, then their expected profits are

$$\Pi_R^{SI} = \frac{2c^2}{9} \quad \text{and}$$

$$\Pi_S^{SI} = \lambda \frac{3a_H^2 - 6a_H c + 7c^2}{12} + (1-\lambda)\frac{3a_L^2 - 6a_L c + 7c^2}{12}.$$

Note that for both of the above cases of encroachment under symmetric information, the expected profit of the reseller is independent of the market size and depends only on the supplier's relative inefficiency, c.[5] The reason for this is that, with symmetric information, the supplier's equilibrium wholesale price induces the reseller to respond by ordering a quantity equal to $(2c)/3$, and the supplier subsequently sets her own quantity to ensure that the reseller's expected per-unit profit margin is $c/3$. As a result, the supplier's development of encroachment capability alters the reseller's preferences so that instead of preferring shared information to no information, he is indifferent between the two.

However, when the reseller has private information, an encroaching supplier can no longer ensure that the reseller's order quantity and profit margin are invariant with respect to the market size, and it is not obvious whether the reseller's having private information affects the expected profits of the supplier or the reseller. Recall that Π_S and Π_R are the expected profits for the supplier and reseller under encroachment when the reseller has private information that we analyzed in §4. In what follows, we compare these to the profit functions above and discuss the managerial implications.

[5] This is also the case in Arya et al. (2007), though they do not discuss it.

5.2. Supplier Preference for an Informationally More or Less Capable Reseller

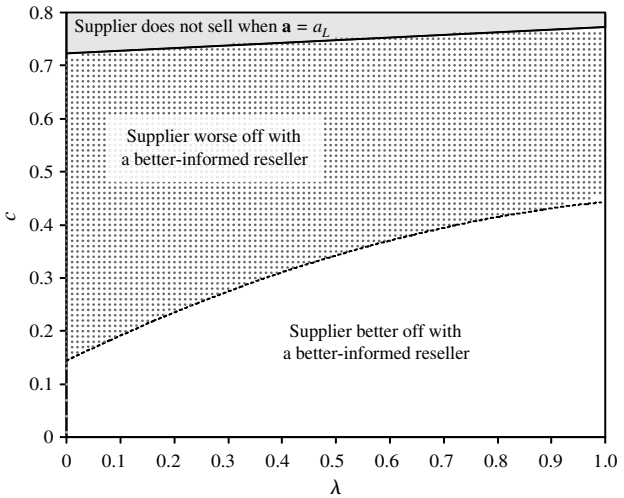
In settings in which a supplier can choose from among multiple potential resellers, it is of interest to understand the conditions under which she should prefer a reseller who is more or less capable of learning the market demand. Specifically, we consider the case where the supplier must choose between one reseller who is informationally more capable and knows the market size perfectly, and another who is less capable who has the same knowledge of the market size as the supplier. While such a choice is stylized, it reflects the reality that resellers are not homogenous in their abilities to collect and interpret data for the purpose of forecasting demand. Recall that, in the absence of encroachment, the supplier is indifferent regarding the reseller's informational capability. However, when the supplier has encroachment capability, we have the following result:

Proposition 5. *The supplier prefers a better-informed reseller if* $c < \min\{(3(1+2\lambda)(a_H - a_L))/8, \bar{c}(\lambda)\}$.

Once the supplier develops the ability to encroach upon the reseller's market, the reseller's knowledge of the true market size matters to the supplier. As long as her own direct selling operations are not too inefficient relative to those of the reseller, she prefers to interact with a reseller who has better knowledge of the market. Note that the condition (i.e., $c < \min\{(3(1+2\lambda)(a_H - a_L))/8, \bar{c}(\lambda)\}$) specified in Proposition 5 serves as a sufficient condition. From our numerical analysis (see Figure 5), however, we can make the following observation:

Observation 1. When the supplier's direct selling cost exceeds a threshold level of inefficiency, she may

Figure 5 Demonstration of the Impact of Downstream Information Advantage on the Supplier's Profitability in the Presence of Supplier Encroachment



Note. In this example, $a_H = 1.35$ and $a_L = 1$.

prefer to interact with a reseller whose information is identical to her own to avoid the adverse effects of downward distortion that would arise with a better-informed reseller.

