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Manufacturer encroachment with consumer digital privacy in dual-channel supply chains

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A B S T R A C T

Utilizing a game-theoretic model, this study distinguishes between privacy-protecting and privacy-disclosing consumers, examining the impact of digital privacy on manufacturers' channel strategies, including no encroachment, encroachment, and shifting. The results indicate that when consumers prefer privacy disclosure, manufacturers consistently opt for the shifting strategy. In contrast, when privacy protection is prioritized, the outcome depends on the intensity of consumer preferences. Specifically, weak preferences lead to encroachment, whereas strong preferences favor no-encroachment. This contingency framework illustrates how privacy preference thresholds shape channel strategy selection. From a practical perspective, the findings offer actionable guidance for manufacturers. First, a win-win outcome depends on the manufacturer's cost-efficiency in channel-shifting operations, suggesting that firms should assess their operational capabilities before implementation. Second, consumer benefits under encroachment imply manufacturers can adopt this strategy for competitive advantage while addressing privacy concerns. These insights equip practitioners with a decision-making toolkit for balancing privacy compliance, channel efficiency, and stakeholder value creation in digital transformation initiatives.

1. Introduction

The digital channel refers to any method of reaching customers through digital technologies, in contrast to the physical channel, which entails face-to-face interactions or physical locations (Alos & Aguila, 2024). Internet-connected technologies and advanced digital tools employed in the digital channels intensify consumers' privacy concerns. While benefiting from digital services, consumers are required to disclose substantial amounts of personal data (Fainmesser et al., 2023). For example, logging into personal accounts for shopping digitally allows firms to collect, store, and analyze basic private data, such as usernames, preferences, categories, and purchase history. Moreover, emerging digital services like live-streaming and virtual reality (VR) necessitate consumer authorization for access to more sensitive data, including cameras, microphones, and photo albums. According to a Deloitte survey conducted in 2021, 66% of consumers express concerns about the handling of their personal data by online-interacting firms (Lee et al., 2021). In contrast, privacy issues among consumers in physical channels are considerably less pronounced (Sánchez & Urbano, 2022).

However, despite privacy-related risks, consumers gain access to rich information through digital media. Media richness, defined as the capacity of information in the media to enhance comprehension over time (Daft & Lengel, 1986), serves as a critical feature in the digital channel. Consumers can access a wide array of digital services and form perceptions of product quality through these interactions. For example, Galanz introduces a VR kitchen on its self-operated website, enabling consumers to experience products virtually (Galanz, 2024). Moreover, Galanz establishes more than ten live-streaming rooms at its Guangdong headquarters to help consumers better understand product functions (Zhou, 2021). Leveraging the distinctive features of digital media, many firms develop digital channels to capitalize on the media richness provided by these tools. For example, firms across various industries—such as Galanz and JWEISHI in home appliances (Wang, 2019), Warrior in apparel (Zhong, 2022), and UGREEN in small electronic devices (UGREEN, 2024), strategically cultivate direct digital channels to deliver enhanced media richness, after experiencing unsatisfactory performance in traditional physical channels.

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Therefore, manufacturers face trade-offs when implementing channel strategies. On the one hand, the digital channel raises substantial privacy concerns. On the other hand, the digital channel leverages high media richness, thereby enhancing consumers' perceptions of product quality. When determining the appropriate strategy, a manufacturer may establish a direct-to-consumer digital channel while continuing to sell through a traditional intermediary reseller, a phenomenon defined as manufacturer encroachment (Hotkar & Gilbert, 2021). For example, Murad, a well-known skincare brand, initially distributes its products exclusively through authorized brick-and-mortar retailers (Murad, 2023). Subsequently, Murad launched a self-operated website (Murad, 2023) to offer virtual dermatologist services to consumers (Portuguez, 2022). The strategy whereby a firm encroaches on the digital channel while retaining its pre-existing indirect physical channel, thus operating via dual channels, referred to as the encroachment strategy (i.e., Strategy *E*). Alternatively, some firms adopt a shifting strategy (i.e., Strategy *S*), transitioning entirely to a self-established direct digital channel while discontinuing the pre-existing indirect physical channel. For instance, in 2021, Amorepacific closed all Innisfree brick-and-mortar stores in North America, redirecting consumer purchases to e-commerce (Kovack, 2022). Additionally, Amorepacific planned to close 80% of its Innisfree stores in mainland China by 2022 as part of a "new round of strategic adjustments" in the Chinese market, placing greater emphasis on e-commerce (Kovack, 2022). Similarly, Be & Cheery, a major player in China's convenience foods industry, initially operates through brick-and-mortar stores (Wang, 2020). However, in 2010, Be & Cheery closed more than 140 physical stores and fully shifted to the digital platform (Zhong, 2020). In summary, the strategic decision of whether a manufacturer undertakes encroachment and whether it retains the initial indirect channel constitutes as the manufacturer's channel development strategy, in which consumers' privacy issues and media richness play pivotal roles.

Despite extensive research on manufacturer encroachment and digital transformation, existing studies largely overlook the role of consumer privacy concerns in shaping channel strategy decisions. While prior literature examines factors such as competition (e.g., Hotkar & Gilbert, 2021), pricing strategies (e.g., Yang et al., 2018), and consumer behavior (e.g., Chiang et al., 2003) in digital channels, the impact of privacy concerns on manufacturers' encroachment decisions remains underexplored. Moreover, little attention is paid to how privacy concerns interact with media richness to influence strategic channel choices. Addressing this gap, our study introduces a novel perspective by integrating consumer privacy concerns into the analysis of manufacturers' encroachment strategies, thereby advancing the understanding of how privacy considerations shape digital transformation decisions. This study explicitly fills this gap by examining the intersection of privacy concerns, media richness, and strategic channel decisions. Motivated by the above practical cases and research gaps, this study explores the following research questions. First, should a firm encroach on the digital channel to optimize profits given the existence of an indirect physical channel? Second, if the firm decides to encroach, should the firm retain the existing indirect physical channel, and which channel development strategy—encroachment or shifting—should be employed? Third, how do different consumer attitudes toward privacy issues affect manufacturers' optimal channel strategy? Fourth, how can a win-win outcome be achieved among participants within the supply chain, considering diverse channel development strategies? Additionally, how do these strategies influence consumer surplus?

To answer the above research questions, this study formulates a game-theoretical model to examine how consumer privacy issues influence a manufacturer's channel development strategies, including decisions on wholesale pricing, retail pricing, and consumer surplus. This analytical approach provides a systematic and rigorous framework to understand the complex decision-making process within the supply chain. Notably, the manufacturer initially operates an indirect physical channel for product distribution via a retailer. The manufacturer then decides whether to encroach on the digital channel and, if so, whether to retain the pre-existing indirect physical channel. Through comprehensive analysis, we obtain the following key findings and implications. First, we find that consumer privacy issues significantly affect the manufacturer's decision to encroach on the digital channel. Higher privacy concerns tend to discourage digital encroachment due to potential adverse consumer reactions. Second, when the manufacturer decides to encroach, the decision to retain the existing physical channel and fully transition to a digital channel is influenced by the degree of media richness the digital channel can offer. Enhanced media richness can mitigate privacy concerns by providing consumers with more comprehensive product information, thereby making the dual-channel strategy more appealing. Third, our analysis shows that optimal pricing strategies vary based on the channel configuration. Manufacturers must carefully balance wholesale and retail prices to maximize profits while accounting for consumer surplus and potential backlash from privacy-conscious consumers. Last, we show that the strategic alignment of channel development, considering both privacy issues and media richness, can generate a win–win outcome for all participants within the supply chain. By carefully navigating these factors, manufacturers can enhance consumer experience, boost demand, and achieve sustainable profitability.

Based on these findings, this study contributes threefold to the existing literature. First, we identify the heterogeneity of consumers' privacy issues between channels (digital vs. physical). While the digital channel exhibits pronounced privacy issues, its media richness introduces a strategic trade-off for manufacturers considering encroachment strategies. Second, we categorize consumers into two types based on their preferences: those who favor privacy disclosure to access the positive utility derived from personalized services and those who prefer privacy protection to mitigate the negative utility associated with improper use of private data. Last, our study pioneers an investigation into how digital privacy issues influence decision-making among supply chain participants. Our findings offer valuable insights for manufacturers aiming to establish direct connections with end consumers, and provide a comprehensive understanding of the interplay among privacy concerns, media richness, and channel strategy choices.

The remainder of this study is organized as follows. Section 2 reviews the relevant literature. Section 3 develops a game-theoretic model and derives equilibrium. Section 4 examines the manufacturer's channel development strategy and its implications for the retailer and consumers. Last, Section 5 concludes.

2. Literature Review

This study builds on and contributes to three streams of literature: consumer privacy, manufacturer encroachment, and media richness.

2.1 Consumer Privacy

The first stream of relevant literature concerns consumer privacy. Firms collect personal data from consumers, which may be excessively used or disclosed to third parties, resulting in consumers' privacy issues (Fainmesser et al., 2023). Several studies in this stream examine the negative impact of privacy issues on consumers from various perspectives (Cong et al., 2021; Chen, 2022). Other studies investigate how consumers employ identity management to address privacy issues, including ex-ante identity management (Valletti & Wu, 2020), interim identity management (Conitzer et al., 2012), and ex-post identity management (Chen et al., 2020). Notably, Hann et al. (2008) analyze two ex-ante identity management techniques (i.e., concealment and deflection) used by consumers to avoid marketing. However, the aforementioned studies only consider the negative effects of consumers' privacy issues. Consumers may also benefit from personalized services enabled by the collection and analysis of personal data, rather than solely experiencing losses from issues such as price discrimination or privacy breaches (Rothschild et al., 2019; Redman & Waitman, 2020; Esposito, 2021). Several studies examine both the benefits and drawbacks of consumers' privacy issues and investigate their implications for corporate strategies, including pricing (Gal-Or et al., 2018), marketing (Gal-Or et al., 2018; Hu et al., 2022), competition (Gal-Or et al., 2018), and digitalization levels (Fainmesser et al., 2023). Similar to this stream of research, this study differentiates between two types of consumers to capture the positive and negative effects of consumers' privacy issues. If consumers prefer privacy disclosure, the collection and analysis of personal data generate positive utility; conversely, if consumers prefer privacy protection, such practices yield negative utility. Nevertheless, the existing literature primarily analyzes the impact of privacy issues on the decisions and profits of monopoly or duopoly firms. Building on these studies, this study extends the analysis to explore the implications of consumers' privacy issues for participants in a multichannel supply chain.

