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Information Disclosure Policy and Its Implications: Ratcheting in Supply Chains

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Abstract

Fear of escalating input prices in response to retail success is a commonly discussed phenomenon affecting supply chains. Such a ratchet effect arises when a retailer feels compelled to modify its investments to better serve the end customers in order to hide positive prospects and restrain future wholesale price hikes. In a two-period model of supply chain interactions, the authors demonstrate that such an endogenous ratchet effect can have multifaceted reverberations. A retailer fearing price hikes may be tempted to curtail near-term profits to ensure favorable long-term pricing. In response, the supplier can use deep discounts in its initial wholesale prices to convince the retailer to focus on its short-term profits rather than long-term pricing concerns. These deep discounts not only encourage mutually beneficial investments but also alleviate double marginalization inefficiencies along the supply chain. In light of these results, the authors show that a mandatory information disclosure policy to reduce the ratchet effect decreases total channel efficiency compared with no information disclosure, precisely because mandatory disclosure interrupts the healthy tension among supply chain partners. Thus, the model presents a scenario in which ratcheting concerns can create a degree of self-enforcing cooperation that results in socially beneficial responses in supply chains.

Keywords

ratcheting, information disclosure, supply chains, pricing

Supply chains exhibit a curious mixture of collaboration and self-interest, in that firms work toward a common goal but also seek to shield themselves from one another's exploitation. Notably, retailers are worried that suppliers may take advantage of information they learn about their affiliated retailers' business. A commonly discussed example involves the automobile industry, in which dealers demonstrate a reluctance to share detailed demand projections with manufacturers, fearing that such information would be used to squeeze margins rather than to coordinate behavior. These themes repeat across many industries, including appliances, clothing, electronics, and medicine (Narayanan and Raman 2004). The fundamental concern that can dissuade transparency is that manufacturers cannot resist the temptation to use favorable profitability news to squeeze retailer margins in hopes of extracting their "fair share" by raising input prices, knowing that their buyers' willingness to pay is higher. Theoretical work has also examined these information sharing issues in depth, and it is now well recognized that concerns about self-interested manufacturer reactions may keep retailers from fully sharing information at their disposal (e.g., Guo and Iyer 2010; He, Marklund, and Vossen 2008; Li 2002).

In this article, we model such concerns in the context of the inferences manufacturers make from publicly known profitability information. In this case, a retailer may take action out of fear of a "ratchet effect." In other words, to reduce opportunistic response from the manufacturer, the retailer may take real action to conceal future prospects conveyed by high accounting profits. This is much more than a theoretical possibility: broad-based empirical evidence has demonstrated that positive earnings news for retailers is viewed as a sign their manufacturers will extract future profits from the relationship (e.g., Pandit, Wasley, and Zach 2011). Our results demonstrate that retailers may take profit-reducing actions solely to avoid a ratcheting of future supplier prices. Suppliers, in turn, respond not in a retaliatory way but instead by offering initial price concessions to encourage more information transparency. In other words, the "problem" of ratcheting is one that ultimately boosts efficiency and cooperation among supply chain partners. This, in turn, has implications for mandatory disclosure regulations.

To elaborate, our analysis makes use of a stylized model with a two-period interaction between a privately informed retailer and its manufacturer. The retailer's private information is indicative of both underlying profitability and the associated

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efficacy of additional investment by the retailer (e.g., various sales promotions, in-store demonstrations). After one period of interaction, the retailer's overall profit information is revealed, and the manufacturer modifies its prevailing input price on the basis of that public information. Opportunistic behavior by the manufacturer is evident: very high earnings reveal strong product demand to the manufacturer who, in turn, finds it optimal to raise its wholesale price as a means of extracting a portion of the boosted demand.

We demonstrate that the retailer, cognizant of the risk of this ratchet effect, may seek to sidestep otherwise profitable investments. In effect, limiting investments mutes initial successes and thereby serves a "signal jamming" role.[1] This notion that a firm may adjust its investment behavior to alter others' inferences is more than a theoretical possibility; in practical terms, it is consistent with the broader view that firms often engage in "real" earnings management to influence perceptions and that this is an important consideration when accounting regulations dictate that information available to outsiders be expanded to include underlying details. For example, the Statement of Financial Accounting Standards No. 131 (a set of regulatory reporting requirements) mandates public disclosure of firms' segment profitability, and the disclosure naturally reveals a retailer's market information to a manufacturer.[2] The benefits and costs of these mandatory reporting requirements are controversial. In particular, the real costs of mandatory reporting have recently received attention from both researchers and practitioners (Goldstein and Yang 2017; Leuz and Wysocki 2016). One of the real costs is that investors' efforts to acquire information are demotivated, and therefore a firm's investment decisions may become inefficient (Jayaraman and Wu 2019). Moreover, many firms that have objected to expanded requirements to publicly disclose segment profitability cite concerns that outside parties would use the information opportunistically, claiming that disclosing parties would not sit idly by but rather change their way of business to avoid such consequences (Arya, Frimor, and Mittendorf 2010; Botosan and Stanford 2008; Ettredge, Kwon, and Smith 2002; Street, Nichols, and Gray 2000).

The conventional view of such signal-jamming efforts is that they come with harmful real effects, as this response to the threat of ratcheting can collectively undercut supply chain efficiency. Our setting is consistent with this view in that the retailer's incentive to bypass investment undermines supply chain profitability, all else being equal. However, we also demonstrate that all else is not equal. To elaborate, we show that a manufacturer may opt to dissuade signal-jamming underinvestment by lowering its initial wholesale price, in effect creating a retailer trade-off between current profitability (via boosted investments) and future profitability (via ensuing boosts in wholesale prices). The end result is that the retailer's concern about the manufacturer's opportunistic behavior may actually lead to lower wholesale prices than would arise otherwise. Furthermore, it is not just the existence of ratcheting in equilibrium but also the mere threat of ratcheting that proves critical in determining how inferences from profit disclosures affect supply chain behaviors.

In light of this, we examine a common regulatory proposal to address ratcheting: mandatory disclosure of the underlying demand information rather than just the accounting profit. We explicitly compare the total channel efficiency both with and without mandatory disclosures. One may expect that mandatory disclosure enhances supply chain efficiency by reducing the retailer's incentive to signal jam, but our results demonstrate that mandatory disclosure can ultimately lead to lower channel efficiency compared with the case of no disclosure. Rather than forcing a retailer to disclose such information, permitting a retailer to withhold it and making the retailer disclose only overall profit may increase the supply chain efficiency because a manufacturer will likely provide a wholesale price discount to elicit the retailer's true underlying market information. This reduces double marginalization and thereby enhances the efficiency of the total supply chain. Perhaps more surprisingly, we even find that no disclosure can improve the total channel efficiency above and beyond the level that complete precommitment to wholesale pricing can achieve. The retailer's temptation to reduce investment gives it a strategic weapon in its interaction with the manufacturer without commitment power, and in turn, this weapon convinces the manufacturer to cut its chosen wholesale price as a means of disarming the retailer. The lower wholesale price reduces double marginalization and, thereby, increases the total supply chain efficiency and achieves the Pareto efficiency gain.

To this end, our model not only presents a scenario in which ratcheting concerns are endogenous but also one in which it can be socially optimal to permit firms to withhold forward-looking information and only disclose realized profits. Though accounting reports based on generally accepted accounting principles (GAAP) are often criticized for providing only aggregate and backward-looking information when decision makers may find forward-looking forecasts more relevant, our results suggest this may be a feature and not a bug of the current standards.

Literature Review

This article lies at the intersection of research examining information sharing in supply chains and research examining incentives to alter behavior so as to limit third-party inference and ratcheting behavior in other contexts. On the first front, many articles mainly focus on the effect of information sharing on supply chain efficiency (Cachon and Fisher 2000; Lee, So, and Tang 2000). Such shared information can help manufacturers achieve operational efficiency through improved inventory management (Cachon and Fisher 2000) or order logistics in procurement (Lee, So, and Tang 2000). Despite these potential benefits from information sharing, the existing literature also points out that strategic retailer behavior may prevent it from

[1] Here, we focus on a particular response to the ratchet effect, which is manifested as jamming market demand information by forgoing a profitable investment opportunity. This is known as "signal jamming."

[2] There are other important financial reporting requirements that stipulate the mandatory disclosure of components of a firm's private information, such as Statement of Financial Accounting Standards No. 47 and Statement of Financial Accounting Standards No. 144.

fully sharing its proprietary information with other channel members (Guo 2009; Guo and Iyer 2010; He, Marklund, and Vossen 2008; Li 2002; Mittendorf, Shin, and Yoon 2013). Sharing forward-looking demand information, for example, may put a retailer at a disadvantage by allowing the manufacturer to tailor its wholesale price to squeeze retail margins by adjusting to the particulars of the market demand situation (Arya and Mittendorf 2013; Narayanan and Raman 2004).

The divergent preference for information sharing between the manufacturer and the retailer is not unique to ratcheting. Jiang et al. (2016) examine a setting in which a manufacturer owns better information than a retailer regarding market demand, whereby a manufacturer decides whether to share information with a retailer by considering the impact of the information on the retailer's pricing in the final market. The authors find that when the manufacturer and the retailer are risk neutral, the retailer prefers no information sharing, whereas the manufacturer prefers information sharing. The key difference between their work and ours is that, in our setting, the retailer possesses better information than the manufacturer. Also, this article focuses on a dynamic game showing a manufacturer's opportunistic choices of wholesale prices over time and a retailer's signal-jamming activity, whereas Jiang et al. (2016) consider only a single period. Finally, we show that the manufacturer's dynamic pricing induces a retailer to reveal truthful information by mitigating the double marginalization problem.

Recently, researchers have examined how such information sharing incentives can be distorted in various market conditions such as in the presence of horizontal competition (Li 2002), uncertainty of information acquisition (Guo 2009), supplier information acquisition (Guo and Iyer 2010), or demand-enhancing investment from the manufacturer (Mittendorf, Shin, and Yoon 2013). In various scenarios, all these articles focused on the issue of information-induced distortions in supply chains. Similar incentives are at play in our work; however, the information revelation does not arise through direct disclosure but rather through manufacturer inference from (observable) profit reports. Not having the flexibility to withhold such information from the manufacturer, the retailer is instead forced to alter its behavior so as to affect the manufacturer's learning or inferences about market information. It is this effect that provides a connection to the wider literature on signal jamming.