The above result is related to that of Taylor and Xiao (2010), who show that for a supplier selling to a newsvendor, the supplier may or may not prefer to have a better-informed reseller. However, our result is driven by entirely different forces that exist only in the presence of supplier encroachment.

5.3. Endogenous Encroachment and Information Strategies

We now consider how a supplier's decision to develop encroachment capability affects the decision of an existing reseller to develop/maintain the infrastructure that provides him with better knowledge of the market demand. Specifically, we consider the following sequence of events: First, the supplier determines whether to develop encroachment capability by developing the infrastructure for a direct channel, and this decision is publicly observed. Second, the reseller decides whether to develop advanced informational capability. Third, the supplier observes the reseller's informational capability and sets the wholesale price. Fourth, the reseller responds with an order quantity. Finally, if the supplier has a direct channel, she determines her own volume of direct sales. Note that an alternative sequence of events would be to assume that the reseller decides whether to acquire specific market information after the wholesale price is announced. However, the sequence that we have proposed is more reasonable in environments where the reseller's information advantage is generated from his informational capability and expertise in predicting the demand, so that even if the supplier and the reseller receive the same data about the market demand, an informationally more capable reseller might be better able to interpret it and thus have a more accurate prediction of the true market size. To gain such informational capability would require a relatively long-term development of infrastructure, e.g., software, data structures, human resource capability; whereas, the wholesale price and ordering decisions can be made instantaneously. For simplicity, we normalize to zero the cost incurred by the reseller to develop informational capability (introducing a fixed cost would not change our results qualitatively). To understand how the reseller will choose his information strategy when the supplier develops encroachment capability, we need to compare his expected profits with private information, Π_R, from §4.2 with his expected profits without information, Π_R^{NI}.

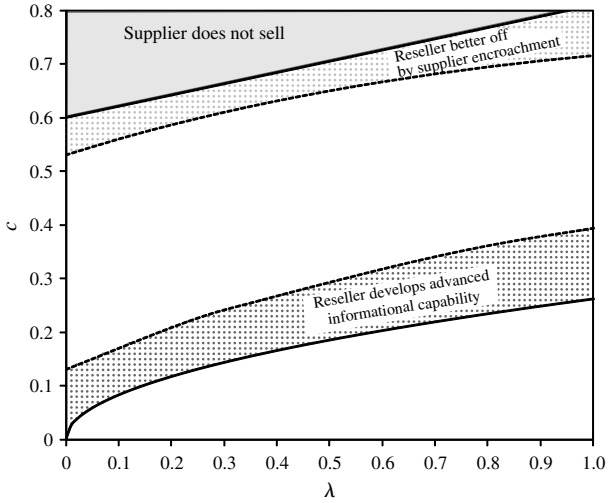
Proposition 6. *If* $c \in ((3\sqrt{\lambda}(a_H - a_L))/4, \min\{(3(1 + 2\lambda)(a_H - a_L))/8, \bar{c}(\lambda)\})$, *then the reseller will develop advanced informational capability relative to the supplier, which benefits both himself and the supplier (i.e.,* $\Pi_R > \Pi_R^{NI}$ *and* $\Pi_S > \Pi_S^{NI}$*). Otherwise, if* $c \in (0, (3\sqrt{\lambda}(a_H - a_L))/4]$ *or* $c \in (\min\{(3(1 + 3\lambda + 4\sqrt{\lambda})(a_H - a_L))/8, \bar{c}(\lambda)\}, \bar{c}(\lambda))$, *then* $\Pi_R < \Pi_R^{NI}$ *and the reseller will choose not to develop advanced informational capability.*

Proposition 6 confirms that even if the supplier has encroachment capability, the reseller can still benefit from having better knowledge of the demand, but only when his efficiency advantage in the selling process is intermediate so that he can avoid substantial distortion of his order quantity. In such a scenario, the dominant effect of private information is that it allows the reseller to tailor his order quantity to the realized market size. Furthermore, the supplier also strictly benefits from the reseller's endogenous decision to be better informed. Recall from the results of Li and Zhang (2002) that this will never occur in the absence of encroachment.