Some particularly relevant studies include Sánchez and Urbano (2022) and Xu et al. (2025). The former focuses exclusively on the disutility arising from privacy concerns and examines the mechanisms used by multichannel monopolies to set retail pricing and convey price-related signals to consumers (Sánchez & Urbano, 2022). The latter analyzes both the positive and negative effects of privacy issues in a single-channel supply chain context (Xu et al., 2025). In other words, Xu et al. (2025) address single-channel supply chain settings, whereas Sánchez and Urbano (2022) investigate multichannel monopoly settings. Building on previous literature, this study examines the impact of consumers' privacy issues on the decision-making of supply chain participants in a multichannel supply chain.

2.2 Manufacturer Encroachment

The second stream of literature relevant to this study concerns manufacturer encroachment, which refers to a manufacturer's ability to sell directly in a marketplace alongside the traditional resell channel (Hotkar & Gilbert, 2021). From an information perspective, several studies examine the effects of information advantages (Li et al., 2014; Li et al., 2015), information transparency (Guan et al., 2020), and information sharing (Huang et al., 2018; Zhao & Li, 2018; Guan et al., 2023; Lu et al., 2023; Zhao et al., 2022) on manufacturers' encroachment decisions. Most existing literature emphasizes the information advantage held by retailers. For example, Huang et al. (2018) find that retailers are more inclined to share demand information voluntarily in response to supplier encroachment voluntarily; Zhao & Li (2018) analyze manufacturers' encroachment decisions under both economic and diseconomies of scale; Lu et al. (2023) investigate the information-sharing strategies of overconfident retailers when confronted with manufacturer encroachment; and Zhao et al. (2022) examine how information acquisition influences manufacturers' encroachment strategies and retailers' information-sharing behavior, noting that manufacturers can also independently gather market information. Additionally, several studies focus on scenarios in which manufacturers hold information advantages. For example, Guan et al. (2023) find that manufacturers consistently benefit from sharing information with retailers when they possess cost information advantages, whereas retailers do not obtain comparable gains. However, the above literature does not adequately distinguish between the characteristics of digital and physical channels. These differences are crucial for manufacturers when deciding whether to expand from existing physical indirect channels into digital direct channels. Notably, this study highlights two inherent characteristics of channels—privacy issues and media richness—and examines how different consumer privacy preferences interact with these features of digital channels to influence manufacturers' channel development strategies.

Moreover, several studies acknowledge the distinctions between digital and physical channels and examine how these differences shape manufacturers' channel strategy decisions across three key dimensions: cost-related, service-related, and consumer-related attributes. Regarding cost-related attributes, most studies find that the unit selling cost (or marginal

operating cost) in digital direct channels is higher than that in physical indirect channels (e.g., Balasubramanian, 1998; Chiang et al., 2003; Cattani et al., 2006; Arya et al., 2007; Dumrongsiri et al., 2008; Cai, 2010; Xiong et al., 2012; Li et al., 2015; Ha et al., 2022; Shi et al., 2023). Additionally, Tsay & Agrawal (2004) highlight differences in sales effort costs and logistics efficiency costs between the two channels. Regarding service-related attributes, prior research shows that firms choose different service levels in direct and indirect channels (e.g., Chen et al., 2008; Dumrongsiri et al., 2008). Notably, Dumrongsiri et al. (2008) examine differences in service quality provided by manufacturers and retailers and account for consumers' heterogeneous sensitivity to service quality. Regarding consumer-related attributes, studies indicate that consumers exert different levels of effort (or cost) when purchasing through digital and physical channels (e.g., Balasubramanian, 1998; Cattani et al., 2006; Chen et al., 2008; Yoo & Lee, 2011) and that their acceptance of digital channels is generally lower than that of physical channels (Chiang et al., 2003).

While this study also examines consumer-related attributes, it introduces a relatively underexplored factor—consumer privacy preferences. Specifically, we analyze how privacy issues differ between physical and digital channels and recognize two distinct consumer types: privacy-protecting and privacy-disclosing consumers. By framing the distinction between digital and physical channels through the lens of consumer digital privacy, this study offers novel insights into how both the type and intensity of consumer privacy preferences shape manufacturers' encroachment strategies.

2.3 Media Richness

The third stream investigates the significance of media richness. Media richness, defined as the capacity of information in the media to facilitate comprehension within a period, is also referred to as information richness (Daft & Lengel, 1986). Early research on media richness emphasizes task-medium fit to enhance communication effectiveness (Watson-Manheim & Bélanger, 2007). Subsequently, numerous studies examine the influence of media richness on consumer purchasing decisions (Maity & Dass, 2014), including effects on cognition (Kahai & Cooper, 2003), attitudes (Vickery et al., 2004), and various behavioral dimensions (Goh et al., 2013). Moreover, Pavlou et al. (2007) and Li et al. (2020) examine the relationship between channel media richness and consumer privacy concerns, providing empirical evidence that media richness significantly affects the extent of such concerns. To the best of our knowledge, no prior study develops a stylized model to capture this link, which distinguishes our work from the existing literature. Building on existing literature, we further explore the influence of media richness on corporate channel strategies and operational decision-making, extending beyond prior research that focuses solely on its effects on consumers. Notably, media richness directly shapes consumer demand, which is closely linked to firm profitability. Therefore, this study incorporates media richness into a firm's operational decision-making framework by modeling its impact on consumer utility.

In summary, this study contributes significantly by clarifying the complex role of consumers' privacy preferences in shaping manufacturers' encroachment strategies within a multichannel supply chain. Additionally, we analyze the comprehensive impact of these preferences on pricing decisions and the profitability of supply chain participants.

3. Model

The manufacturer (denoted by subscript m) produces and distributes products indirectly through a retailer (denoted by subscript r) in a physical channel. Since the manufacturer operates its own digital channel while the retailer participates only in the indirect physical channel, the subscript i also indicates the channel type (i.e., $i = m$ refers to the direct digital channel, and $i = r$ refers to the indirect physical channel). Based on the initial indirect physical channel, the manufacturer determines its channel development strategy, denoted by superscript j ($j \in \{N, E, S\}$). The manufacturer can choose whether to encroach: Under Strategy N, there is no encroachment; under encroachment, the original indirect channel may or may not be retained. Specifically, Strategy E refers to retaining the original channel and selling through both channels, whereas Strategy S refers to abandoning the original channel and shifting entirely to the direct digital channel. The manufacturer sells a homogeneous product through the direct digital and indirect physical channels. Table 1 summarizes the notation used in our model.

Table 1
Model Notation

Notation	Description
i	Channel type $i \in \{m, r\}$
j	Channel development strategy $j \in \{N, E, S\}$
θ	A consumer's willingness-to-pay for unit product quality, $\theta \sim U[0,1]$
λ_i	The media richness in the channel type i
s_i	The degree of consumers' privacy preferences in the channel type i
k	Cost-efficiency parameter that measures the marginal cost of providing channel media, $k > 0$
q	The actual quality of the product, $q > 0$
w^j	The wholesale price in the indirect channel under Strategy $j \in \{N, E\}$
p_i^j	Retail price in the channel type i under Strategy j
d_i^j	Quantity of sales in the channel type i under Strategy j
U_i^j	Consumer utility in the channel type i under Strategy j
π_i^j	Profit of the player i under Strategy j
π_{sc}^j	Profit of the overall supply chain under Strategy j
CS^j	Total consumer surplus under Strategy j

We formulate a Stackelberg game in which the manufacturer acts as the leader and the retailer as the follower. In the first stage, the manufacturer determines its channel development strategy ($j \in \{N, E, S\}$). The second stage specifies the operational strategy. If the manufacturer deploys Strategy N, the retailer decides the optimal retail price after observing the wholesale price determined by the manufacturer. Under Strategy E, the manufacturer first decides on the optimal wholesale price. Afterward, the manufacturer determines the optimal retail price for the direct digital channel, and the retailer simultaneously decides the optimal retail price in the indirect physical channel. Under Strategy S, the manufacturer decides only on the optimal retail price for the direct digital channel. The timeline of the model is presented in Fig. 1.