Starting with Holmstrom (1999), Fudenberg and Tirole (1986), and Stein (1989), research on signal jamming has demonstrated individuals' and firms' incentives to take action with the sole intent of influencing the inferences others make from observed outcomes. For example, several articles in marketing study signal jamming in the context of advertising communication (Grunewald and Krëel 2017; Mayzlin and Shin 2011; Shapiro 2006; Shin 2005; Shin and Yu 2021). Also, such signaling effects have been shown in supply chains in the context of conveying information to suppliers through observed inventory levels (Zhang, Nagarajan, and Sosic 2010). In an empirical setting closely related to our study, Raman and Shahrur (2008) find that customers and suppliers manage earnings to influence the other party's inference about their financial status and thereby to induce more relationship-specific investments in supply chains. These results suggest another venue for future research in which customers and suppliers may manipulate even real activities, as shown in Roychowdhury (2006), to motivate more investments. Consistent with these notions permeating extant literature, our article shows that a retailer can manipulate a real activity (investment decision) to affect a manufacturer's inference about market demand to subsequently obtain a favorable wholesale price. That is, herein, we demonstrate that profit disclosures can also have an information-signaling role when supply chain firms engage in dynamic relationships and that this signaling role can alter retailer investment in demand-enhancing activities such as promotion, in-store demonstrations, and advertising.

In particular, the retailer's signal-jamming activity in our setting is rooted in the manufacturer's opportunistic behaviors, which result in a higher wholesale price in the next period. In this sense, our model is also closely aligned with research examining concerns of ratcheting that can arise in collaborative interactions, be they supply chains, joint ventures, or employment relationships (e.g., Bouwens and Kroos 2011; Freixas, Guesnerie, and Tirole 1985; Misra and Nair 2011; Weitzman 1980). Strategic behaviors based on revealed information typically aim to extract higher rent from the other party, but they often cause unintended strategic responses in the dynamic relationship.[3] For example, if agents anticipate that high performance in the current period will increase both the principal's expectation and future target, they have less incentive to exert high effort in the current period (Weitzman 1980). This strategic response to the ratchet effect, in which an agent modifies their actions in the current period to alter incentives of other agents in future periods, is well established in several areas of marketing and economics such as workforce management (Bouwens and Kroos 2011; Misra and Nair 2011; Weitzman 1980) and career concerns in organizations (Meyer and Vickers 1997; Ridlon and Shin 2013).

As in the previous literature, the present study also examines the ratcheting issue but with a different implication. The setting in this article focuses on the ratcheting behavior in a supply chain, and it shows that the ratcheting problem can actually prove helpful in strained supply chain relationships. Ratcheting helps enhance supply chain efficiency by compelling a manufacturer to take action to elicit market information from a retailer worried about the other party's opportunistic behaviors. In this case, the tool at the manufacturer's disposal—an initial wholesale price discount—is one that alleviates supply chain frictions. Importantly, we demonstrate that in the context of supply chain ratcheting, manufacturers themselves can take action to preempt a retailer's defenses against opportunistic behaviors. We also show that such manufacturer responses to the threat of ratcheting can actually lead to signal jamming concerns being a productive force that

[3] Even in the firm–customer relationship, firms can use revealed information from the customer's past purchases for price discrimination (Villas-Boas 2004, Shin and Sudhir 2010).

improves the efficiency of the supply chain, rather than being a detriment to it as conventional wisdom suggests.

Model Setup

We consider a two-period model between a manufacturer (she) and a retailer (he) in a supply chain. The market demand in period t is captured by the following linear demand function, which is in line with previous research (Arya, Mittendorf, and Sappington 2007; Guo 2009; Li 2002; Li, Gilbert, and Lai 2014; Mittendorf, Shin, and Yoon 2013)[4]:

$$\begin{aligned} D_t &= a + e_t \cdot \theta - p_t \\ &= q_t - p_t, \end{aligned} \tag{1}$$

where $a > 0$ is a basic market demand, p_t is the (observable) chosen retail price in period t, $q_t = a + e_t \cdot \theta$ is the realized market size, and $e_t \in \{0, 1\}$ is the retailer's marketing effort or investment that can enhance market demand, such as promotions, in-store service, or advertising (e.g., Mittendorf, Shin, and Yoon 2013; Xia and Gilbert 2007). Therefore, the total demand is endogenous and determined by the retailer's demand-enhancing effort, which itself is unobservable to the manufacturer. This reflects the practical reality that retail prices are observable and accounting reports reveal overall profitability information such as sales and revenues (D_t) but, at the same time, it is hard to observe the counterfactual of potential demand and/or the retailer's underlying marketing efforts such as luring customers to stores with various sales efforts that ended up bolstering those overall results. That is, the model reflects current GAAP that entail disclosure of top-line financial performance (e.g., profits and revenue) but not disaggregated forward-looking information that makes up these performance figures (e.g., investment efforts or forecasts in particular markets).

The market potential θ is either high or low, $\theta = \{\theta_L, \theta_H\}$, where $\theta_H = d > \theta_L = 0$ without loss of generality.[5] The size of d, $d \in [0, a]$, is known to both the retailer and manufacturer. We assume that only the retailer learns the true state of market potential θ (i.e., whether it is a high-potential or low-potential market) because of his proximity to the final consumers and his operational experience in that market. For simplicity, we presume the market potential possibilities are equally likely ex ante, that is, $\Pr(\theta = \theta_H) = \Pr(\theta = \theta_L) = 1/2$. After the manufacturer observes the realized retailer profitability (i.e., demand, D_1) in Period 1, she updates her belief about the market potential in Period 2. Here, the manufacturer's posterior belief is denoted by $\tilde{\mu}(D_1)$.[6]

Table 1. Market Poetential and Retailer's Effort.

		Effort	
		High (e = 1)	**Low (e = 0)**
Market Potential (θ)	High (θ_H)	$q_t = a + d$	$q_t = a$
	Low (θ_L)	$q_t = a$	$q_t = a$

Also, the retailer incurs a fixed cost $c \geq 0$ for engaging in demand-enhancing activities: $C(e_t = 1) = c$ and $C(e_t = 0) = 0$. We assume that $c \leq ad/4$ to ensure that investment under high market conditions is preferred by the retailer absent information effects (otherwise, there is no investment irrespective of market condition θ).

The retailer's investment strategy is defined as follows: for a given θ, he chooses an effort level, $e_t = 1$ or $e_t = 0$. When the market potential is high ($\theta = \theta_H$), the retailer can enhance the demand by expanding his promotional effort ($e_t = 1$). At the same time, a manufacturer's strategy is to charge a periodic wholesale price, $w_t \geq 0$, to maximize her profit for a given market demand D_t. Table 1 summarizes the retailer's strategy based on the realized retail demand.[7]

The profit functions of two parties are as follows:

$$\begin{aligned} \Pi^M &= \sum_t w_t D_t; \\ \Pi^R &= \sum_t (p_t - w_t) D_t - c \cdot e_t. \end{aligned} \tag{2}$$

Both the retailer and manufacturer are strategic and forward-looking, and thus they maximize their expected total profit over two periods. The model examines the two-period repeated game with demand uncertainty, in which market potential is unknown to the manufacturer a priori.

The timing of the game is as follows. First, at $t = 0$ before the game starts, a retailer learns information about the market potential (θ). Second, at $t = 1$, a manufacturer first sets a wholesale price (w_1) based on her belief about the market potential. Then, the retailer decides how much effort to put in (e_1) to enhance

[4] One can consider alternative specifications such as $D_t = a + \theta + \lambda e_t \cdot \theta - p_t$, where θ not only interacts with the retailer effort but also affects demand directly. Even in this demand specification, the primary premise of the setting remains as long as the manufacturer cannot infer the market condition (θ) perfectly due to the unobservability of the retailer's efforts. Our main results do not depend on a particular demand specification—the key is the endogenous market demand and the unobservability of the retailer's effort.

[5] The current $\theta_L = 0$ assumption helps us to understand the main forces behind the results and intuition with the least complexity. Nevertheless, we can show that our main results still hold when $\theta_L > 0$, although it imposes significant computational burden without adding new insight.

[6] More precisely, the manufacturer can observe the retail price, p_1, and the market demand, D_1. Thus, she can perfectly infer the realized market size, $q_1 = D_1 - p_1$. Therefore, the manufacturer's information set (Ω) includes the observation of price (p_1) and quantity or demand (D_1). The manufacturer's updated posterior belief should be $\tilde{\mu}(\Omega) = \Pr(\theta = \theta_H | p_1, D_1)$. We denote this notion as $\tilde{\mu}(D_1)$ subsequently for simplicity.

[7] We assume that c and d are known because they are not stochastic. The uncertain term, θ, is presumed to be unobservable. This uncertain term is private information because only retailers have direct access to end-consumer data, for example, by using the data collection technology based on scanner system and online data processing in channels (Fisher et al. 1994). This distinction (nonstochastic terms and underlying distributions are common knowledge but realizations of stochastic demand are privately observed) is largely intended to most simply capture the notion that a retailer may have more knowledge about consumers than its supplier and that realized profits may reveal some of that knowledge.

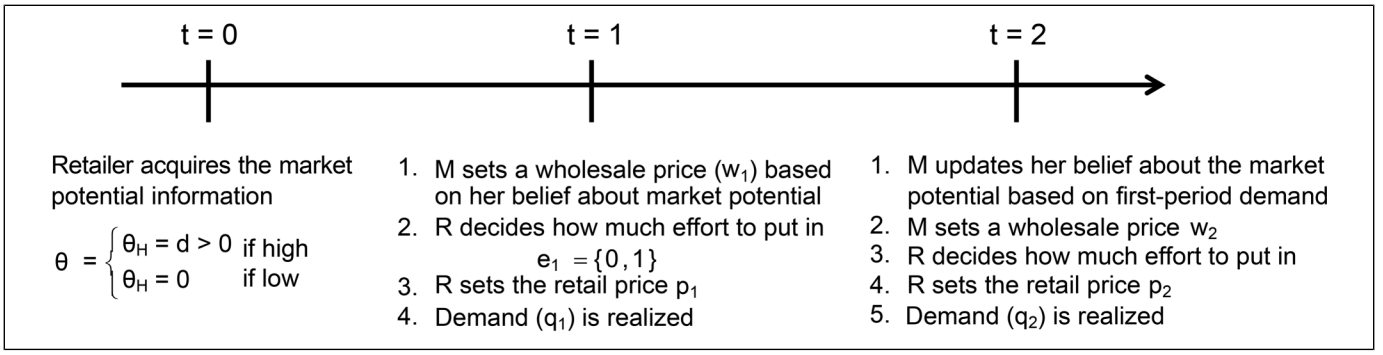

Figure 1. Timing of the game.

the market demand for that period. Note that the retailer can do so by exerting his promotional effort ($e_1 = 1$). Also, the retailer decides how much to charge in the market (p_1), after which the ensuing demand and profits are realized for Period 1. Next, after the first-period demand is realized and observed, the manufacturer updates her beliefs about the market potential and sets her Period 2 wholesale price (w_2) while the retailer determines how much effort to put in (e_2) and the prevailing retail price (p_2) after observing the wholesale price.