However, Proposition 6 also affirms that under supplier encroachment, the reseller is worse off by having better knowledge when his advantage in the selling process is either small or large. In particular, when $c \in (0, (3\sqrt{\lambda}(a_H - a_L))/4]$, the supplier will set a high wholesale price for a privately informed reseller that induces him to order a positive quantity only if the market size is large. Because the supplier is only slightly less efficient than the reseller, she is willing to monopolize the market when demand is small in return for setting a wholesale price that is more precisely targeted at the large market size. This more precisely targeted (higher) wholesale price hurts the reseller. At the other extreme, when the reseller's selling cost advantage is large, i.e., $c \in (\min\{(3(1 + 3\lambda + 4\sqrt{\lambda})(a_H - a_L))/8, \bar{c}(\lambda)\}, \bar{c}(\lambda))$, access to private demand information causes him to substantially distort his ordering quantity under low demand, which can result in his earning lower profit in expectation than if he did not have access to the information. Note that to compare the reseller's profits with and without advanced informational capability when $c \in (\min\{(3(1 + 2\lambda)(a_H - a_L))/8, \bar{c}(\lambda)\}, \min\{(3(1 + 3\lambda + 4\sqrt{\lambda})(a_H - a_L))/8, \bar{c}(\lambda)\})$ is technically challenging, but we observe from our numerical analysis (see Figure 6) that, within this region, there exists a threshold on the cost, c, above (below) which the reseller is worse off (better off) with advanced informational capability.

To understand the impact of a reseller's endogenous information strategy upon the supplier's decision about whether to develop encroachment capability, we resort to a numerical investigation. For the example depicted in Figure 6, where $a_H = 1.35$ and $a_L = 1$, the reseller develops advanced informational capability for only a relatively small range of parameters. However, this is not enough to deter the supplier

Figure 6 **Demonstration of the Impact of Endogenous Downstream Information Strategy on the Reseller's Profitability in the Presence of Supplier Encroachment**



Note. In this example, $a_H = 1.35$ and $a_L = 1$.

from encroaching. Regardless of the value of λ, the supplier benefits from encroachment over the entire range of c for which she would exercise her ability to encroach if she could.

To further explore how the development of encroachment capability affects the profits of the supplier and the reseller, we have plotted the ratio of profits with encroachment capability to profits without encroachment capability for the supplier, the reseller, and the supply chain in Figure 7. (A profit ratio larger than unity implies a benefit from encroachment capability.) Notice that in all three subfigures, curves are not smooth. In particular, the plots of the profit ratios shift upward when there is positive variance and c is in the range for which the reseller develops informational capability. This occurs for $c \in (0.18, 0.3)$ for $\sigma^2 = 0.03$ and for $c \in (0.28, 0.48)$ for $\sigma^2 = 0.07$.

There are several things worth noting in these plots. First, observe that for the supplier, the profit ratio is greater than one over the entire range of c; i.e., she benefits from having encroachment capability even when it discourages the reseller from developing advanced informational capability. Second, notice that for the reseller, outside of the range of c for which he is better informed, greater demand variance reduces his profit ratio; i.e., he does not benefit as much from demand variance under encroachment as he does without it. As a consequence, we can see that as demand variance increases, there is a reduction in the range of c for which the reseller benefits from encroachment, i.e., where his profit ratio exceeds 1. Also note that in the range of c for which the reseller is better informed under $\sigma^2 = 0.03$ (and $\sigma^2 = 0.07$), his profit ratio exceeds that for $\sigma^2 = 0$. This is because when the reseller endogenously develops advanced informational capability, there is little or no ordering distortion, and demand variance reduces the extent to which he is harmed by encroachment, though not by enough to allow him to benefit.