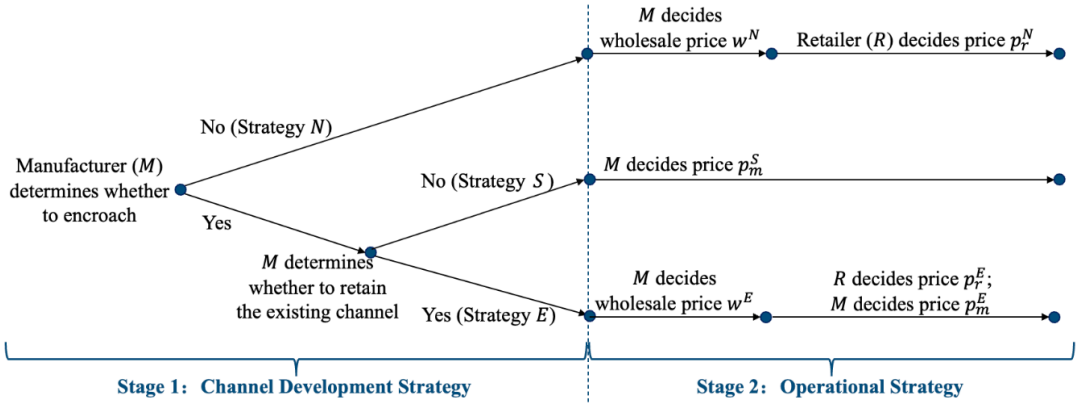

Fig. 1. Timeline of the Model

One key factor influencing the manufacturer's strategic choice is consumers' privacy concerns (i.e., s_i, where $i \in \{m, r\}$), which differ between digital and physical channels, thereby influencing consumers' purchasing decisions. As previously noted, digital media heightens consumers' privacy issues while simultaneously offering high media richness (i.e., λ_i). Here, λ_i characterizes the media richness of channel type i, and high media richness may lead to privacy issues among consumers because it entails extensive collection and analysis of personal data by firms. Consequently, these privacy issues associated with media richness generate additional utility for consumers, which can be expressed as $-s_i\lambda_i$ (the linear form consistent with Chen, 2022; Conitzer et al., 2012; Wang et al., 2023). The sign of this impact depends on the consumer type characterized by the value of s_i. When $s_i > 0$, consumers prefer privacy protection, and any privacy breach results in negative utility. Conversely, when $s_i < 0$, consumers favor privacy disclosure to access more precise services, thereby generating positive utility. Last, when $s_i = 0$, consumers' privacy issues do not significantly affect their utility. Moreover, s_i is a continuous variable measuring the degree of consumers' privacy preferences. The greater the degree of consumers' privacy preference, the stronger the impact of privacy issues on consumer utility. We assume that consumers purchasing through the digital channel face privacy issues, whereas those in the physical channel do not, i.e., $s_r = 0$ and $s_m = s$ (Sánchez & Urbano, 2022). Since $s = 0$ indicates no significant privacy impact on utility in the digital channel, this case is excluded from the present analysis.

Another crucial factor in the manufacturer's strategic decision is the difference in media richness between the digital and physical channels (i.e., λ_i, where $i \in \{m, r\}$). Media richness influences consumers' perceptions of the actual quality of the product (denoted as q and $q > 0$) and thus affects the consumers' valuation of the product. This relationship is expressed as $v_i = \lambda_i q$ (Hou et al., 2021). Higher media richness corresponds to an elevated consumer perception of product quality, resulting in increased utility. Furthermore, we normalize the media richness of the physical channel to one (i.e., $\lambda_r = 1$), and denote $\lambda_m = \lambda$ as the relative media richness of the digital channel. Specifically, we assume that media richness in the digital channel exceeds that of the physical channel due to the greater diversity in the utilization of digital tools within the digital channel. Consequently, consumers perceive higher product quality when purchasing through the digital channel compared to the physical channel. Without loss of generality, we normalize the potential market size to be one, and assume each consumer purchases at most one unit of the product. Therefore, the consumer's utility from purchasing the product with quality q and price p_i^j in the channel type i is given by $U_i^j = \theta v_i - p_i^j - s_i\lambda_i$ ($j \in \{N, E, S\}$), where $\theta \sim U[0,1]$ represents the consumer's willingness-to-pay for unit product quality, capturing the natural variation in consumers' quality preferences (Zhang et al., 2024). Moreover, $v_i = \lambda_i q$ characterizes the consumer's valuation of the product's quality-related attributes in a particular channel, while $s_i\lambda_i$ represents the consumer's utility impact from privacy preference in different channels. A positive s_i indicates a preference for privacy protection, whereas a negative s_i denotes a preference for privacy disclosure; λ_i modulates the influence of this privacy preference based on the channel's media richness. To further clarify the utility function, we provide an illustrative example. Suppose a consumer is considering purchasing a smart home device through either a digital or physical channel with price p. The product quality (q) is the same across both channels, but the digital channel offers additional virtual demonstrations, making its media richness (λ) higher. If the consumer values privacy highly (i.e., s is large), they may experience a significant disutility when purchasing through the digital channel due to personal data concerns. Consequently, their overall utility from digital purchases will be lower than that of the physical channel. Conversely, if the consumer prioritizes information accessibility, they may derive greater utility from the digital channel despite privacy

concerns. This example illustrates how privacy preferences (s) and media richness (λ) jointly shape consumer utility and, consequently, channel choices.

3.1 Benchmark: Strategy N

If the manufacturer produces and distributes products only through the physical retailer (i.e., $j = N$), consumers can only purchase products from the indirect physical channel or choose not to purchase. The demand function can be derived as Eq. (1).

$$d_r^N(p_r^N) = 1 - \frac{p_r^N + s_r\lambda_r}{\lambda_r q}. \tag{1}$$

Furthermore, the consumer surplus can be derived from the demand function as Eq. (2).

$$CS^N = \int_0^{d_r^{N*}} [\lambda_r(q - s_r - qx) - p_r^{N*}]\, dx. \tag{2}$$

Whether or not the manufacturer chooses to encroach, the retailer pays wholesale prices w^j for purchasing products from the manufacturer and then selling them at retail prices p_r^j to the end consumer ($j \in \{N, E\}$). To simplify the analysis, we normalize the retailer's unit selling cost to zero (Ha et al., 2022; Lin et al., 2024). Hence, the retailer's profit function is formulated in Eq. (3). Especially under Strategy S, the retailer's profit equals zero.

$$\pi_r^j(p_r^j) = (p_r^j - w^j)d_r^j. \tag{3}$$

Under Strategy N, the manufacturer's revenue is derived from only distributing products to the retailer. Without loss of generality, the manufacturer's unit production cost is normalized to zero (Cao et al., 2023; Wang et al., 2023). Furthermore, because of the heterogeneity in media richness between channels, the manufacturer pays different costs for providing physical or digital channels, and the cost follows the form of a linear function (Fainmesser et al., 2023; Valletti & Wu, 2020), where k is the cost-efficiency parameter. Therefore, the manufacturer's profit function can be expressed in Eq. (4).

$$\pi_m^N(w^N) = w^N d_r^N - k\lambda_r. \tag{4}$$

3.2 Strategy E

If the manufacturer determines to distribute products through dual channels (i.e., $j = E$), consumers choose whether to purchase from the digital or physical channels based on their utility. If the utility of purchasing a product is negative, consumers refrain from making the purchase. The demand function can be derived as Eq. (5).

$$\begin{cases} d_r^E(p_r^E) = \frac{-\lambda_m p_r^E + \lambda_r[p_m^E + \lambda_m(s_m - s_r)]}{\lambda_r(\lambda_m - \lambda_r)q}, \\ d_m^E(p_m^E) = 1 + \frac{p_r^E - p_m^E - s_m\lambda_m + s_r\lambda_r}{(\lambda_m - \lambda_r)q}. \end{cases} \tag{5}$$

Then, the optimal consumer surplus can be formulated in Eq. (6).

$$\begin{aligned} CS^E = &\int_0^{d_r^{E*}} \left[\frac{\lambda_r(p_m^{E*} + \lambda_r qx)}{\lambda_m} + \lambda_r(s_m - s_r) - \lambda_r qx - p_r^{E*}\right] dx \\ &+ \int_0^{d_m^{E*}} [p_r^{E*} + (\lambda_m - \lambda_r)q(1 - x) - s_m\lambda_m + s_r\lambda_r - p_m^{E*}]\, dx. \end{aligned} \tag{6}$$

Moreover, the manufacturer's profit function is the sum of the profits from the existing physical channel and the encroached digital channel, which can be formulated in Eq. (7). It is worth noting that the manufacturer needs to pay the costs of the two channels.

$$\pi_m^E(w^E, p_m^E) = w^E d_r^E + p_m^E d_m^E - k(\lambda_r + \lambda_m). \tag{7}$$

3.3 Strategy S

When the manufacturer establishes its own direct digital channel, revenue in the indirect physical channel may become negative, preventing the manufacturer from retaining the indirect channel. In this situation, the manufacturer completely shifts

to the direct digital channel from the indirect physical channel (i.e., $j = S$). Consequently, consumers can only purchase products through the direct digital channel or choose not to purchase. The demand function is derived as shown in Eq. (8).

$$d_m^S(p_m^S) = 1 - \frac{p_m^S + s_m\lambda_m}{\lambda_m q}. \tag{8}$$

Then, the optimal consumer surplus can be formulated in Eq. (9).

$$CS^S = \int_0^{d_m^{S*}} [\lambda_m q(1-x) - s_m\lambda_m - p_m^{S*}]\, dx. \tag{9}$$

The manufacturer's profit function is derived from only selling products to the end consumers directly, which can be formulated in Eq. (10).

$$\pi_m^S(p_m^S) = p_m^S d_m^S - k\lambda_m. \tag{10}$$

Table 2 summarizes the equilibrium wholesale price, retail price, sales, and profit under different channel development strategies.