Regarding the information structure in the game, at the beginning of Period 1, only the retailer knows about the market potential (θ), while this information is unknown to the manufacturer. The manufacturer has the prior belief, $\Pr(\theta = \theta_H) = \Pr(\theta = \theta_L) = 1/2$. At the start of Period 2, the manufacturer updates her belief on the basis of the realized demand in Period 1 and her presumption of the retailer's investment strategy, denoted $\tilde{\mu}(D_1) = \Pr(\theta = \theta_H | D_1)$, which we abbreviate to $\tilde{\mu}$. The sequence of events is summarized in Figure 1. Using this setup, we identify the perfect Bayesian equilibria of the game and their implications.

Benchmark I: Full Commitment

We first examine the benchmark in which the manufacturer commits in advance to her two-period pricing structure, thereby ensuring that inference from first-period profitability has no impact on subsequent interactions.[8] This commitment case serves as a useful benchmark to assess how dynamic pricing under ratcheting concerns affects parties in the supply chain as well as overall supply channel efficiency and social welfare. To derive the equilibrium in this case, we work backward in the game, starting with the retailer's pricing (and investment) decision in Period 2. Given this presumption and the fact that the maximum wholesale price a manufacturer would rationally charge in either period is $(a + d)/2$, the retailer's terminal investment decision is $e_2 = 1$ ($e_2 = 0$) if $\theta = \theta_H$ (if $\theta = \theta_L$).

The retailer chooses his price in Period 2 then by solving

$$\underset{p_2}{\text{Max}}\, \Pi^R \equiv (p_1 - w_1)D_1 - c \cdot e_1 + (p_2 - w_2)(q_2 - p_2) - c \cdot e_2, \tag{3}$$

which yields $p_2 = \frac{q_2 + w_2}{2}$, where $q_2 = a + d$ when $\theta = \theta_H$ (with price denoted p_{2H}) and $q_2 = a$ when $\theta = \theta_L$ (with price denoted p_{2L}).

Because w_1 and w_2 are fixed under commitment when the retailer chooses his first-period investment and price, it is straightforward to confirm that the retailer's Period 1 investment and pricing choices precisely mirror those in Period 2, that is, when $\theta = \theta_H$, $e_1 = 1$ and $p_1 = (a + d + w_1)/2$, and when $\theta = \theta_L$, $e_1 = 0$ and $p_1 = (a + w_1)/2$. Taking this induced retailer behavior into account, the manufacturer sets wholesale prices to maximize her total expected profit at the outset of the game:

$$\begin{aligned}\underset{w_1, w_2}{\text{Max}}\, \mathbb{E}_\theta[\Pi^M] = \frac{1}{2}\Bigg[& w_1\left(a + d - \frac{a + d + w_1}{2}\right) \\ & + w_2\left(a + d - \frac{a + d + w_2}{2}\right)\Bigg] \\ & + \frac{1}{2}\left[w_1\left(a - \frac{a + w_1}{2}\right) + w_2\left(a - \frac{a + w_2}{2}\right)\right].\end{aligned}$$

The first-order condition reveals the manufacturer's benchmark wholesale prices: $w_1 = w_2 = \overline{w} = (\frac{a+d/2}{2})$. We summarize the benchmark findings in the following lemma. In the lemma, the superscript C denotes the commitment case.

Lemma 1. When the manufacturer precommits to two-period wholesale pricing (where "C" denotes "commitment"):

1. Wholesale prices, retailer investments, and retail prices are: $w_t^C = \overline{w} = (\frac{a+d/2}{2})$; $e_{tH}^C = 1$, $e_{tL}^C = 0$; $p_{tH}^C = (6a + 5d)/8$, $p_{tL}^C = (6a + d)/8$, for $t = 1, 2$.
2. Expected profits for manufacturer and retailer are: $\mathbb{E}_\theta[\Pi^{MC}] = (2a + d)^2/16$ and $\mathbb{E}_\theta[\Pi^{RC}] = (4a^2 + 4ad + 5d^2)/32 - c$.

[8] The role of commitment is well documented in the literature (Hart and Tirole 1988; Stokey 1979; Villas-Boas 2004). In a durable good context, Stokey (1979) shows that when firms can commit to the time path of prices, the monopolist commits to having the same price in all periods, which ends up being the static monopoly price. Hart and Tirole (1988) show that the same conclusion applies when the firm can engage in behavior-based price discrimination: The optimal policy in this context is to forgo the ability to price discriminate and simply charge the static monopoly price in every period. Villas-Boas (2004) shows that the result also applies when there are overlapping generations of consumers.

This benchmark case offers some intuitive results. First and foremost, second-period wholesale price does not vary when first-period retailer demand is high—the benchmark is, by design, one without concerns of ratcheting. Second, the wholesale prices in each period reflect the manufacturer's ex ante assessment of expected retail demand. Equilibrium retail prices, in turn, reflect this. Even when demand turns out to be low, prices are higher when manufacturer ex ante expectations are higher because that is when wholesale prices are higher: p^C_{tH} and p^C_{tL} are each increasing in d. With this benchmark established, we now consider the outcome under the second benchmark of mandatory disclosure, wherein the manufacturer sets her prevailing price at the beginning of each period and there are no issues of the retailer signal jamming realized profits since the underlying demand information is publicly disclosed.

Benchmark II: Mandatory Disclosure

Here, we consider the equilibrium outcome under sequential strategic play with mandatory information disclosure of underlying demand information θ. In particular, when the retailer is compelled to directly disclose his private information about demand, the interactions in the two periods effectively separate, and although ratcheting of expectations arises, it is not driven by realized first-period profits but instead by the disclosed underlying demand information. Under high demand $\theta = \theta_H$, the disclosure requirement mitigates any retailer incentive to distort his investment decision in Period 1 because the released true demand information would allow the manufacturer to adjust a wholesale price in Period 2 regardless of the retailer's investment decision in Period 1. In this circumstance, the retailer makes an investment whenever a high demand is realized, knowing that there will be no reverberations from this choice in Period 2.

More precisely, working backwards in the game, first consider the retailer's pricing (and investment) decision in Period 2. The retailer's terminal investment decision is $e_2 = 1$ ($e_2 = 0$) if $\theta = \theta_H$ (if $\theta = \theta_L$). Under mandatory information disclosure, the market information will be revealed at the outset of Period 2, and thus, the manufacturer would choose the optimal wholesale price for the given market potential θ. That is, the manufacturer's second-period wholesale pricing decision reflects the true demand in this context because she does not have an ability to credibly commit otherwise. Thus, $w_2(\theta = \theta_H) = w^M_{2H} = \text{argmax}_{w_2}(a + d - p_{2H})w_2 = (a + d)/2$ and $w_2(\theta = \theta_L) = w^M_{2L} = \text{argmax}_{w_2}(a - p_{2L})w_2 = a/2$, where the superscript M denotes mandatory information disclosure. In this case, the retailer's preferred retail prices in Period 1 if $\theta = \theta_H$ and $\theta = \theta_L$ solve:

$$\underset{p_1}{\text{Max}}\, \Pi^R_H(\theta_H) \equiv (p_1 - w_1)(a + d - p_1) - c + (p_{2H} - w^M_{2H})(a + d - p_{2H}) - c, \quad (4)$$

$$\underset{p_1}{\text{Max}}\, \Pi^R_L(\theta_L) \equiv (p_1 - w_1)(a - p_1) + (p_{2L} - w^M_{2L})(a - p_{2L}). \quad (5)$$

The first-order conditions of Equations 4 and 5 yield $p^M_{1H}(w_1) = (a + d + w_1)/2$ if $\theta = \theta_H$ and $p^M_{1L}(w_1) = (a + w_1)/2$ if $\theta = \theta_L$. Note that in this scenario, the price cannot serve as a signal because the retailer is aware that private market potential information will be revealed regardless of the chosen retail price. The retailer simply chooses the investment and price that maximize the first-period profits. In the first period, the manufacturer sets the wholesale price w_1 to maximize her total expected profit as the following:

$$\underset{w_1}{\text{Max}}\, \mathbb{E}_\theta[\Pi^M] = \frac{1}{2}\left[w_1\left(a + d - \frac{a + d + w_1}{2}\right) + w^M_{2H}\left(a + d - \frac{a + d + w^M_{2H}}{2}\right)\right] + \frac{1}{2}\left[w_1\left(a - \frac{a + w_1}{2}\right) + w^M_{2L}\left(a - \frac{a + w^M_{2L}}{2}\right)\right]. \quad (6)$$

With the looming disclosure, the equilibrium wholesale price emanating from Equation 6 is familiar: $w^M_1 = \overline{w} = (\frac{a+d/2}{2})$. The equilibrium outcomes under the mandatory information disclosure are summarized in Lemma 2.

Lemma 2. Under mandatory information disclosure (where "M" denotes "mandatory information disclosure"):

1. Wholesale prices, retailer investments, and retail prices are $w^M_1 = \overline{w}$; $w^M_{2H} = (a + d)/2$, $w^M_{2L} = a/2$; $e^M_{tH} = 1$, $e^M_{tL} = 0$; $p^M_{1H} = (1/8)(6a + 5d)$, $p^M_{1L} = (1/8)(6a + d)$; and $p^M_{2H} = (3/4)(a + d)$, $p^M_{2L} = 3a/4$.
2. Expected profits for manufacturer and retailer are: $\mathbb{E}_\theta[\Pi^{MM}] = (8a^2 + 8ad + 3d^2)/32$ and $\mathbb{E}_\theta[\Pi^{RM}] = (8a^2 + 8ad + 7d^2)/64 - c$.

As seen in this lemma, regulation that forces the retailer to disclose true underlying demand information at the end of Period 1 dissuades any investment distortions to reduce inference from profit realizations. However, the revealed truthful information does allow the manufacturer to charge a wholesale price contingent on realized market demand.

Endogenous Ratcheting

We now address the equilibrium outcome when there is no disclosure of the underlying demand information, in which case the manufacturer must instead rely on inference from revealed retailer profit. Working backward in the game, consider the manufacturer's Period 2 opportunistic behavior based on the revealed demand information. Upon observing high demand or high retail profit (note that the high demand or profit can only arise when $\theta = \theta_H$ and $e_1 = 1$), the manufacturer knows with certainty that $\theta = \theta_H$. Therefore, the posterior belief $\tilde{\mu} = 1$, where we denote manufacturer belief that $\theta = \theta_H$ by $\tilde{\mu}$. The result is a high Period 2 wholesale price, just as with mandatory disclosure; that is, $w_2(\tilde{\mu} = 1) = w^E_{2H} = \arg\max_{w_2}(a + d - p_{2H})w_2 = (a + d)/2 = w^M_{2H}$.