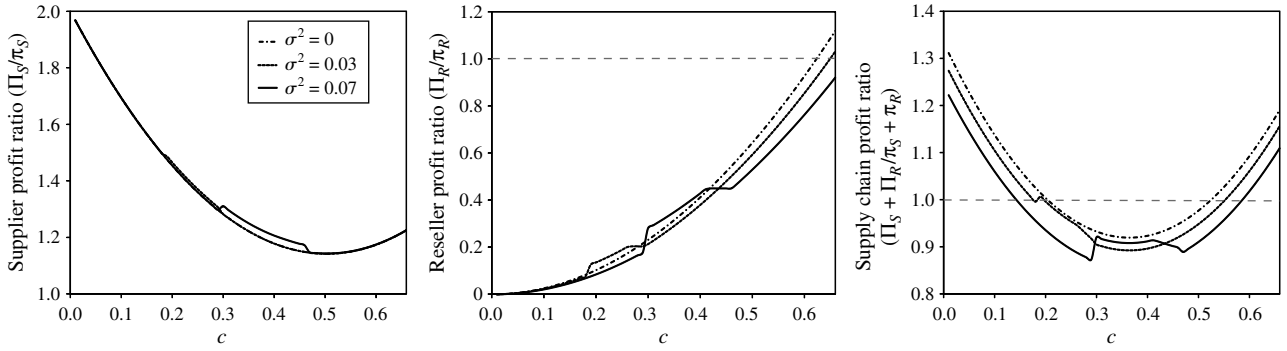
Finally, we can observe that the range of c for which the entire supply chain is harmed by the supplier's development of encroachment capability is increasing in demand variance. This can be confirmed by the fact that, as σ^2 increases, a larger portion of the supply chain profit ratio curve lies below 1.0. This is a result of the fact that encroachment discourages the development of advanced informational capability at the reseller, whereas in the absence of encroachment, the total supply chain profit increases when the reseller develops advanced informational capability.

5.4. Credible Information Sharing

Thus far, we have assumed that there does not exist a credible mechanism for information sharing. Let us now relax this assumption and consider how the supplier's development of encroachment capability might affect the incentives for both firms to pursue a means for credibly sharing information.

It is well established in the literature that, in the absence of supplier encroachment, $\pi_R \geq \pi_R^{SI}$, while

Figure 7 **Impact of Demand Uncertainty on the Efficiency of the Supply Chain**



Note. In this example, $\lambda = 0.5$; $a_H = a_L = 1.175$ for the scenario with $\sigma^2 = 0$; $a_H = 1.35$ and $a_L = 1$ for the scenario with $\sigma^2 = 0.03$; and $a_H = 1.45$ and $a_L = 0.9$ for the scenario with $\sigma^2 = 0.07$.

$\pi_S^{SI} \geq \pi_S$; i.e., the reseller prefers being privately informed over having shared information with the supplier, while the supplier would prefer shared information over the reseller's having private information (see, e.g., Li and Zhang 2002). However, once the supplier has encroachment capability, both the supplier's and the reseller's preferences between information structures can change as described in the following proposition.

Proposition 7. (i) *When the supplier has encroachment capability, information sharing always benefits the supplier* (*i.e.*, $\Pi_S^{SI} \geq \Pi_S$).

(ii) *However, the reseller prefers to share his information* (*i.e.*, $\Pi_R^{SI} > \Pi_R$) *when* $c \in (0, (3\sqrt{\lambda}(a_H - a_L))/4]$ *or* $c \in (\min\{(3(1 + 3\lambda + 4\sqrt{\lambda})(a_H - a_L))/8, \bar{c}(\lambda)\}, \bar{c}(\lambda))$, *and she prefers not to share his information* (*i.e.*, $\Pi_R > \Pi_R^{SI}$) *when* $c \in ((3\sqrt{\lambda}(a_H - a_L))/4, \min\{(3(1 + 2\lambda)(a_H - a_L))/8, \bar{c}(\lambda)\})$.