Table 2
Equilibrium Results

	Benchmark	Encroachment Strategy	Shifting Strategy ($j = S$)	
	($j = N$)	($j = E$)	$q + s \geq 0$	$q + s < 0$
w^{j*}	$\frac{q}{2}$	$\frac{q}{2} - \frac{s}{2(1+8\lambda)}$	NA	NA
p_r^{j*}	$\frac{3q}{4}$	$\frac{q}{2} + \frac{s(1+4\lambda)}{2(1+8\lambda)}$	NA	NA
p_m^{j*}	NA	$\lambda\left[\frac{q}{2} + \frac{s(1-8\lambda)}{2(1+8\lambda)}\right]$	$\frac{\lambda(q-s)}{2}$	$-s\lambda$
d_r^{j*}	$\frac{1}{4}$	$\frac{\lambda s(1+2\lambda)}{q\tau_1}$	NA	NA
d_m^{j*}	NA	$\frac{1}{2} + \frac{s+\lambda s(1-8\lambda)}{2q\tau_1}$	$\frac{(q-s)}{2q}$	1
π_r^{j*}	$\frac{q}{16}$	$\frac{\lambda s^2(1+2\lambda)^2}{q\tau_1(1+8\lambda)}$	NA	NA
π_m^{j*}	$\frac{q}{8} - k$	$-k(1+\lambda) + \frac{\lambda(q^2\tau_1 - 2qs\tau_6 + s^2\tau_2)}{4q\tau_1}$	$\frac{\lambda[(q-s)^2 - 4kq]}{4q}$	$-\lambda(k+s)$
CS^{j*}	$\frac{q}{32}$	$\frac{\lambda[q^2\tau_1(1+8\lambda) - 2qs\tau_1(3+8\lambda) + s^2\tau_3]}{8q\tau_1(1+8\lambda)}$	$\frac{\lambda(q-s)^2}{8q}$	$\frac{q\lambda}{2}$

Note: As we assumed $\lambda > 1$ before, we have $\tau_1 = (\lambda-1)(1+8\lambda) > 0$, $\tau_2 = -1 - 3\lambda + 8\lambda^2 > 0$, $\tau_3 = -5 - 23\lambda + 64\lambda^3 > 0$, and $\tau_6 = -1 - 7\lambda + 8\lambda^2 > 0$.

Lemma 1. *$d_m^{E*} = 0$, when $s < 0$; and $d_m^{E*} > 0$, when $s > 0$.*

Lemma 1 shows that for consumers who prefer privacy disclosure (i.e., $s < 0$), the manufacturer can completely shift to the digital channel only if it engages in encroachment. The direct digital channel, under the manufacturer's control, confers competitive superiority and strengthens its market power relative to the retailer. Consequently, the manufacturer tends to set a higher wholesale price in the indirect physical channel. Conversely, the retailer must adopt a lower retail price to gain a foothold in a market where the physical channel is already competitively disadvantaged. This pricing dynamic causes the wholesale price to exceed the retail price in the indirect physical channel (i.e., $w^{E*} = \frac{q}{2} - \frac{s}{2(1+8\lambda)} > p_r^{E*} = \frac{q}{2} + \frac{s(1+4\lambda)}{2(1+8\lambda)}$ if $s < 0$), leading to zero sales (i.e., $d_r^{E*} = 0$), and rendering the physical channel is nonviable. In contrast, if consumers prefer privacy protection (i.e., $s > 0$), the manufacturer can maintain the physical channel while distributing products through dual channels simultaneously (i.e., if $s > 0$, then $w^{E*} < p_r^{E*}$ and $d_r^{E*} > 0$).

To clarify, when the manufacturer engages in encroachment, if consumers prefer privacy disclosure (i.e., $s < 0$), the manufacturer adopts Strategy S; conversely, if consumers prefer privacy protection (i.e., $s > 0$), the manufacturer adopts Strategy E. Accordingly, if consumers prefer privacy disclosure (or protection), we compare the equilibrium outcomes under

Strategy S (or Strategy E) with those under Strategy N to examine whether the manufacturer should engage in encroachment in the subsequent section.

4. Analysis

This section identifies the conditions under which the manufacturer adopts different channel development strategies through comparative analysis. Moreover, we comprehensively examine the effects on supply chain participants and consumer surplus.

4.1 Decisions on Channel Development Strategies

The manufacturer's channel development strategy follows a two-step decision process. The first step is to determine whether to encroach on the digital channel, and the second is to decide whether to fully shift to the digital channel while abandoning the original indirect channel. Our investigation reveals that the manufacturer's decision-making process depends on both the type and intensity of consumers' privacy preferences.

Proposition 1. ***Impact of Consumers' Privacy Preferences on Shifting Strategy.*** *For the type of consumers who prefer privacy disclosure (i.e., $s < 0$), the manufacturer chooses the shifting strategy to gain more profits (i.e., $\pi_m^{S*} > \pi_m^{N*}$).*

Proposition 1 shows that when consumers prefer privacy disclosure, the manufacturer can increase profitability by adopting Strategy S rather than maintaining the existing indirect physical channel. Compared with the indirect physical channel, the direct digital channel offers a clear competitive advantage due to its ability to provide precise quality assessment and personalized services. On the one hand, the digital channel's higher media richness enables consumers to evaluate product quality accurately, thereby enhancing purchase intention and utility. On the other hand, greater privacy disclosure allows access to enhanced service levels, such as personalized recommendations, which further improve consumer utility. Therefore, the manufacturer is motivated to shift fully to the direct digital channel to bolster its profits.

Proposition 2. ***Impact of Consumers' Privacy Preferences on Encroachment Strategy.*** *For the type of consumers who prefer privacy protection (i.e., $s > 0$), if the degree of consumers' privacy preferences is relatively low (or high), the manufacturer chooses (or not) the encroachment strategy to gain more profits. Namely, $\pi_m^{E*} > \pi_m^{N*}$ if $0 < s < \hat{s}_1(\lambda)$, and vice versa, where $\hat{s}_1(\lambda) = \frac{2q\lambda\tau_1 - q\tau_1\sqrt{\frac{2\lambda[8k\lambda\tau_2 - q(1+3\lambda)]}{q\tau_1}}}{2\lambda\tau_2}$, $\tau_1 = (\lambda-1)(8+\lambda) > 0$, and $\tau_2 = -1 - 3\lambda + 8\lambda^2 > 0$.*

Proposition 2 examines the effect of consumers' privacy protection levels on the manufacturer's profitability. It shows that when consumers' privacy protection falls below a certain threshold (i.e., $s < \hat{s}_1(\lambda)$), Strategy E is more profitable; conversely, Strategy N yields higher profits. This outcome arises from the manufacturer's need to balance the positive utility (improved quality perception) and the negative utility (consumers' privacy concerns) associated with higher media richness. When consumers' privacy protection is relatively low (i.e., $s < \hat{s}_1(\lambda)$), consumer concerns about data leakage are minimal. Consequently, the direct digital channel gains a competitive advantage over the indirect physical channel, and the manufacturer's gain from establishing an exclusive digital channel exceeds any associated losses. In contrast, when consumers display a relatively high degree of privacy protection (i.e., $s > \hat{s}_1(\lambda)$), concerns arise regarding the potential disclosure of their private information through purchases in the direct digital channel. Consequently, the direct digital channel loses its competitiveness, making the manufacturer's encroachment strategy unprofitable.

The results of Propositions 1 and 2 suggest that the manufacturer should carefully evaluate both the type and degree of consumers' privacy preferences when considering encroachment. Specifically, in the presence of heterogeneous consumer profiles, the manufacturer needs to assess the feasibility of encroachment and identify the optimal timing for abandoning the existing indirect channel. Fig. 2 visually represents the results from both Proposition 1 and Proposition 2, which are fundamental to understanding the complex relationship between consumers' privacy preferences and the manufacturer's channel development strategies. It vividly demonstrates how the type and degree of consumers' privacy preferences influence the manufacturer's channel development strategy selection.[1] More specifically, the insights derived from Fig. 2 align with the conclusions of Proposition 1 and Proposition 2. In the region where $s < 0$ (i.e., the gray area to the left of the dashed line), the manufacturer's choice of Strategy S is most advantageous, which aligns with the conclusion of Proposition 1. Regardless of the degree of consumer privacy preferences, as long as consumers prefer privacy disclosure, the digital channel can better exploit the value of data, thus bolstering its competitiveness over the physical channel. In contrast, in the region where $s > 0$, if consumer privacy preferences are relatively low (i.e., the red area to the left of the threshold $\hat{s}_1(\lambda)$), the manufacturer should adopt Strategy E; otherwise, Strategy N should be chosen (i.e., the blue area to the right of the threshold $\hat{s}_1(\lambda)$). When consumers favor privacy protection, the data leakage risk in digital channels is higher compared to physical channels, resulting in a competitive disadvantage. And if consumer privacy preferences are low, the manufacturer can profitably encroach on the

[1] Note: *NA* denotes the infeasible region where the equilibrium solution is non-positive.

digital channel, which aligns with Proposition 2. Overall, Fig. 2 highlights the complex relationship between consumer privacy preferences (both type and degree) and the manufacturer's channel development strategy.

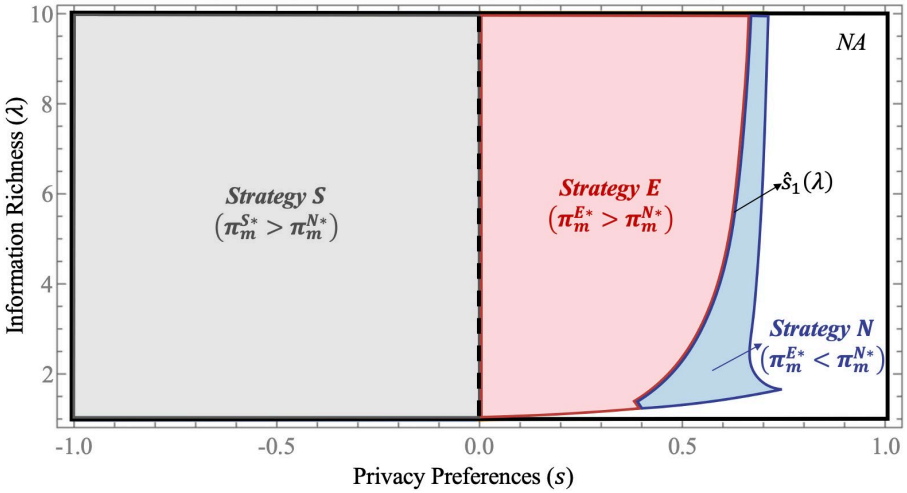

Fig. 2. Impact of Consumers' Privacy Preferences on Manufacturer's Profit ($q = 1.5$, $k = 0.1$)

Corollary 1. $d_m^{E*} + d_r^{E*} > d_r^{N*}$ *and* $d_m^{S*} > d_r^{N*}$.
Corollary 1 indicates that manufacturer encroachment on the digital channel has the potential to amplify sales. By leveraging diverse digital tools, consumers gain access to abundant information, which enhances their perception of product quality. Consequently, establishing a digital channel stimulates consumers' willingness to purchase, thereby expanding sales. Therefore, when the manufacturer's primary objective is to bolster sales, pursuing encroachment is a sound strategic choice.