Upon observing low demand, the manufacturer cannot directly infer θ. Lower demand could either indicate $\theta = \theta_L$

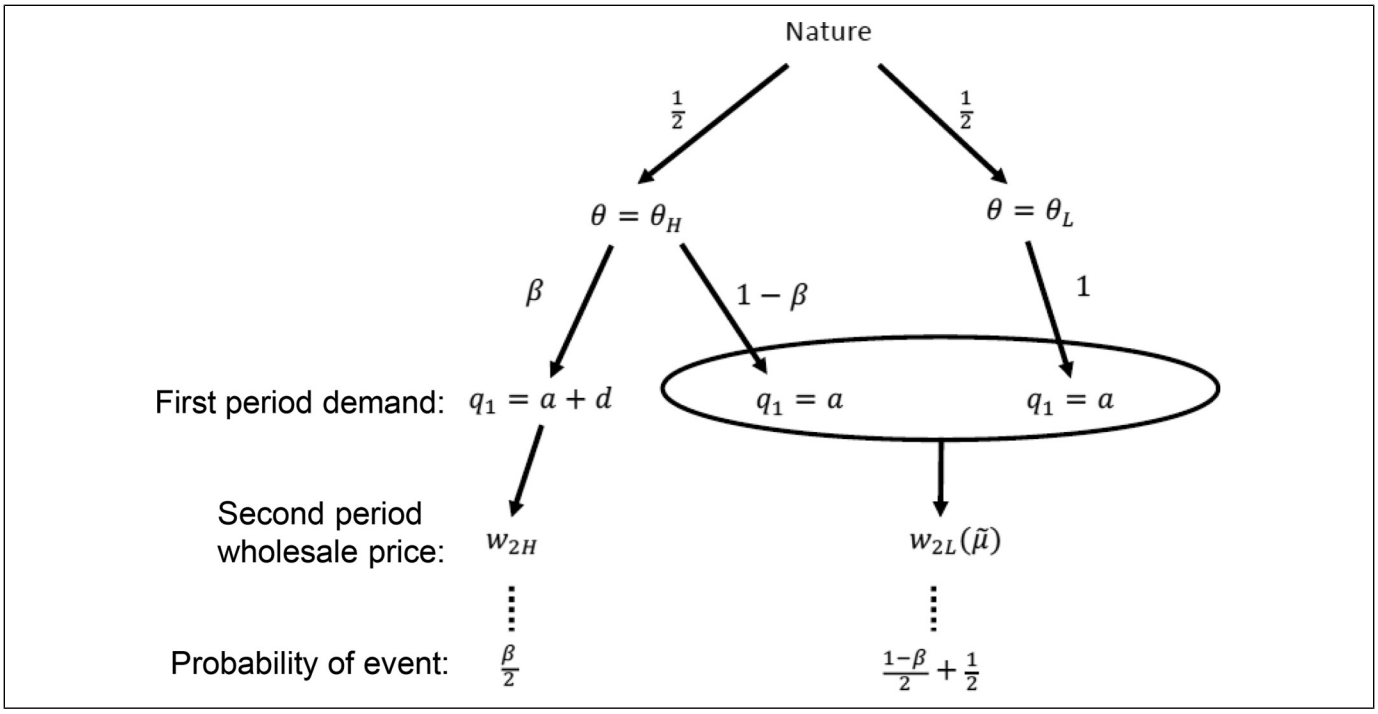

Figure 2. Game tree for mixed strategy.

or $\theta = \theta_H$ with $e_1 = 0$. As a result, the manufacturer imperfectly updates her prior beliefs about the market condition $\theta \in \{\theta_L, \theta_H\}$. In this case, $\tilde{\mu}$ is assured to be no more than 1 / 2 (low realized profit cannot feasibly lead to a heightened belief about the demand environment). Given this belief, the manufacturer's Period 2 price given low realized profit is as follows:

$$\begin{aligned} w_{2L}^E &= w_{2L}(\tilde{\mu}) \\ &= \text{argmax}_{w_2} \tilde{\mu}(a + d - p_{2H})w_2 + (1 - \tilde{\mu})(a - p_{2L})w_2 \\ &= \frac{a + \tilde{\mu}d}{2}. \end{aligned} \tag{7}$$

Comparing w_{2H}^E and w_{2L}^E confirms that $w_{2H}^E > w_{2L}^E$ for all $\tilde{\mu} \leq 1/2$. In other words, high initial profits invariably ratchet expectations and thereby ratchet pricing. This endogenous ratcheting is, of course, anticipated by the retailer, who can then adjust initial investments to attempt to influence beliefs and pricing.

In particular, when the retailer observes $\theta = \theta_L$, the investment decision (and the ensuing pricing choice) is straightforward: because investment cannot alter demand, its only effect is to induce a cost. So, the investment decision is $e_1 = 0$ and the price is $p_1 = (a + w_1)/2$. In contrast, when market potential is high, the retailer is inclined to make an investment and choose $p_1 = (a + d + w_1)/2$, all else being equal. However, another option is to forgo the investment opportunity and set $p_1 = (a + w_1)/2$, thus concealing the favorable market condition (signal jamming) to avoid the manufacturer's strategic exploitation of that information to charge a high second-period wholesale price. Permitting the possibility of a mixed strategy, we denote the retailer's probability of choosing the investment and high profit option as β. In other words, β is the probability the retailer makes a (truth-telling) investment given the true state $\theta = \theta_H$. With a probability $1 - \beta$, the retailer makes no investment to conceal his market condition. Figure 2 shows the game structure with endogenous ratcheting.

For any given initial choice of w_1, a perfect Bayesian equilibrium outcome can then be defined as a β and $\tilde{\mu}$ such that (1) β is an optimal choice for the retailer given the ensuing prices that come from $\tilde{\mu}$, and (2) $\tilde{\mu}$ is a rational expectation given the retailer's strategy. That is, the posterior belief for the manufacturer is following the Bayes rule:

$$\tilde{\mu} = \frac{(1 - \beta)/2}{(1 - \beta)/2 + 1/2} = \frac{1 - \beta}{2 - \beta}. \tag{8}$$

Consider first the possibility of a fully separating equilibrium (i.e., $\beta = 1$). For this to be an equilibrium, it must be the case that even for $\tilde{\mu} = 0$ (i.e., the belief the manufacturer will hold if the retailer deviates by choosing $e_1 = 0$ when $\theta = \theta_H$), the retailer nonetheless prefers an investment in Period 1 to instead bypassing investment and mimicking $\theta = \theta_L$ to secure a lower Period 2 wholesale price. This is satisfied if

$$\begin{aligned} &\left(\frac{a + d + w_1}{2} - w_1\right)\left(a + d - \frac{a + d + w_1}{2}\right) - c \\ &\quad + \left(\frac{a + d + w_{2H}^E}{2} - w_{2H}^E\right)\left(a + d - \frac{a + d + w_{2H}^E}{2}\right) - c \\ &\geq \left(\frac{a + w_1}{2} - w_1\right)\left(a - \frac{a + w_1}{2}\right) \\ &\quad + \left(\frac{a + d + w_{2L}^E}{2} - w_{2L}^E\right)\left(a + d - \frac{a + d + w_{2L}^E}{2}\right) - c. \end{aligned} \tag{9}$$

Note from the condition in Equation 9 that the main consequences of investment are (1) incurring cost c, (2) boosting Period 1 demand/profit, and (3) inducing higher Period 2 wholesale price. Using the expressions for w_{2H}^E and w_{2L}^E with $\beta = 1$ in Equation 7 reveals that a separating equilibrium can arise when $w_1 \leq (1/8)[6a + d - (16c/d)] = w_1^s$. Intuitively, for low values of w_1, the possible Period 1 profit advantage from investing outweighs any Period 2 advantage from mimicking a low-potential state ($\theta = \theta_L$) and, thereby, encourages full revelation.

Now consider the other extreme: a fully pooling equilibrium. This is the case of $\beta = 0$, in which the retailer is inclined to forgo initial investment so as to not tip his hand to the manufacturer. For this to be an equilibrium, it must be the case that for $\tilde{\mu} = 1/2$ (i.e., the belief the manufacturer will hold from Equation 8 with $\beta = 0$), the retailer in a favorable environment prefers skipping an investment in Period 1 to secure the lower Period 2 wholesale price that reflects an averaging of types. This is satisfied if

$$\begin{aligned}&\left(\frac{a+w_1}{2}-w_1\right)\left(a-\frac{a+w_1}{2}\right)+\left(\frac{a+d+w_{2L}^E}{2}-w_{2L}^E\right)\\&\times\left(a+d-\frac{a+d+w_{2L}^E}{2}\right)-c\\&\geq\left(\frac{a+d+w_1}{2}-w_1\right)\left(a+d-\frac{a+d+w_1}{2}\right)-c\\&+\left(\frac{a+d+w_{2H}^E}{2}-w_{2H}^E\right)\left(a+d-\frac{a+d+w_{2H}^E}{2}\right)-c. \quad (10)\end{aligned}$$

Using the expressions for w_{2H}^E and w_{2L}^E with $\beta = 0$ in Equation 7 reveals that a pooling equilibrium can arise when $w_1 \geq \frac{1}{8}(7a + 11d/4 - 16c/d) = w_1^p$. Intuitively, for very high values of w_1, any temptation to deviate from the pooling equilibrium and invest in Period 1 demand is tempered since the profits from investment are limited because of the high wholesale price. Also, it is clear that $w_1^s < w_1^p$.