Knowing the exact market scenario always benefits the supplier because she can set a targeted wholesale price for each market size and avoid reseller order distortion. However, for the reseller, having shared information with the supplier is a double-edged sword. On one hand, shared information allows the supplier to optimize the wholesale price for each market size. Of course, this hurts the reseller as a consequence of the fact that his profit function is concave in the wholesale price. On the other hand, when an encroaching supplier obtains access to the same market information as the reseller, it alters her strategy in setting the wholesale price, so the reseller is induced to sell a positive quantity even when the market size is small and the supplier's cost disadvantage is small (i.e., $c \in (0, (3\sqrt{\lambda}(a_H - a_L))/4))$; furthermore, information sharing will also cure the reseller's incentive to distort his order quantity when the supplier's direct selling cost is large (e.g., $c \in (\min\{(3(1 + 3\lambda + 4\sqrt{\lambda})(a_H - a_L))/8, \bar{c}(\lambda)\}, \bar{c}(\lambda)))$, which will improve the efficiency. As a result, in contrast to the case without supplier encroachment, Proposition 7 asserts that under supplier encroachment, both the supplier and the reseller may benefit from the development of some means by which the reseller can credibly share its demand information. In other words, once the supplier has encroachment capability, a shift from an information structure in which the reseller is privately informed to one in which both firms have shared information is Pareto improving. This is not the case without encroachment, and suggests that the development of mechanisms for credibly sharing information might be more likely to occur in supply chains in which the supplier has its own direct channel.

6. Discussion and Conclusion

In this paper, we investigate supplier encroachment in the presence of information asymmetry where the reseller has private information about the market size. We show that in such a setting, if the supplier uses a linear wholesale price, supplier encroachment can cause the reseller to practice costly signaling and distort his order quantity downward. In addition, the supplier may increase her wholesale price and thus amplify double marginalization. Consequently, there are parameters for which supplier encroachment leads to win–win, win–lose, lose–win, and lose–lose outcomes for the supplier and the reseller. These findings complement existing results that show how supplier encroachment mitigates double marginalization when both firms have the same information.

We also demonstrate that supplier encroachment can have significant implications for information management in supply chains. We find that when the supplier has the ability to encroach, she will strictly prefer to sell to a better-informed reseller when her efficiency disadvantage in the selling process is not large; otherwise, she will prefer to sell to an equally informed reseller. This result complements prior literature that has shown that with a reselling channel alone, the supplier is indifferent toward the reseller's state of information. On the other hand, we find that when the supplier has encroachment capability, the reseller may prefer to remain uninformed about demand, which contrasts with existing results that have been obtained without encroachment. We further show that even though encroachment always benefits the supplier after the reseller's information strategy is endogenized, it can hurt the total supply chain performance because the reseller is discouraged from obtaining advanced information. Finally, our study reveals that both the supplier and the reseller may benefit from the development of a mechanism that will allow the reseller to credibly reveal his private demand information, which does not happen in the absence of encroachment.

Of course, our model also has some limitations. First, to avoid unnecessary complications, we have assumed that the reseller releases to the market all of the units that he orders, even if it might be ex post suboptimal to do so. If we were to allow the reseller a *free-disposal* option, this will tend to undermine the reseller's ability to commit to a sales quantity, but only when the wholesale price is relatively high. Consequently, a free-disposal option plays a role only when both the ratio a_H/a_L is large and the probability of a large market, λ, is sufficiently small. When it does play a role, it causes the reseller to order less for the large market size, and forces him to further distort his order quantity for the small market size. However, our main insights are robust to the free-disposal option. For further discussion of this, we refer readers to Online Appendix C.

A second limitation is the fact that we do not consider the possibility thatonce the supplier develops a

direct channel, she may have access to a new source of information. In Online Appendix C, we extend our model to allow for the supplier to receive a noisy signal about demand if she develops encroachment capability. This enables the supplier to tailor her wholesale price according to the signal that she receives. However, so long as the signal is imperfect, the signaling game between the supplier and reseller always arises, and all of our main results continue to hold qualitatively. Of course, it is also possible that both the supplier and the reseller may have imperfect signals about demand. Because it would introduce the possibility of signaling behavior for both the supplier and the reseller, this may alter the dynamics, which is a worthy subject for future research.