4.2 Participants' Profits and Consumer Surplus

We conduct a comprehensive analysis to examine the potential benefits of specific channel development strategies for the retailer, the entire supply chain, and consumers. Furthermore, we investigate how the degree of privacy preference affects each participant.

First, we analyze the impact of manufacturer encroachment on the retailer's profit by comparing Strategy E with Strategy N (specifically focusing on situations when $s > 0$). We limit this analysis to scenarios with privacy-protecting consumers because when consumers prefer privacy disclosure (i.e., $s < 0$), the manufacturer's only encroachment option is Strategy S, which clearly disadvantages the retailer. This is because, under Strategy S, the manufacturer completely abandons the physical channel and shifts to the digital channel.

Lemma 2. $w^{E*} < w^{N*}$ *and* $p_r^{E*} < p_r^{N*}$.

Lemma 2 demonstrates that manufacturer encroachment leads to price reductions in the physical channel. For the retailer, channel competition arises due to the manufacturer's encroachment on the digital channel. Additionally, the digital channel inherently benefits from media richness. Consequently, the retailer must lower its retail price to sustain sales and remain competitive. For the manufacturer, establishing a new channel requires maintaining the integrity of the original channel and ensuring the stability of the channel structure. Therefore, the manufacturer considers reducing the wholesale price to assist the retailer in surviving the intense channel competition. This indicates that when both the manufacturer and the retailer face the manufacturer's encroachment strategy, they mutually adjust prices to preserve channel structure stability, reflecting a cooperative approach.

Lemma 3. $d_r^{E*} < d_r^{N*}$ *if* $0 < s < \hat{s}_2(\lambda)$, *and vice versa, where* $\hat{s}_2(\lambda) = \frac{q(1+8\lambda)(\lambda-1)}{4\lambda(1+2\lambda)}$.

Lemma 3 demonstrates that if consumers exhibit a relatively low degree of privacy protection (i.e., $0 < s < \hat{s}_2(\lambda)$), the retailer invariably incurs sales losses due to manufacturer encroachment. In contrast, if consumers display a relatively high degree of privacy protection (i.e., $s > \hat{s}_2(\lambda) > 0$), the retailer can increase sales through manufacturer encroachment. This effect arises from the abundant digital tools available in the digital channel, which offers consumers an information-rich experience, making digital purchases highly attractive. If consumers have relatively low privacy protection levels (i.e., $0 < s < \hat{s}_2(\lambda)$), privacy concerns cause only minor discomfort, insufficient to deter consumers from engaging with the information-rich digital channel. Conversely, if consumers possess relatively high privacy protection levels (i.e., $s > \hat{s}_2(\lambda) > 0$), their significant concerns about potential misuse of private information outweigh the benefits of media richness. Consequently, consumers

tend to favor purchases through the physical channel. This suggests that retailers can infer consumers' privacy protection levels and assess how manufacturer encroachment impacts their sales accordingly.

Proposition 3. ***Impact of Encroachment Strategy on Retailer's Profit.*** *If the degree of consumers' privacy protection is relatively high (or low), the retailer can earn more (or less) profits under manufacturer encroachment. Namely,* $\pi_r^{E*} > \pi_r^{N*}$ *if* $s > \hat{s}_3(\lambda)$*, and vice versa, where* $\hat{s}_3(\lambda) = \frac{q(1+8\lambda)\sqrt{\lambda-1}}{4(1+2\lambda)\sqrt{\lambda}} > \hat{s}_2(\lambda)$.

Proposition 3 shows that, in contrast to Strategy S, which inevitably results in losses for the retailer when consumers favor privacy disclosure (i.e., $s < 0$), Strategy E may benefit the retailer when consumers prefer privacy protection (i.e., $s > 0$). Specifically, Strategy E yields higher retailer profits when consumers exhibit a sufficiently high degree of privacy protection (i.e., $s > \hat{s}_3(\lambda) > 0$), whereas Strategy N becomes preferable otherwise. This pattern stems from the positive correlation between the consumers' increased preference for privacy protection and their tendency to favor the indirect physical channel over the direct digital channel. Consequently, the physical channel gains a competitive advantage, allowing the retailer to increase product sales and generate higher profits. Conversely, if consumers display a relatively low inclination for privacy protection (i.e., $0 < s < \hat{s}_3(\lambda)$), the physical channel faces a competitive disadvantage, causing losses for the retailer in the channel competition. These findings suggest that the retailer can achieve profit growth through the manufacturer's encroachment strategy.

Fig. 3 graphically presents the results from Proposition 3, Lemma 2, and Lemma 3, providing insights into the impact of the manufacturer's channel strategies on the retailer's profitability under varying degrees of consumers' privacy preferences. In Region *I*, where consumers favor privacy disclosure, the retailer inevitably incurs losses when the manufacturer pursues encroachment due to the inability to maintain the physical channel, consistent with the finding in Lemma 1. Regions *II* and *III* both indicate that if consumers prefer privacy protection, the retailer experiences adverse outcomes under Strategy E compared to Strategy N. By synthesizing insights from Lemmas 2 and 3, we conduct a comprehensive analysis of the retailer's gains and losses. In Region *II* (left of the threshold $\hat{s}_2(\lambda)$), the retailer faces reductions in both retail prices and sales volume under Strategy E, resulting in lower profits than under Strategy N. Region *III* (right of the threshold $\hat{s}_2(\lambda)$) shows that although the physical channel's retail prices are lower under Strategy E than under Strategy N, increased sales volumes partially offset this effect. However, the positive impact of higher sales is insufficient to compensate for price reductions, preventing the retailer from achieving greater profits under Strategy E. Additionally, Region *IV* illustrates that the positive effect of expanded sales outweighs the negative effect of price reductions, allowing the retailer to benefit from Strategy E compared to Strategy N.

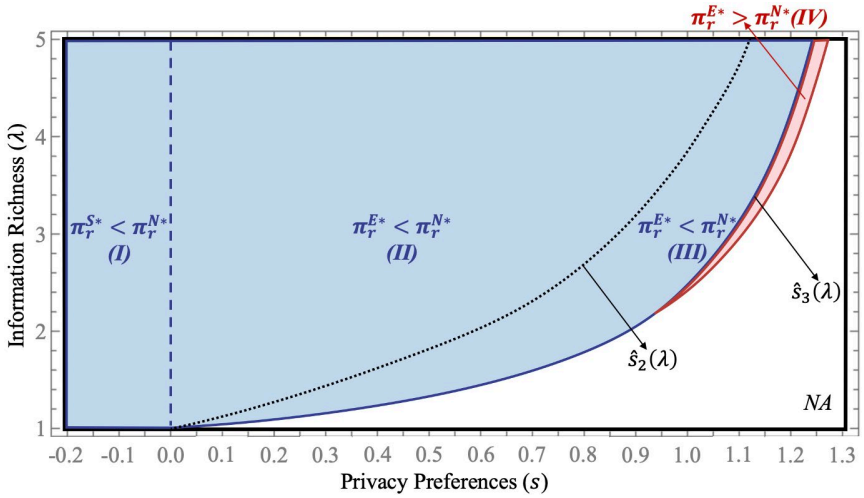

Fig. 3. Impact of Consumers' Privacy Preferences on Retailer's Profit ($q = 1.5$, $k = 0.03$)

Corollary 2. $\pi_m^{E*} > \pi_m^{N*}$ *and* $\pi_r^{E*} > \pi_r^{N*}$ *exist if* $0 < k < \hat{k}_1$; $\pi_m^{E*} < \pi_m^{N*}$ *and* $\pi_r^{E*} < \pi_r^{N*}$ *exist if* $k > \hat{k}_1$, *where* $\hat{k}_1 = \frac{q\left[9+8(1+10\lambda+16\lambda^2)\sqrt{\lambda(\lambda-1)}+\lambda(27-16\lambda-128\lambda^2)\right]}{64\lambda(1+2\lambda)^2}$.

The manufacturer's relatively high cost-efficiency in channel provision (i.e., $k < \hat{k}_1$) enables dual-channel distribution with lower costs. Consequently, the manufacturer can better absorb losses from consumer concerns over privacy infringements. The threshold $\hat{s}_1(\lambda)$ at which the manufacturer can achieve superior profits through Strategy E is significantly higher, indicating $\hat{s}_1(\lambda) > \hat{s}_3(\lambda)$. Thus, three possible scenarios arise between the manufacturer and the retailer (i.e., win-win, win-lose, and lose-win), allowing for mutually beneficial outcomes. Conversely, if the cost-efficiency is relatively low (i.e., $k > \hat{k}_1$), the manufacturer faces significant expenses to pursue encroachment. The threshold $\hat{s}_1(\lambda)$ for superior profits via Strategy E is notably lower, indicating $\hat{s}_1(\lambda) < \hat{s}_3(\lambda)$. Consequently, three possible scenarios exist between the manufacturer and the

retailer (i.e., lose-lose, win-lose, and lose-win), with the potential for a lose-lose outcome. Therefore, the retailer does not need to strongly oppose the manufacturer's encroachment strategy. When the manufacturer is relatively cost-efficient, opportunities for win-win outcomes between supply chain members arise.