For intermediate values of $w_1 \in [w_1^s, w_1^p]$, then, no pure strategy equilibrium exists. Instead, the equilibrium entails a partially separating outcome where $\beta \in [0, 1]$. In particular, the semi-separating equilibrium is defined as the β value that solves the following indifference condition:

$$\begin{aligned}&\left(\frac{a+w_1}{2}-w_1\right)\left(a-\frac{a+w_1}{2}\right)\\&+\left(\frac{a+d+w_{2L}^E}{2}-w_{2L}^E\right)\left(a+d-\frac{a+d+w_{2L}^E}{2}\right)-c\\&=\left(\frac{a+d+w_1}{2}-w_1\right)\left(a+d-\frac{a+d+w_1}{2}\right)-c\\&+\left(\frac{a+d+w_{2H}^E}{2}-w_{2H}^E\right)\left(a+d-\frac{a+d+w_{2H}^E}{2}\right)-c. \quad (11)\end{aligned}$$

When the market potential is high ($\theta = \theta_H$), for the retailer to mix between exerting an effort ($e_1 = 1$) and no effort ($e_1 = 0$), it must be the case that the expected payoff from either case should be the same. This is the indifference condition for the existence of semi-separating equilibrium. Using $\tilde{\mu} = (1-\beta)/(2-\beta)$ in Equation 8 and solving Equation 11 reveals that the semi-separating equilibrium entails

$$\begin{aligned}\beta^* &= \frac{2a+3d-2\sqrt{a^2-16c+10ad+5d^2-8dw_1}}{a+d-\sqrt{a^2-16c+10ad+5d^2-8dw_1}}\\&= \frac{2a+3d-2\varphi(w_1)}{a+d-\varphi(w_1)}, \quad (12)\end{aligned}$$

where $\varphi(w_1) = \sqrt{a^2 - 16c + 10ad + 5d^2 - 8dw_1}$.

Note that at $w_1^s = (1/8)[6a + d - 16c/d]$, $\beta^*=1$ and at $w_1^p = (1/8)[7a + 11d/4 - 16c/d]$, $\beta^* = 0$. Furthermore, for interior values of $w_1 \in [w_1^s, w_1^p]$, β^* is decreasing in w_1: $(\partial\beta^*/\partial w_1) = -4d^2/[\varphi(w_1)(a + d - \varphi(w_1))] < 0$. Therefore, this equation confirms the existence of a semi-separating equilibrium for intermediate values of w_1. The following proposition uses these results to provide the conditions under which any of three types of equilibrium—fully separating, partially separating, or pooling—can arise as the unique outcome.

Proposition 1. For a given initial wholesale price, w_1, the equilibrium outcome of the retailer–manufacturer game is as follows:

1. For $w_1 \leq w_1^s = (1/8)[6a + d - 16c/d]$, the equilibrium entails full information revelation through the retailer's investment choice, that is, $\beta = 1$.
2. For $w_1^s < w_1 < w_1^p = (1/8)[7a + 11d/4 - 16c/d]$, the equilibrium entails signal jamming through the retailer's mixed-strategy investment choice; in particular, $\beta^* = (2a + 3d - 2\varphi(w_1))/(a + d - \varphi(w_1))$.
3. For $w_1 \geq w_1^p$, the equilibrium entails signal jamming whereby the retailer bypasses the initial investment, that is, $\beta = 0$.

Figure 3 provides a graphical depiction of the results in Proposition 1 and illustrates the three regions for the different types of equilibria.

In summary, the firm's early performance can have an information-signaling role within a supply chain, and the signaling role of the performance can alter the retailer's incentives to engage in profitable demand-enhancing investments. In effect, the retailer's decision to forgo investment can serve as a signal jam that hinders the manufacturer's ability to make inferences about market demand. These results demonstrate that the possibility of manufacturers ratcheting expectations (and, thus, wholesale prices) can lead the retailer to take real action to curb the potential consequences (as in the semi-separating and pooling equilibrium cases). We next consider the manufacturer's endogenous response in light of these incentives. Although intuition may suggest that the retailer has a harmful incentive to withhold demand information by forgoing his investment opportunity in the first period to avoid the manufacturer's strategic choice of wholesale prices in the second period, a savvy manufacturer may opt to stave off such behavior with a sufficiently low initial wholesale price.

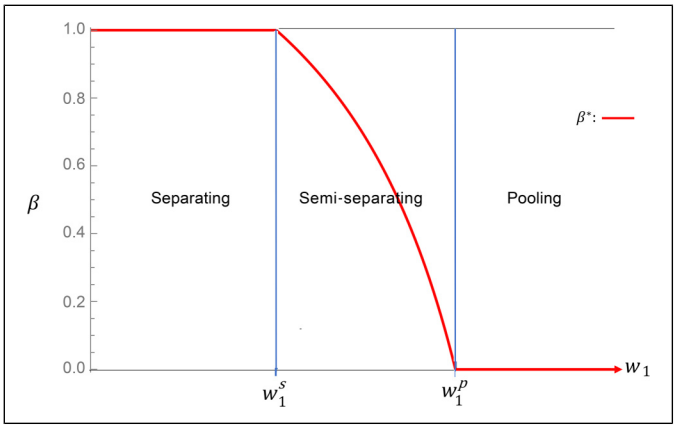

Figure 3. Equilibrium regions and investment.

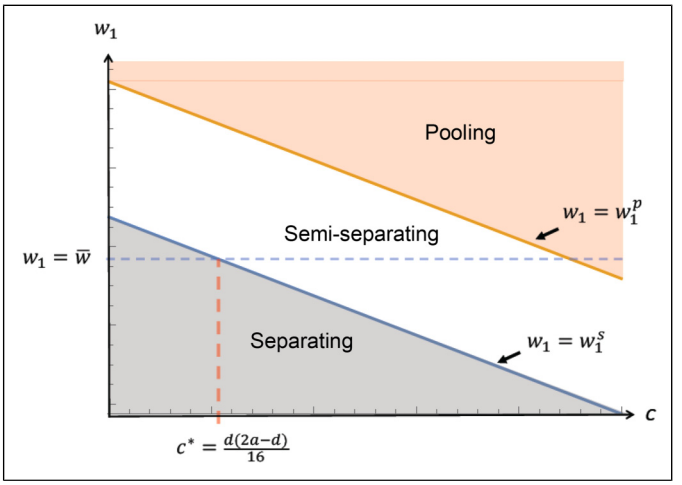

Figure 4. Equilibrium regions as a function of w_1 and c.

Dynamic Wholesale Pricing

Endogenous ratcheting suggests a key inefficiency that can arise from a manufacturer potentially learning underlying demand information indirectly from a retailer's realized profit rather than directly from mandatory disclosure: a retailer may choose to forgo profitable investment to signal jam the inference from accounting profit. To get a sense for how this can arise, consider the outcome if a naive manufacturer simply uses the initial wholesale price under the presumption of mandatory disclosure, where $w_1^M = \overline{w} = (\frac{a+d/2}{2})$.

Reviewing the results in Proposition 1, this wholesale price can conceivably induce a separating equilibrium, semi-separating equilibrium, or pooling equilibrium, depending on the value of c. For example, when $w_1 \leq w_1^s = (1/8)[6a + d - 16c/d]$, the full separating equilibrium is an equilibrium outcome. Given the wholesale price $w_1^M = \overline{w} = (2a+d)/4$, this condition translates into $w_1 = \overline{w} = (2a+d)/4 \leq w_1^s = (1/8)(6a + d - 16c/d) \Leftrightarrow \quad c \leq d(2a-d)/16 \equiv c^*$. Therefore, for $c \leq d(2a-d)/16$, it becomes that $\overline{w} \leq w_1^s$. Thus, the retailer benefit of investment is so compelling that he is willing to invest even though a hike in wholesale price will ensue. In contrast, if $c > d(2a-d)/16$, we have $\overline{w} > w_1^s$, and thus, the naive manufacturer will be disappointed to learn that her chosen wholesale price has induced costly signal jamming by the retailer (i.e., semi-separating or pooling depending on the value of c). This same consideration plays out for any other value of w_1 as well. Given a choice of w_1, low values of c cement full information revelation via the investment choice, whereas high values of c induce signal jamming by the retailer. This tradeoff is depicted graphically in Figure 4. The grey area under the line $w_1^s = \frac{1}{8}(6a + d - 16c/d)$ represents the parameter space for the separating equilibrium, and the red area above the line $w_1^p = (1/8)(7a + 11d/4 - 16c/d)$ represents the parameter space for pooling. Also, the white area between these two lines represents the area for semi-separating equilibrium.

The question that remains is under what conditions the manufacturer will choose a w_1 that induces full information revelation even if $\overline{w}$ does not do the trick. To elaborate, as noted previously, full information revelation and corresponding optimal wholesale price $w_1 = \overline{w}$ comes for "free" for low c values, that is, $c \leq d(2a-d)/16$. As can be seen in Figure 4, even for c values above $d(2a-d)/16$, the manufacturer can choose to move w_1 below $\overline{w}$ to ensure the separating equilibrium. The minimum deviation that ensures this is, in fact, $w_1 = w_1^s$. As it turns out, as long as c is not too large, such a reduction in w_1 proves optimal, as confirmed in the next proposition.

Proposition 2. The manufacturer optimally chooses an initial wholesale price to ensure voluntary information revelation (the separating equilibrium) if and only if $c \leq c^{**} \equiv d(2a-d)/16 + d^2(a+d)/[4(a+3d)]$. In this case, $w_1 = \overline{w}$ if $c \leq c^* \equiv d(2a-d)/16$, and $w_1 = w_1^s$ otherwise.

Proof. See the Appendix. □

The proposition shows that a manufacturer opts to dissuade a retailer's signal jamming by offering a sufficiently low first-period wholesale price as an enticement. This entails a lower wholesale price than the one under the mandatory disclosure benchmark when $c > d(2a-d)/16$. This circumstance reflects what we refer to as "dynamic pricing discounts," whereby manufacturers provide a lower initial wholesale price than benchmarks would prescribe to create an added incentive for first-period investment.

More precisely, using the wholesale prices in Proposition 2 in comparison to pricing under mandatory disclosure, we can derive that the dynamic wholesale price discount is as follows:

$$\triangle w = w_1^M - w_1^S = \frac{1}{8d}(16c + d^2 - 2ad). \tag{13}$$

Proposition 3. Consider $c \in [c^*, c^{**}]$ where $c^* \equiv d(2a-d)/16$ and $c^{**} \equiv d(2a-d)/16 + d^2(a+d)/[4(a+3d)]$. Then, the price discount ($\triangle w$) decreases in the size of base demand (a) and the size of market potential (d) but increases in the cost of investment (c): $(\partial \triangle w/\partial a) < 0$, $(\partial \triangle w/\partial d) < 0$, $(\partial \triangle w/\partial c) > 0$.

Proof. See the Appendix.

Intuitively, the proposition confirms that the price discount put in place to entice a separating equilibrium is one that encourages investment: The more intrinsically attractive investment becomes (higher a, higher d, or lower c), the smaller the discount a manufacturer needs to provide to get such voluntary compliance from the retailer.