Finally, our model assumes that the supplier is limited to a linear wholesale price. Because linear wholesale prices are common in practice and are standard in the literature, it is useful to focus on them initially. However, it is also of interest to understand the implications of encroachment when a supplier can use a more sophisticated pricing mechanism. Under a nonlinear pricing policy, the issues shift from signalling to screening. The analysis and insights are fundamentally different, as revealed in Li et al. (2013).

Acknowledgments

The authors are grateful to the department editor, the associate editor, and the referees for their thoughtful comments and suggestions that improved this paper.

References

Anand KS, Goyal M (2009) Strategic information management under leakage in a supply chain. *Management Sci.* 55(3):438–452.

Arya A, Mittendorf B, Sappington DEM (2007) The bright side of supplier encroachment. *Marketing Sci.* 26(5):651–659.

Cachon GP (2003) Supply chain coordination with contracts. Graves G, de Kok T, eds. *Supply Chain Management: Design, Coordination and Operation*, Handbooks in Operations Research and Management Science, Vol. 11 (North-Holland, Amsterdam), 229–340.

Cachon GP, Lariviere MA (2001) Contracting to assure supply: How to share demand forecasts in a supply chain. *Management Sci.* 47(5):629–646.

Cattani K, Gilland W, Heese HS, Swaminathan J (2006) Boiling frogs: Pricing strategies for a manufacturer adding a direct channel that competes with the traditional channel. *Production Oper. Management* 15(1):40–56.

Chiang WK, Chhajed D, Hess JD (2003) Direct marketing, indirect profits: A strategic analysis of dual-channel supply-chain design. *Management Sci.* 49(1):1–20.

Cho IK, Kreps DM (1987) Signaling games and stable equilibria. *Quart. J. Econom.* 102(2):179–221.

Fein AJ, Anderson E (1997) Patterns of credible commitments: Territory and brand selectivity in industrial distribution channels. *J. Marketing* 61(2):19–34.

Frazier GL, Lassar WM (1996) Determinants of distribution intensity. *J. Marketing* 60(4):39–51.

Ha AY, Tong S (2008) Contracting and information sharing under supply chain competition. *Management Sci.* 54(4):701–715.

Ha AY, Tong S, Zhang H (2011) Sharing demand information in competing supply chains with production diseconomies. *Management Sci.* 57(3):566–581.

Jiang B, Jerath K, Srinivasan K (2011) Firm strategies in the "mid tail" of platform-based retailing. *Marketing Sci.* 30(5):757–775.

Kong G, Rajagopalan S, Zhang H (2013) Revenue sharing and information leakage in a supply chain. *Management Sci.* 59(3): 556–572.

Lariviere MA, Porteus EL (2001) Selling to the newsvendor: An analysis of price-only contracts. *Manufacturing Service Oper. Management* 3(4):293–305.

Li L (2002) Information sharing in a supply chain with horizontal competition. *Management Sci.* 48(9):1196–1212.

Li L, Zhang H (2002) Supply chain information sharing in a competitive environment. Song JS, Yao DD, eds. *Supply Chain Structures: Coordination, Information and Optimization* (Kluwer Academic Publishers, Norwell, MA), 161–201.

Li Z, Gilbert S, Lai G (2013) Supplier encroachment as an enhancement or a hindrance to nonlinear pricing. Working paper, University of Texas at Austin, Austin.

McGuire TW, Staelin R (1983) An industry equilibrium analysis of downstream vertical integration. *Marketing Sci.* 2(2):161–191.

Nair G, Pleasance D (2005) Mitigating channel conflict. *McKinsey Quart.* 3:16–17.

Taylor TA, Xiao W (2010) Does a manufacturer benefit from selling to a better-forecasting retailer? *Management Sci.* 56(9): 1584–1598.

Tsay AA, Agrawal N (2004) Channel conflict and coordination in the e-commerce age. *Production Oper. Management* 13(1):93–110.

Zhang H (2002) Vertical information exchange in a supply chain with duopoly retailers. *Production Oper. Management* 11(4):531–546.