Fig. 4 visually illustrates the insight derived from Corollary 2, showing that the manufacturer consistently achieves either increased or decreased profits under Strategy E, depending on the degree of cost-efficiency. Moreover, if consumers exhibit a relatively high (or low) inclination toward privacy protection, the retailer correspondingly experiences increased (or reduced) profits under Strategy E, consistent with the conclusions in Proposition 3.

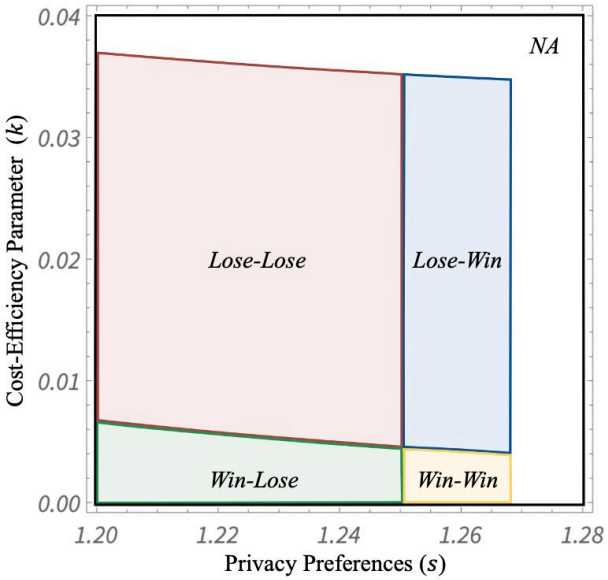

Fig. 4. Possible Outcomes for Both Players in the Game ($q = 1.5, \lambda = 5$)

Second, in examining a dyadic supply chain with a single manufacturer and a single retailer, assessing the impact of consumers' privacy preferences on overall supply chain profitability becomes more complex.

Proposition 4. ***Profit-improving Effect on the Supply Chain Under Shifting Strategy.*** *For the type of consumers who prefer privacy disclosure (i.e., $s < 0$), the profit of the overall supply chain is always higher after encroaching (i.e., $\pi_{sc}^{S*} > \pi_{sc}^{N*}$).*

Proposition 4 shows that if consumers favor privacy disclosure (i.e., $s < 0$), overall supply chain profitability remains unaffected by encroachment. Compared with Strategy N, although the retailer's profit decreases, the rise in the manufacturer's profit under Strategy S leads to an improvement in the overall supply chain's profitability. Therefore, in situations where consumers favor privacy disclosure, it is beneficial for the manufacturer to pursue encroachment to enhance overall supply chain profitability.

Proposition 5. ***Effect of Privacy Preferences on the Supply Chain Under Encroachment Strategy.*** *For the type of consumers who prefer privacy protection (i.e., $s > 0$), if the degree of consumers' privacy preferences is relatively intermediate (too high or too low), the profit of the overall supply chain decreases (increases) under the encroachment strategy. Namely, $\pi_{sc}^{E*} < \pi_{sc}^{N*}$ if $0 < \hat{s}_4(\lambda) < s < \hat{s}_5(\lambda)$, and vice versa, where $\hat{s}_4(\lambda) = \frac{2q\lambda\tau_1(1+8\lambda) - q\tau_1\sqrt{\frac{\lambda(16k\lambda\tau_9 - q\tau_8)}{q(\lambda-1)}}}{2\lambda\tau_9}$, $\hat{s}_5(\lambda) = \frac{2q\lambda\tau_1(1+8\lambda) + q\tau_1\sqrt{\frac{\lambda(16k\lambda\tau_9 - q\tau_8)}{q(\lambda-1)}}}{2\lambda\tau_9}$, $\tau_1 = (\lambda-1)(8+\lambda) > 0$, $\tau_8 = -9 + \lambda + 80\lambda^2 > 0$, and $\tau_9 = 3 + 5\lambda + 64\lambda^3 > 0$.*

Proposition 5 reveals that if consumers' privacy protection falls within a moderate range (i.e., $\hat{s}_4(\lambda) < s < \hat{s}_5(\lambda)$), encroachment reduces overall supply chain profit. Conversely, encroachment benefits the supply chain only if consumers' privacy protection is either extremely low or excessively high (i.e., $s < \hat{s}_4(\lambda)$ or $s > \hat{s}_5(\lambda)$). The profit of the overall supply chain is the aggregate of the manufacturer's and retailer's profits, expressed as $\pi_{sc}^{j*} = \pi_m^{j*} + \pi_r^{j*}$ ($j \in \{N, E\}$). In situations where consumers' privacy protection is relatively low or high (i.e., $s < \hat{s}_4(\lambda)$ or $s > \hat{s}_5(\lambda)$), the higher profit of one member offsets the reduced profit of the other under Strategy E compared with Strategy N, leading to a net gain for the supply chain. Conversely, if consumers' privacy protection lies in the intermediate range (i.e., $\hat{s}_4(\lambda) < s < \hat{s}_5(\lambda)$), the losses outweigh the gains after offsetting, resulting in a decline in overall supply chain profitability under Strategy E relative to Strategy N. Nevertheless, as indicated by Corollary 2, the profit interaction between the manufacturer and the retailer more complex. Therefore, we conduct a numerical analysis to visually illustrate the relationship between overall supply chain profit and the individual profits of both players.

Fig. 5 graphically presents the outcomes described in Proposition 5. Thresholds $\hat{s}_1(\lambda)$ and $\hat{s}_3(\lambda)$ are defined in Propositions 2 and 3, respectively. The thresholds $\hat{s}_1(\lambda)$, $\hat{s}_3(\lambda)$, and $\hat{s}_4(\lambda)$ (or $\hat{s}_5(\lambda)$) converge at the point $\hat{k}_1(\lambda)$. Regions *I* and *VI* both depict scenarios in which the manufacturer earns higher profits while the retailer incurs losses under Strategy E compared with Strategy N. However, Region *I* signifies a more significant loss for the retailer than gains for the manufacturer, while Region *VI* suggests that the manufacturer's gains outweigh the retailer's losses. Similarly, Regions *III* and *IV* represent scenarios in which the retailer gains more while the manufacturer loses under Strategy E relative to Strategy N. However, Region *III* suggests that the manufacturer's losses outweigh the retailer's gains, while Region *IV* indicates that the retailer's gains surpass the manufacturer's losses. Furthermore, Region *II* represents a scenario where both parties incur losses, leading to a reduction in overall supply chain profit under Strategy E compared with Strategy N. Region *V* indicates a win-win outcome in which both parties benefit, leading to an increase in overall supply chain profit under Strategy E relative to Strategy N.

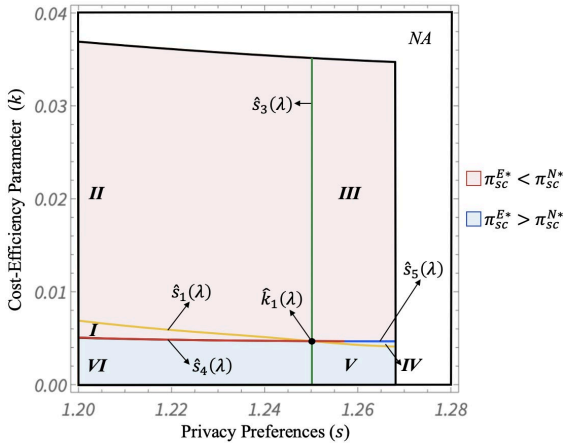

Fig. 5. Impact of Consumers' Privacy Preference on Supply Chain ($q = 1.5, \lambda = 5$)

Last, we examine the impact of manufacturer encroachment on consumer surplus.

Proposition 6. ***Consumer Surplus Enhancement Effect.*** *The manufacturer chooses to encroach can always enhance consumer surplus compared to not encroaching, i.e.,* $CS^{S*} > CS^{N*}$ *and* $CS^{E*} > CS^{N*}$.

Consumers consistently benefit when the manufacturer adopts an exclusive digital channel. Under Strategy S, consumer surplus increases due to improved quality perception and service precision, as described in Proposition 1. Under Strategy E, in addition to accurate product quality perception in the digital channel, the competition between the indirect physical channel and the direct digital channel further enhances consumer surplus. Therefore, the results indicate that manufacturers should consistently pursue encroachment to improve consumer surplus.

5. Conclusion

Based on a game-theoretical model, this study examines how the type and degree of consumers' privacy preferences affect a manufacturer's strategic encroachment decisions. Specifically, we analyze whether the manufacturer should encroach on the digital channel and whether to retain the existing indirect physical channel after encroaching. Operating in the digital channel enables the manufacturer to provide higher media richness to consumers, but it often raises significant privacy issues. Therefore, a manufacturer that initially distributes products exclusively through traditional physical retailers must carefully balance the benefits of media richness against the drawbacks of consumers' privacy issues when formulating its channel development strategies.