The equilibrium outcomes under dynamic wholesale pricing discounts are summarized in Proposition 4:

Proposition 4. Consider $c \in [c^*, c^{**}]$. In this case, the equilibrium entails dynamic wholesale pricing discounts (where "D" denotes "dynamic pricing"). The equilibrium outcome is as follows:

1. Wholesale prices are: $w_1 = w_1^D = w_1^s$; $w_{2H}^D = (a + d) / 2$, $w_{2L}^D = a / 2$.
2. Retailer investments and retail prices are: $e_{tH}^D = 1$, $e_{tL}^D = 0$; $p_{1H}^D = (14ad + 9d^2 - 16c) / 16d$, $p_{2H}^D = 3(a + d)/4$; $p_{1L}^D = (14ad + d^2 - 16c) / 16d$, $p_{2L}^D = 3a / 4$, for $t = 1, 2$.
3. Expected profits for Manufacturer and Retailer are:

$$\mathbb{E}_\theta[\Pi^{MD}] = \frac{7a^2}{32} + \frac{ac}{2d} + \frac{9ad}{32} + \frac{11d^2}{128} - \frac{2c^2}{d^2} - \frac{c}{4}$$

$$\mathbb{E}_\theta[\Pi^{RD}] = \frac{5a^2}{64} - \frac{5c}{8} + \frac{c^2}{d^2} + \frac{ac}{4d} + \frac{7ad}{64} + \frac{33d^2}{256}.$$

Channel Efficiency

In this section, we show that when dynamic wholesale pricing discounts (endogenous manufacturer concessions) constitute the chosen equilibrium outcome, it can increase the channel efficiency above and beyond the levels of channel efficiency attainable from either benchmark case. Therefore, our results suggest that public policy should allow retailers to withhold their private demand information and parties should be permitted to adjust pricing over time to meet demand conditions, as the dynamic interactions surrounding the ratchet effect can actually work to enhance total supply channel efficiency.

Comparison: information disclosure versus no information disclosure. First, we compare the results of a dynamic wholesale pricing approach (in which there is no information disclosure) with the mandatory information disclosure case. Mandatory information disclosure represents the natural knee-jerk reaction to concerns of gaming information inference from accounting disclosures. As the next proposition confirms, the knee-jerk regulatory reaction fails to consider the positive endogenous strategic response to these concerns.

Proposition 5. For $c \in [c^*, c^{**}]$, a mandatory information disclosure policy decreases supply channel efficiency: $\mathbb{E}_\theta[\Pi^{MD}] + \mathbb{E}_\theta[\Pi^{RD}] \geq \mathbb{E}_\theta[\Pi^{MM}] + \mathbb{E}_\theta[\Pi^{RM}]$. Furthermore, a mandatory information disclosure increases (decreases) a manufacturer's (a retailer's) profit: $\mathbb{E}_\theta[\Pi^{MD}] \leq \mathbb{E}_\theta[\Pi^{MM}]$ ($\mathbb{E}_\theta[\Pi^{RD}] \geq \mathbb{E}_\theta[\Pi^{RM}]$).

Proof. See the Appendix.

The result suggests that the retailer's temptation to reduce investment gives him a strategic weapon in the interaction with the manufacturer, and this weapon, in turn, convinces the manufacturer to lower her chosen wholesale price as a means of disarming the retailer. Rather than the threat of ratcheting manifesting as costly signal jamming, it instead manifests as beneficial wholesale price cuts.

To elaborate, a natural reaction to concerns of costly signal jamming is to propose mandatory disclosure of the underlying information, which in this case is forward-looking demand information. Unlike the lay belief about the efficiency of such a policy, a regulation that mandates the disclosure of more information may alleviate information differences between supply chain members but not necessarily improve the underlying supply channel efficiency when we consider the firms' real decisions, such as those made about investment and pricing. Moreover, permitting a retailer to withhold market information and making him disclose only the realized market information may increase supply chain efficiency because a manufacturer will more actively provide a concession (e.g., price discount) to elicit the market information on her own, thereby increasing the supply chain efficiency.

Comparison: dynamic wholesale pricing versus commitment. Next, we evaluate the supply chain efficiency gain from the dynamic pricing equilibrium by comparing it to the case of commitment for the circumstance in which unfettered pricing results in dynamic pricing adjustments.

Proposition 6. When $\bar{c} \in (\underline{c}, \bar{c})$ (where $c^* \leq \underline{c} \equiv d\left(4\sqrt{a^2 + ad + d^2} - (2a + 3d)\right) / 16$ and $\bar{c} \equiv d(2a + d) / 16 \leq c^{**}$), supply chain efficiency under the dynamic pricing equilibrium is greater than that of the commitment case: $\mathbb{E}_\theta[\Pi^{MD}] + \mathbb{E}_\theta[\Pi^{RD}] > \mathbb{E}_\theta[\Pi^{MC}] + \mathbb{E}_\theta[\Pi^{RC}]$. Furthermore, under this condition, both the manufacturer and retailer are better off under the dynamic pricing equilibrium than the commitment case: $\mathbb{E}_\theta[\Pi^{MD}] > \mathbb{E}_\theta[\Pi^{MC}]$ and $\mathbb{E}_\theta[\Pi^{RD}] > \mathbb{E}_\theta[\Pi^{RC}]$.

Proof. See the Appendix. □

This result is in stark contrast to the conventional wisdom that the ratchet effect creates perverse inefficiencies. The proposition implies that the retailer's concern about the manufacturer's opportunistic behavior and his ensuing strategic response to shield his demand information (which one might assume hurts the channel efficiency) can be a blessing in disguise. In fact, it can increase supply chain efficiency even more than in the commitment case. Though signal jamming appears to be a threat to efficiency, it turns out to be one that is off-equilibrium. As such, the dynamic pricing outcome represents the best of both worlds: information-relevant profitability figures along with a reduction in double marginalization brought about by the threat of signal jamming. The retailer's threat of signal jamming provokes the manufacturer to lower the first-period retail price below that of the commitment case, thereby alleviating the double marginalization problem in the supply chain.

For the retailer, the primary benefit of dynamic pricing relative to precommitment comes from the reduction in double marginalization. For the manufacturer, being forced to set a lower initial wholesale price turns out to be worthwhile because dynamic pricing also permits circumstance-contingent pricing in Period 2. This give-and-take means that not only is efficiency enhanced relative to precommitment but this enhanced efficiency can also naturally take the form of Pareto gains.

Two-Part Tariff Contracts

The setting studied herein considers supply chain ratcheting arising under short-term linear wholesale pricing arrangements. Besides representing the succinct case of supply chain inefficiencies, this formulation also reflects the empirical regularity of such simple linear contracts (e.g., Iyer and Villas-Boas 2003; Lobel and Xiao 2017). In this section, we digress to discuss the importance of this stylized contractual presumption on the results in a more general setting.

If one were to expand the contractual arrangement to entail a full commitment to a general, profit-contingent, long-term contract, ratcheting is a nonissue. After all, the well-known revelation principle (Myerson 1979) demonstrates that under such unlimited contracting and commitment, any equilibrium outcome can be replicated under a fully revealing direct revelation mechanism, that is, one in which a firm can credibly commit not to ratchet expectations. A necessary condition for ratcheting to be a pressing issue, then, is some form of contractual incompleteness. Though our setting reflects such incompleteness in the form of dynamic linear contracts, the critical feature is that the manufacturer cannot fully precommit to how she will respond to information learned after the first period. It is that inability to commit that fosters ratcheting concerns. Knowing the manufacturer will respond to information revelation in her own self-interest, the retailer is prone to signal jamming to manage the information environment and the manufacturer's exploitation thereof.

To see how the forces play out in another contractual environment, consider the case in which the buyer can offer successive menus of two-part tariff contracts, where the fixed-fee and (nonnegative) variable tariff are denoted F and v, respectively. In effect, this translates our game of signaling under simple contracts to one of adverse selection under a wider selection of contracts. A typical view is that two-part tariffs overcome contractual inefficiencies in supply chains and thereby achieve first-best outcomes. However, with information asymmetry, even this is not necessarily the case. The retailer's private information creates two considerations relative to the first-best. First, as is typical in adverse selection settings, the manufacturer is willing to introduce an inefficiency to limit retailer information rents. Here, this takes the form of a nonzero marginal tariff that results in rationed production. Second, the two-period nature of the game introduces the key feature of our setting, which is that the seller's fear of ratcheting requires a first-period concession to induce investment because such investment undercuts information advantage. Notably, these two features work in opposite directions: while a one-shot adverse selection game would stipulate high marginal tariffs to overcome information rents, the concessions needed to assuage ratcheting fears take the form of reduced tariffs. More precisely, the next proposition demonstrates the adverse selection inefficiencies of marginal tariffs above marginal cost (seen in the mandatory disclosure case of Part 1), the endogenous concessions that arise under the threat of ratcheting (Part 2), and the ensuing efficiency benefits of dynamic pricing (Part 3).

Proposition 7. With successive two-part tariff contract menus.

1. Under mandatory disclosure, the optimal first-period contract entails $F = F_L = (1/4)(a-d)^2$ and $v = v_L = d$ when $\theta = \theta_L$, and $F = F_H = (1/4)(a^2 + 2d^2)$ and $v = v_H = 0$ when $\theta = \theta_H$. The second-period contracts entail $v = 0$ and fixed fees to extract the full surplus.
2. Under dynamic pricing without disclosure, the optimal first-period contract entails a fully separating equilibrium in which $F = (1/4)a^2$, $v = 0$ and the retailer invests when $\theta = \theta_H$ but does not invest when $\theta = \theta_L$. The second-period contracts entail $v = 0$ and fixed fees to extract the full surplus.
3. Supply channel efficiency is greater under dynamic pricing than under mandatory disclosure.

Proof. See the Appendix. □

Intuitively, with mandatory disclosure after the first period, the optimal initial contract takes the form of a fully revealing mechanism in which the manufacturer offers a menu of contracts from which the retailer can choose: when $\theta = \theta_L$, the contract choice entails a marginal tariff of d, whereas it is 0 when $\theta = \theta_H$. This contract exhibits the usual adverse selection features of production distortions for one type (here, a marginal tariff above zero when $\theta = \theta_L$) and information rents for the other type (when $\theta = \theta_H$). In other words, the fixed fee in Proposition 7, Part 1, permits a high-type retailer to retain some profit (information rent) when investing. In addition, to limit such profit concessions, the manufacturer sets an above-cost tariff to dissuade a high-type retailer from mimicking a low-type retailer.