Our analysis yields several noteworthy findings. *First*, if consumers prefer privacy disclosure, the manufacturer cannot retain the original indirect channel and invariably adopts a shifting strategy to achieve encroachment. Additionally, if consumers prefer privacy protection, the manufacturer can preserve the original indirect channel. However, the manufacturer's decision to encroach depends on the degree of consumers' privacy protection. In particular, if consumers exhibit relatively low preferences for privacy protection, the manufacturer chooses an encroaching strategy to maximize profits. Conversely, if consumers exhibit relatively high preferences for privacy protection, the manufacturer selects a no-encroachment strategy. *Second*, the retailer does not inevitably incur losses when the manufacturer encroaches. If consumers exhibit relatively high preferences for privacy protection, the retailer may potentially achieve a win-win outcome with the manufacturer through encroachment, especially when the manufacturer has high cost-efficiency. In contrast, if consumers exhibit relatively low preferences for privacy protection or favor privacy disclosure, the retailer incurs losses when the manufacturer encroaches. *Third*, whether the supply chain's profit increases as a result of the manufacturer's encroachment

depends on the type and degree of consumers' privacy preferences. If consumers prefer privacy disclosure, the supply chain's profit unambiguously increases with the manufacturer encroachment, leveraging the digital channel's substantial competitive advantages. However, if consumers prefer privacy protection, the supply chain attains higher profits when the degree of privacy protection is either extremely high or extremely low. *Last*, consumer surplus consistently increases when the manufacturer engages in encroachment. On the one hand, this results from the media-rich experience offered by the digital channel; on the other hand, it arises from the intensified inter-channel competition caused by manufacturer encroachment, which further enhances consumer surplus.

Our findings provide several key managerial insights into how manufacturers can strategically navigate digital transformation while accounting for consumer privacy preferences. *First*, manufacturers should recognize that consumer privacy preferences substantially shape their optimal channel strategy. If consumers prefer privacy disclosure, manufacturers should shift entirely to the digital channel, as maintaining the original indirect channel is not feasible. Conversely, if consumers prefer privacy protection, manufacturers can retain the existing channel and decide whether to encroach based on the degree of privacy concern. This insight is particularly relevant for firms transitioning to digital platforms, as they must evaluate privacy concerns to inform channel development decisions. *Second*, the results highlight that manufacturer encroachment does not invariably cause retailer losses. In cases where consumers strongly prefer privacy protection, encroachment may create a win-win outcome, especially if the manufacturer's digital channel is cost-efficient. This implies that manufacturers and retailers should collaborate to monitor consumer privacy preferences. If privacy concerns are high, retailers can benefit from the expanded consumer reach enabled by the manufacturer's digital presence. Conversely, when consumers exhibit low privacy concerns or favor disclosure, retailers face a higher risk of financial losses, underscoring the need for proactive adaptation strategies. *Last*, given the heterogeneous effects of privacy preferences on supply chain dynamics, firms should actively track evolving privacy regulations and consumer sentiment. To align with consumer expectations, businesses expanding into digital channels should implement privacy-friendly policies, such as customizable data-sharing options and secure encryption methods. This strategic alignment serves as a competitive advantage, fostering consumer trust and enhancing long-term brand loyalty. By integrating these insights, firms can optimize digital transformation strategies, sustain retailer relationships, and improve overall supply chain performance while balancing consumer privacy expectations.

This study contributes theoretically by extending the literature on manufacturer encroachment, consumer privacy, and media richness. Additionally, this study offers managerial implications for manufacturers considering the establishment of a direct channel to encroach on the digital sphere. If consumers prefer privacy disclosure, encroachment clearly benefits the manufacturer but may require abandoning the original indirect channel. Conversely, if consumers prefer privacy protection, the manufacturer should treat the degree of consumers' privacy protection as a crucial factor in channel strategy selection.

This study provides directions for future research by examining the relationship between consumer privacy and manufacturer encroachment. First, this study primarily focuses on consumers' perspectives on privacy issues, and future research may explore the normative role of policymakers in addressing consumers' privacy issues. Second, future research can further investigate media richness by distinguishing between two distinct dimensions: information quality and quantity.

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APPENDIX

A.1 Proof of Table 2

(1) Benchmark: No-encroachment Strategy ($j = N$)

When the manufacturer chooses not to encroach on the direct digital channel, the utility function of consumers purchasing through the physical channel is $U_r^N = \theta q - p_r^N$. When $\theta \geq \frac{p_r^N}{q}$, the consumer's net utility is non-negative (i.e., $U_r^N \geq 0$). Therefore, the consumer demand function in the indirect physical channel without developing a new channel can be obtained as Eq.(1), i.e., $d_r^N = 1 - \frac{p_r^N}{q}$.

From Eq.(1), we get the profit of the retailer is $\pi_r^N(w^N) = \frac{(q-p_r^N)(p_r^N - w^N)}{q}$. Given w^N, taking the first-order and second-order derivatives of $\pi_r^N(w^N)$ with regard to p_r^N respectively, we have $\frac{\partial \pi_r^N(w^N)}{\partial p_r^N} = \frac{q+w^N-2p_r^N}{q}$ and $\frac{\partial^2 \pi_r^N(w^N)}{\partial (p_r^N)^2} = -\frac{2}{q}$. When $q > 0$, we get $\frac{\partial^2 \pi_r^N(w^N)}{\partial (p_r^N)^2} < 0$. Namely, the retailer's profit function $\pi_r^N(w^N)$ is concave in terms of p_r^N. Thus, according to the first-order optimality condition (FOC) and let $\frac{\partial \pi_r^N(w^N)}{\partial p_r^N} = 0$, we have the best response function as $p_r^N(w^N) = \frac{q+w^N}{2}$.

Substituting $p_r^N(w^N)$ into the manufacturer's profit function, we have $\pi_m^N = -k + w^N - \frac{w^N(q-w^N)}{2q}$. Then, taking the first-order and second-order derivatives of π_m^N with regard to w^N yields $\frac{\partial \pi_m^N}{\partial w^N} = \frac{q-2w^N}{2q}$ and $\frac{\partial^2 \pi_m^N}{\partial (w^N)^2} = -\frac{1}{q}$. So, we get $\frac{\partial^2 \pi_m^N}{\partial (w^N)^2} < 0$ because $q > 0$, which implies that π_m^N is concave in terms of w^N. Thus, according to the FOC and let $\frac{\partial \pi_m^N}{\partial w^N} = 0$, we have the equilibrium wholesale price is $w^{N*} = \frac{q}{2}$.

Substituting w^{N*} in $p_r^N(w^N)$, we have the equilibrium price in the indirect physical channel without developing a new channel is $p_r^{N*} = \frac{3q}{4}$.

Then, according to Eq.(3) and Eq.(4), we have the retailer's and manufacturer's optimal profit without developing a new channel as

$$\pi_r^{N*} = \frac{q}{16}, \tag{A.1}$$

$$\pi_m^{N*} = \frac{q}{8} - k. \tag{A.2}$$

In addition, according to Eq.(2), the consumer's surplus can be calculated as $CS^{N*} = \frac{q}{32}$.

(2) Encroachment Strategy ($j = E$)

When the manufacturer chooses to encroach on the digital channel based on the existing indirect physical channel, the utility functions of consumers purchasing through the physical channel and the digital channel are as follows:

$$\begin{cases} U_r^E = \theta q - p_r^E, \\ U_m^E = \theta \lambda q - p_m^E - s\lambda. \end{cases} \tag{A.3}$$

According to Eq.(A.3) we have the consumer's net utility in the indirect physical channel is non-negative (i.e., $U_r^E \geq 0$), and the consumer has more utility in the indirect physical channel than in the direct digital channel (i.e., $U_r^E \geq U_m^E$) when $\frac{p_r^E}{q} \leq \theta \leq \frac{p_r^E - p_m^E - s\lambda}{q(1-\lambda)}$. Similarly, when $\theta > \frac{p_r^E - p_m^E - s\lambda}{q(1-\lambda)}$, we have the consumer's net utility in the direct digital channel is non-negative (i.e., $U_m^E \geq 0$), and the consumer has more utility in the direct digital channel than in the indirect physical channel (i.e., $U_m^E > U_r^E$). Therefore, the consumer demand function when the manufacturer chooses the encroachment strategy can be obtained as Eq.(5), i.e., $d_r^E = \frac{p_m^E - (p_r^E - s)\lambda}{q(\lambda-1)}$ and $d_m^E = 1 + \frac{p_r^E - p_m^E - s\lambda}{q(\lambda-1)}$.

Substituting Eq.(5) in Eq.(3), we get the profit of the retailer is $\pi_r^E(w^E) = \frac{(p_r^E - w^E)(p_m^E - p_r^E\lambda + s\lambda)}{q(\lambda-1)}$. Given w^E, taking the first-order and second-order derivatives of $\pi_r^E(w^E)$ with regard to p_r^E respectively, we have

$\frac{\partial \pi_r^E(w^E)}{\partial p_r^E} = \frac{p_m^E+\lambda(s+w^E-2p_r^E)}{q(\lambda-1)}$ and $\frac{\partial^2 \pi_r^E(w^E)}{\partial (p_r^E)^2} = -\frac{2\lambda}{q(\lambda-1)}$.

Meanwhile, substituting Eq.(5) in Eq.(7), we have the manufacturer's profit function is $\pi_m^E(w^E) = \frac{p_m^E(p_r^E-p_m^E-q+w^E)+\lambda p_m^E(q-s)+\lambda w^E(s-p_r^E)+kq(1-\lambda^2)}{q(\lambda-1)}$. Given w^E, taking the first-order and second-order derivatives of $\pi_m^E(w^E)$ with regard to p_m^E respectively, we have $\frac{\partial \pi_m^E(w^E)}{\partial p_m^E} = \frac{p_r^E-2p_m^E+w^E+q(\lambda-1)-s\lambda}{q(\lambda-1)}$ and $\frac{\partial^2 \pi_m^E(w^E)}{\partial (p_m^E)^2} = -\frac{2}{q(\lambda-1)}$.