As in our primary setup, the dynamic game again evokes concerns of ratcheting: If the retailer reveals its type in Period 1, it stands to lose out on potential information rents from the contract that would be offered in the presence of information asymmetry in the second period. After all, as shown in Part 1 of the proposition, revelation of information at the end of Period 1 ensures the entire surplus will be extracted by the manufacturer in Period 2. The threat of ratcheting, in turn, makes it more difficult for the manufacturer to elicit information about retailer type in the first-period contract. Just as in in the case of simple linear contracts, the manufacturer is forced to make concessions in the first period to assuage ratcheting concerns. In this case, the remedy is quite stark: knowing a retailer facing $\theta = \theta_H$ can mimic $\theta = \theta_L$ by refusing investment and creating a wide-open space for exploiting gains from investment in the subsequent period, the manufacturer must provide that wide-open space in the first period to ensure she can at least extract the gains from investment in Period 2. This takes the form of treating the retailer as if

$\theta = \theta_L$ and permitting him to walk away with the added profits from investment in the first period.

In other words, concessions to ease concerns of ratcheting persist in the case of menus of (successive) two-part tariff contracts for any c under the same condition in the main model (i.e., $c \leq ad / 4$). The concessions effectively take the form of the parties agreeing to take turns reaping the benefits of investment. This détente of sorts opens the door to supply chain gains that could not accrue if mandatory disclosure were in place.

Many other contractual arrangements are possible, and each would introduce a new consideration and alter equilibrium outcomes.[9] The goal here is not to identify the ideal or most practical contractual arrangement. Rather, the point is to identify that the primary forces are robust to contractual form provided there remains a degree of contractual incompleteness. It is a manufacturer's inability to fully commit to how she will respond to learning new information—not how this is manifest in specific contractual arrangements—that is the key feature that can give rise to ratcheting, signal jamming, and welfare-enhancing manufacturer concessions.

Conclusion

Long-term relationships not subject to long-term contractual commitments often end up involving concerns about ratcheting. This article presents a simple model of such a commonly discussed concern in the context of supply chain relationships. By examining dynamic supply chain interactions, we not only demonstrate that ratcheting is a legitimate concern among repeated buyer–supplier relationships but also that such relationships may introduce a natural solution to the conflict, one that alleviates another source of conflict in the channel. In particular, to assuage a retailer's fears of opportunistic ratcheting of input pricing, a manufacturer may offer initial price concessions. These price concessions, in turn, reduce double marginalization and promote greater supply chain efficiency. The end result is that not only can ratcheting concerns be naturally addressed by supply chain partners but they may also actually prove to be a salve in strained supply chains.

Thus, our results suggest that a manufacturer may rationally consider a wholesale price that coordinates a supply chain rather than one that maximizes its own short-term profit. The lower wholesale price may appear as suboptimal in the short run, but it actually can enhance the manufacturer's profit in the long run as well as the supply chain efficiency by inducing the retailer to make an efficient investment decision, thereby communicating the demand information to the manufacturer. This endogenous give-and-take, in turn, can provide some justification for the absence of regulations requiring disclosure of forward-looking financial information.

A key driver of both the concern of ratcheting and the parties' reactions to it in this setting is the intertemporal correlation in demand that gives rise to backward-looking profit figures potentially revealing future conditions. Absent such correlation, the forces of interest would be moot. Other limitations are the chosen contractual forms (i.e., linear wholesale pricing) and the simple monopoly framework. Future work may examine how ratcheting concerns and a retailer's natural desire to signal jam his profit reports influence supply chain interactions when competitors, at both the wholesale level and retail level, are also key strategic observers. It may also consider how such signal jamming is influenced by the degree of aggregation inherent in reported profits, that is, whether the natural aggregation of profit obtained from various industries or geographical markets could complement or substitute for a retailer's incentive to tailor investment choices to influence outside inference from profit disclosures and how this, in turn, can affect prevailing manufacturer prices.

Technical Appendix

Proof of Proposition 2 First, if $c \leq d(2a - d) / 16$, $w_1 = \overline{w} = \frac{2a+d}{4} \leq w_1^s = (1 / 8)(6a + d - 16c / d)$ and $w_1 = \overline{w}$ ensures voluntary information revelation by satisfying the (IC) constraint in Equation 9. In contrast, if $c > d(2a - d) / 16$, $\overline{w} = \frac{2a+d}{4} > w_1^s = (1 / 8)(6a + d - 16c / d)$, a manufacturer has to choose $w_1 = w_1^s = (1 / 8)[6a + d - 16c / d]$, which satisfies Equation 9 while inducing the retailer's information disclosure and minimizing distortion of a wholesale price between $\overline{w}$ and w_1.

Second, we show the condition under which a manufacturer's profit under the separating equilibrium with dynamic pricing is greater than those under both semi-separating equilibrium and pooling equilibrium. The manufacturer's profit under dynamic pricing with $w_1^s = (1 / 8)[6a + d - 16c / d]$ is as follows:

$$\mathbb{E}_\theta[\Pi^{MD}] = (1 / 128) \times \left(28a^2 - 32c - \frac{256c^2}{d^2} + \frac{64ac}{d} + 36ad + 11d^2\right).$$

Also, by using Equation 11, the equilibrium wholesale price under semi-separating equilibrium is $w_1 = (1 / 8)(2a(\tilde{\mu} + 3) - d(\tilde{\mu} - 4)\tilde{\mu} + d) - 2c / d$ with $\tilde{\mu} = (1 - \beta) / (2 - \beta)$. Using this equilibrium wholesale price, the manufacturer's expected profit under semi-separating equilibrium can be expressed as a function of β, denoted $\mathbb{E}_\theta[\Pi^{MS}; \beta]$. Taking the derivative of

[9] Nevertheless, we argue that nonlinear contracts such as the two-part tariffs are not widely used in conventional retail sectors and "its magnitude and the incidence of two-part tariffs may be quite insignificant" (Iyer and Villas-Boas 2003, p. 81). Several researchers have examined the limitation of nonlinear contracts, and they offer various explanations for its limited usage from different perspectives such as loss aversion (Ho and Zhang 2008), bargaining and the nonspecifiability of the contract (Iyer and Villas-Boas 2003), fairness concern (Cui, Raju, and John Zhang 2007), and channel coordination in the presence of private brands (Amaldoss and Shin 2015). Therefore, our analysis based on the linear wholesale pricing may be more relevant in those practical situations.

$\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta]$ with respect to c yields the following:

$$\frac{\partial(\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta])}{\partial c} = -\frac{(1-\beta)(2a(2-\beta) + d(15 - 11\beta + 2\beta^2))}{4d(2-\beta)^2} \leq 0.$$

Because this inequality is strict for $\beta < 1$, higher values of c favor the semi-separating equilibrium.

Also, we take the first derivative of $\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta]$ with respect to β:

$$\frac{\partial(\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}])}{\partial \beta} = \frac{1}{32}\left(\frac{16ac - 4a^2d - 4ad^2 + 16cd - 3d^3}{(2-\beta)^2 d} + \frac{2(a^2 + 8c + d^2)}{(2-\beta)^3} - 4(d(2a+d) - 4c) + \frac{3d(a+d)}{(2-\beta)^4} + \frac{d^2}{(2-\beta)^5}\right).$$

We first find a sufficient condition c^{**} such that $(\partial(\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}]) / \partial\beta) < 0$ when $\beta = 1$. By plugging in $\beta = 1$,

$$\frac{\partial(\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}])|_{\beta=1}}{\partial \beta} = \frac{48cd + 16ac - 2a^2d - 9ad^2 - d^3}{32d} < 0 \Leftrightarrow c < \frac{d(2a-d)}{16} + \frac{d^2(a+d)}{4(a+3d)} \equiv c^{**}.$$

Next, we demonstrate that the separating equilibrium under dynamic pricing is strictly preferred by the manufacturer for $c \in (c^*, c^{**})$. First, we note that the lowest value of $\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta]$ arises as $c \to c^{**}$ because $(\partial(\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta]) / \partial c) \leq 0$ for any $\beta \in [0, 1]$. Then, we only need to show that $\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta] \geq 0$ for all $\beta \in [0, 1]$ when evaluated at $c = c^{**}$. Plugging in $c = c^{**}$ to the profit expressions and taking the derivative with respect to β yields the following:

$$\frac{\partial(\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta])|_{c=c^{**}}}{\partial \beta} = \frac{-(1-\beta)(2a^3(2-\beta)^2 + (2-\beta)(97 - 6\beta^3 + 42\beta^2 - 107\beta)a^2d + (19\beta^4 - 171\beta^3 + 594\beta^2 - 945\beta + 579)ad^2 + (11\beta^4 - 99\beta^3 + 349\beta^2 - 572\beta + 367)d^3)}{32(2-\beta)^5(a+3d)} \leq 0.$$

Given the difference is strictly decreasing in β for $\beta < 1$, the manufacturer's preference for the separating equilibrium is confirmed by noting that $\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta = 1] = 0$. Therefore, for $c \in (c^*, c^{**})$, $\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MS}; \beta] > 0$ for any $\beta < 1$; thus, the manufacturer strictly prefers $w_1 = w_1^s = (1/8)[6a + d - 16c/d]$ to any w_1 that induces a semi-separating equilibrium.

Finally, we compare the manufacturer's profit under the induced separating equilibrium with the profit under the pooling equilibrium (i.e., $\beta = 0$). When $c \leq c^{**}$, $w_1^p = (1/8)[7a + 11d/4 - 16c/d] > a/2$ and w_1^p maximizes the pooling equilibrium profit. Then:

$$\mathbb{E}_\theta[\Pi^{MP}(w_1 = w_1^p)] = \frac{368a^2 - 8ad - 57d^2}{2048} + \frac{1}{16}c\left(\frac{12a}{d} + 11\right) - \frac{2c^2}{d^2}.$$

If we compare the two profits,

$$\mathbb{E}_\theta[\Pi^{MD}(w_1 = w_1^s)] - \mathbb{E}_\theta[\Pi^{MP}(w_1 = w_1^p)] = \frac{80(a^2 - 24c)d + 584ad^2 + 233d^3 - 512ac}{2048d},$$

which is positive if $c \leq c^{**}$ and the difference is decreasing in c. Therefore, if $c \leq c^{**}$, the manufacturer's profit is grater under the separating equilibrium with dynamic pricing than under the pooling equilibrium. In summary, the separating equilibrium with dynamic pricing is preferable in terms of both the profit under the semi-separating equilibrium and the profit under the pooling equilibrium when $c \in (c^*, c^{**})$.[10] □

Proof of Proposition 3 It is clear that $(\partial\triangle w / \partial a) = -1/4 < 0$, $(\partial\triangle w / \partial d) = (d^2 - 16c)/8d^2 < 0$ when $c \geq (1/16)d^2$. Under the region where $d(2a-d)/16 \leq c$, we have $d^2/16 \leq c$ because $a > d$. Finally, $(\partial\triangle w / \partial c) = 2/d > 0$. □

Proof of Proposition 5 $\mathbb{E}_\theta[\Pi^{MD}] + \mathbb{E}_\theta[\Pi^{RD}] - \{\mathbb{E}_\theta[\Pi^{MM}] + \mathbb{E}_\theta[\Pi^{RM}]\} = [d(2a-d) - 16c][d(10a+3d) - 16c]/256d^2 \geq 0$ if $c \geq (2a-d)d/16$. Also, $\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MM}] = -(d(2a-d) - 16c)^2/128d^2 \leq 0$; $\mathbb{E}_\theta[\Pi^{RD}] - \mathbb{E}_\theta[\Pi^{RM}] = (16C - d(2a-d))(16c + d(6a+5d))/256d^2 \geq$ if $c \geq (2a-d)d/16$. □

Proof of Proposition 6 $\mathbb{E}_\theta[\Pi^{MD}] + \mathbb{E}_\theta[\Pi^{RD}] = \frac{19a^2}{64} + \frac{3ac}{4d} + \frac{25ad}{64} + \frac{55d^2}{256} - \frac{7c}{8} - \frac{c^2}{d^2}$ and $\mathbb{E}_\theta[\Pi^{MC}] + \mathbb{E}_\theta[\Pi^{RC}] = 3a(a+d)/8 + 7d^2/32 - c$. If we compare the supply chain efficiency under the dynamic pricing equilibrium to that under commitment, $\mathbb{E}_\theta[\Pi^{MD}] + \mathbb{E}_\theta[\Pi^{RD}] > \mathbb{E}_\theta[\Pi^{MC}] + \mathbb{E}_\theta[\Pi^{RC}]$ when $c \in \left(d\left(6a + d - 4\sqrt{a(a+d)}\right)/16), d(2a-d)/16 + d^2(a+d)/4(a+3d)\right)$. Also, $\mathbb{E}_\theta[\Pi^{MD}] - \mathbb{E}_\theta[\Pi^{MC}] = d(2a+d) - 16c)(d(3d-2a) + 16c)/128d^2 > 0$ when $c \in (d(2a-d)/16, d(2a+d)/16)$.

[10] Though it is not the focus of this study, it can be confirmed that there also exists a $c^{***} > c^{**}$ such that for $c \in (c^{**}, c^{***})$, the supplier chooses an initial input price that induces partial signal jamming by the retailer through a semi-separating equilibrium, whereas for $c > c^{***}$, the supplier chooses an initial price that induces full signal jamming in a pooling equilibrium (details for this are available from the authors).

$\mathbb{E}_\theta[\Pi^{RD}] - \mathbb{E}_\theta[\Pi^{RC}] = ac/4d + c^2/d^2 - 3a^2/64 + 3c/8 - ad/64 - 7d^2/256 > 0$ when $c \in \left(\frac{d\left(4\sqrt{a^2+ad+d^2}-(2a+3d)\right)}{16}, \frac{d(2a-d)}{16} + \frac{d^2(a+d)}{4(a+3d)}\right)$.

Note that after a few algebraic steps, we can confirm $\underline{c} \equiv d\left(4\sqrt{a^2+ad+d^2} - (2a+3d)\right)/16 > d\left(6a + d - 4\sqrt{a(a+d)}\right)/16$ and $\underline{c} \equiv d\left(4\sqrt{a^2+ad+d^2} - (2a+3d)/16 > c^* \equiv d(2a-d)/16\right.$. Furthermore, $c^{**} \equiv d(2a-d)/16 + d^2(a+d)/4(a+3d) > \bar{c} \equiv d(2a+d)/16$. This confirms that $c^* < \underline{c}$ and $\bar{c} < c^{**}$. Therefore, when $c \in (\underline{c}, \bar{c})$, $\mathbb{E}_\theta[\Pi^{MD}] + \mathbb{E}_\theta[\Pi^{RD}] > \mathbb{E}_\theta[\Pi^{MC}] + \mathbb{E}_\theta[\Pi^{RC}]$, $\mathbb{E}_\theta[\Pi^{MD}] > \mathbb{E}_\theta[\Pi^{MC}]$, and $\mathbb{E}_\theta[\Pi^{RD}] > \mathbb{E}_\theta[\Pi^{RC}]$. □

Proof of Proposition 7 Working backwards in the game, first consider the contractual outcome in Period 2 under two scenarios: (a) Period 1 presents a fully revealing equilibrium and (b) the Period 1 outcome leaves uncertainty about the retailer's type.

a. Period 1 presents a fully revealing equilibrium case: In this case, because the manufacturer knows the retailer's type, it is straightforward to show that the Period 2 contract is written such that the marginal tariff ensures maximum supply chain profit and the fixed fee extracts the entire profit, that is, when $\theta = \theta_L(\theta = \theta_H)$, $v = 0(v = 0)$ and $F = a^2/4$ $(F = a^2/4 + d2a + d)/4 - c)$.
b. Period 1 outcome leaves uncertainty about the retailer's type: In this case, denote the manufacturer's belief that $\theta = \theta_H$ by $\tilde{\mu}$, where $\tilde{\mu} = (1-\beta)/(2-\beta) \leq 1/2$ (this is assured given the nature of the information environment: A θ_H -type retailer can mimic a θ_L-type retailer but not vice versa, so any outcome yielding type uncertainty necessarily involves an ex post belief not more than the ex ante belief). Given the ability to commit to the contract governing the remainder of the game, it is without loss of generality (Myerson 1979) to consider a menu of contracts that fully reveals retailer type. Denote the menu of contracts by $(\{F_L^2, v_L^2\}, \{F_H^2, v_H^2\})$. As is typical in adverse selection games, the binding constraints will be those that (1) ensure truth telling when $\theta = \theta_H$ and (2) ensure participation when $\theta = \theta_L$. (This is readily confirmed by solving the equilibrium by dropping the other constraints and showing that the solution satisfies the remaining constraints as well.) Using these binding constraints to solve for fixed fees, plugging them into the manufacturer's expected second-period profit expression, and optimizing marginal tariffs yields $v_L^2 = [d \cdot \tilde{\mu}/(1-\tilde{\mu})]$ and $v_H^2 = 0$, and thereby $F_L^2 = (1/4)\frac{1}{4}\left[a - \frac{d \cdot \tilde{\mu}}{1-\tilde{\mu}}\right]^2$ and $F_H^2 = (1/4)[a^2 + 2d^2 \cdot \tilde{\mu}/(1-\tilde{\mu})]$.

With these Period 2 possibilities in place, first consider the Period 1 contract under mandatory disclosure. In this context, Period 2 is, by construction, case (a) regardless of how Period 1 plays out. As a result of the deterministic Period 2 outcome, the manufacturer's problem condenses to a one-period game of commitment to which we can thus apply the revelation principle and only consider a fully revealing equilibrium Period 1 contract without loss of generality. Following the logic in (b), with $\tilde{\mu} = (1/2)$, confirms the optimal contract in part (1) of the proposition.

Now consider the outcome under dynamic pricing, denoting the menu of contracts by $(\{F_L^1, v_L^1\}, \{F_H^1, v_H^1\})$. There are three possibilities for the chosen contract to induce:

A. The Period 1 contract induces full revelation, that is, the menu ensures truth telling.
B. The Period 1 contract induces a partially separating equilibrium, that is, the menu ensures indifference when $\theta = \theta_H$, in which case the retailer adopts a mixed strategy.
C. The Period 1 contract induces a pooling equilibrium, that is, the menu provides the same contract to each type and ensures no investment when $\theta = \theta_H$.

In case (A), we will again examine a simplified game in which only two constraints are in place: (1) when $\theta = \theta_H$, the retailer will prefer to choose that contract and invest than to mimic $\theta = \theta_L$ by choosing that contract and not investing, and (2) when $\theta = \theta_L$, the retailer's expected profit from the chosen contract is nonnegative. Given the solution to this relaxed problem, we can readily confirm that the other omitted constraints are satisfied. In this case, if $\theta = \theta_H$ and the retailer chooses the contract designed for $\theta = \theta_H$, it gets that contract for Period 1. However, it can get the lower fixed fee in Period 2 as long as it deviates and opts not to invest in Period 1, that is, the fixed fee saving (including the investment cost saving c) is $F = a^2/4$ versus $F = a^2/4 + d(2a+d)/4 - c$. Using these binding constraints to solve for fixed fees, plugging them into the manufacturer's expected second period profit expression given full revelation, and optimizing marginal tariffs yields $v_L^1 = 0$ and $v_H^1 = 0$, as well as $F_L^1 = a^2/4$ and $F_H^1 = a^2/4$.

In cases (B) and (C), again consider the preferred Period 1 contract of the manufacturer under a relaxed optimization problem in which only two constraints are in place. If we can demonstrate that case (A) is preferred even under this relaxed game, then it is surely preferable to the optimal contractual solution under (B) or (C). Say that when $\theta = \theta_H$, the retailer chooses the $\theta = \theta_L$ contract with probability $1 - \beta \in (0, 1)$, corresponding to case (B), and $\beta = 0$ corresponds to case (C). For this to be viable, it must again be the case that when $\theta = \theta_H$, the retailer is indifferent between the two contract possibilities. In this case, the ensuing Period 2 contract when the $\theta = \theta_H$ contract is chosen in Period 1 is as in (a); in contrast, the Period 2 contract when the $\theta = \theta_L$ contract and no investment is chosen is as in (b) with $\tilde{\mu} = [(1-\beta)/2]/[(1-\beta)/2 + 1/2] = (1-\beta)/(2-\beta)$. Plugging the indifference point for $\theta = \theta_H$ and the participation constraint when $\theta = \theta_L$ into the Period 1 objective function and maximizing with respect to the marginal tariff yields $v_L^1 = 0$ and $v_H^2 = 0$, as well as $F_L^1 = a^2/4$ and $F_H^1 = a^2/4 + d^2 \cdot (1-\beta)/2$. Note from the contractual form that this particular contract may not satisfy the additional constraints when they are included. Nonetheless, comparing expected manufacturer profit under contracts in this relaxed game to those under part (A) confirms that expected profit under part (A) is higher for all $\beta \in [0, 1)$ (given $a \geq d$ and $c \leq ad/4$). Because (A) is preferable to the optimal

contract in the relaxed game, it will surely be preferable to the contract with additional constraints. This confirms part (2) of the proposition.

Part (3) of the proposition follows from two observations. First, the second-period outcomes are identical under both mandatory disclosure and dynamic pricing. Second, although both cases ensure channel-optimizing (first-best) investment levels in Period 1, only dynamic pricing prescribes a Period 1 marginal tariff that permits first-best retail pricing. □

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