So, we get $\frac{\partial^2 \pi_r^E(w^E)}{\partial (p_r^E)^2} < 0$ and $\frac{\partial^2 \pi_m^E(w^E)}{\partial (p_m^E)^2} < 0$, because $q > 0$ and $\lambda > 1$, which implies that $\pi_r^E(w^E)$ and $\pi_m^E(w^E)$ are concave in terms of p_r^E and p_m^E, respectively. Thus, according to the FOCs and by letting $\frac{\partial \pi_r^E(w^E)}{\partial p_r^E} = 0$ and $\frac{\partial \pi_m^E(w^E)}{\partial p_m^E} = 0$ respectively, we obtain the best response functions in Eq.(A.4).

$$\begin{cases} p_r^E(w^E) = \dfrac{w^E - q + \lambda(q+s+2w^E)}{4\lambda-1}, \\ p_m^E(w^E) = \dfrac{\lambda\left[s+3w^E+2q(\lambda-1)-2s\lambda\right]}{4\lambda-1}. \end{cases} \tag{A.4}$$

Then, anticipating Eq.(A.4), the manufacturer's profit function can be written as $\pi_m^E = \frac{-k\tau_4(1+\lambda)+\tau_5-sw^E\lambda(\lambda-1)-\lambda\tau_6(w^E)^2+q\lambda\tau_1 w^E-4s\tau_7}{\tau_4}$, where $\tau_1 = (\lambda-1)(1+8\lambda) > 0$, $\tau_4 = q(\lambda-1)(1-4\lambda)^2 > 0$, $\tau_5 = [s\lambda(1-2\lambda)]^2 + [2q\lambda(\lambda-1)]^2 > 0$, $\tau_6 = -1-7\lambda+8\lambda^2 > 0$, and $\tau_7 = q\lambda(\lambda-1)(2\lambda-1) > 0$. Taking the first-order and second-order derivatives of π_m^E with regard to w^E respectively, yields $\frac{\partial \pi_m^E}{\partial w^E} = \frac{\lambda\left[q-s+8q\lambda-2w^E(1+8\lambda)\right]}{q(1-4\lambda)^2}$ and $\frac{\partial^2 \pi_m^E}{\partial (w^E)^2} = -\frac{2\lambda(1+8\lambda)}{q(1-4\lambda)^2}$.

It's straightforward that $\frac{\partial^2 \pi_m^E}{\partial (w^E)^2} < 0$ because $q > 0$ and $\lambda > 1$. So, according to the FOC and by letting $\frac{\partial \pi_m^E}{\partial w^E} = 0$, we have the equilibrium wholesale price $w^{E*} = \frac{q}{2} - \frac{s}{2(1+8\lambda)}$.

Thus, by substituting in Eq.(A.4), we get the equilibrium price of the retailer is $p_r^{E*} = \frac{q}{2} + \frac{s(1+4\lambda)}{2(1+8\lambda)}$, and the equilibrium price of the manufacturer is $p_m^{E*} = \lambda\left[\frac{q}{2} + \frac{s(1-8\lambda)}{2(1+8\lambda)}\right]$.

Then, according to w^{E*}, p_r^{E*}, and p_m^{E*}, we get the equilibrium profits of players and the optimal consumer surplus are:

$$\pi_r^{E*} = \frac{\lambda s^2(1+2\lambda)^2}{q\tau_1(1+8\lambda)}, \tag{A.5}$$

$$\pi_m^{E*} = -k(1+\lambda) + \frac{\lambda\left[q^2\tau_1 - 2qs\tau_6 + s^2\tau_2\right]}{4q\tau_1}, \tag{A.6}$$

$$CS^{E*} = \frac{\lambda\left[q^2\tau_1(1+8\lambda) - 2qs\tau_1(3+8\lambda) + s^2\tau_3\right]}{8q\tau_1(1+8\lambda)}, \tag{A.7}$$

where $\tau_1 = (\lambda-1)(1+8\lambda) > 0$, $\tau_2 = -1-3\lambda+8\lambda^2 > 0$, $\tau_3 = -5-23\lambda+64\lambda^3 > 0$, and $\tau_6 = -1-7\lambda+8\lambda^2 > 0$.

(3) Shifting Strategy ($j = S$)

When the manufacturer chooses to shift to the direct digital channel from the existing indirect physical channel, the utility function of consumers purchasing through the only digital channel is $U_m^S = \theta\lambda q - p_m^S - s\lambda$. When $\theta \geq \frac{p_m^S+s\lambda}{q\lambda}$, the consumer's net utility is non-negative (i.e., $U_m^S \geq 0$). Therefore, the consumer demand function in the indirect physical channel can be obtained as Eq.(8), i.e., $d_m^S = 1 - \frac{p_m^S+s\lambda}{q\lambda}$. To ensure $\frac{p_m^S+s\lambda}{q\lambda} \geq 0$, we construct a Lagrangian problem for the manufacturer $L\pi_m^S = p_m^S d_m^S - k\lambda + \mu_1(\frac{p_m^S+s\lambda}{q\lambda})$. There are two cases:

① When $\mu_1 = 0$:

From Eq.(8), we get the profit of the manufacture is $\pi_m^S = -k\lambda + p_m^S(1 - \frac{p_m^S+s\lambda}{q\lambda})$. Taking the first-order and second-order derivatives of π_m^S with regard to p_m^S, we have $\frac{\partial \pi_m^S}{\partial p_m^S} = \frac{(q-s)\lambda-2p_m^S}{q\lambda}$ and $\frac{\partial^2 \pi_m^S}{\partial (p_m^S)^2} = -\frac{2}{q\lambda}$. So, we get $\frac{\partial^2 \pi_m^S}{\partial (p_m^S)^2} < 0$ because $q > 0$ and $\lambda > 1$. Namely, the manufacturer's profit function π_m^S is concave in

terms of p_m^S. Thus, according to the first-order optimality condition (FOC) and let $\frac{\partial \pi_m^S}{\partial p_m^S} = 0$, we have the equilibrium retail price of the manufacturer is $p_m^{S*} = \frac{(q-s)\lambda}{2}$.

Substituting p_m^{S*} in Eq.(9) and Eq.(10), we have the manufacturer's optimal profit and the optimal consumer surplus as

$$\pi_m^{S*} = \frac{\lambda\left[(q-s)^2 - 4kq\right]}{4q}, \tag{A.8}$$

$$CS^{S*} = \frac{\lambda(q-s)^2}{8q}. \tag{A.9}$$

$\frac{p_m^{S*}+s\lambda}{q\lambda} \geq 0$ requires $q+s \geq 0$. Thus, when $q+s \geq 0$, we can obtain the equilibrium solutions mentioned above.

② When $\mu_1 > 0$:

From Eq.(8), the Lagrangian problem for the manufacturer is to maximize $L\pi_m^S = \frac{p_m^S(q\lambda - s\lambda + \mu_1) - (p_m^S)^2 + \lambda(s\mu_1 - kq\lambda)}{q\lambda}$. Taking the first-order and second-order derivatives of $L\pi_m^S$ with regard to p_m^S, we have $\frac{\partial L\pi_m^S}{\partial p_m^S} = \frac{(q-s)\lambda - 2p_m^S + \mu_1}{q\lambda}$ and $\frac{\partial^2 L\pi_m^S}{\partial (p_m^S)^2} = -\frac{2}{q\lambda}$. Taking the first-order derivative of $L\pi_m^S$ with regard to μ_1, we have $\frac{\partial L\pi_m^S}{\partial \mu_1} = \frac{p_m^S + s\lambda}{q\lambda}$. So, we get $\frac{\partial^2 L\pi_m^S}{\partial (p_m^S)^2} < 0$ because $q > 0$ and $\lambda > 1$. Namely, $L\pi_m^S$ is concave in terms of p_m^S. Thus, according to the FOCs and let $\frac{\partial L\pi_m^S}{\partial p_m^S} = 0$ and $\frac{\partial L\pi_m^S}{\partial \mu_1} = 0$, we obtain $p_m^{S*} = -s\lambda$ and $\mu_1^* = -(q+s)\lambda$.

Substituting p_m^{S*} in Eq.(9) and Eq.(10), we have the manufacturer's optimal profit and the optimal consumer surplus as

$$\pi_m^{S*} = -(k+s)\lambda, \tag{A.10}$$

$$CS^{S*} = \frac{q\lambda}{2}. \tag{A.11}$$

$\mu_1^* > 0$ and $\frac{p_m^{S*}+s\lambda}{q\lambda} \geq 0$ require $q+s < 0$. Thus, when $q+s < 0$, we can obtain the equilibrium solutions mentioned above.

A.2 Proof of Lemma 1

From Table 2, we have $w^{E*} = \frac{q}{2} - \frac{s}{2(1+8\lambda)}$ and $p_r^{E*} = \frac{q}{2} + \frac{s(1+4\lambda)}{2(1+8\lambda)}$. When $s < 0$, we get $w^{E*} > \frac{q}{2} > p_r^{E*}$ because of $\lambda > 1$. When $s > 0$, we get $w^{E*} < \frac{q}{2} < p_r^{E*}$ because of $\lambda > 1$.

A.3 Proof of Proposition 1

When $s < 0$, it cannot be guaranteed that the equilibrium wholesale price is less than the equilibrium retail price in the indirect physical channel (i.e., $w^{E*} = \frac{q}{2} - \frac{s}{2(1+8\lambda)} > p_r^{E*} = \frac{q}{2} + \frac{s(1+4\lambda)}{2(1+8\lambda)}$). In this situation, the manufacturer chooses Strategy S, which means he distributes products only through the direct digital channel.

① When $q+s \geq 0$:

From Table 2, we have $\Delta\pi_m^{SN*} = \pi_m^{S*} - \pi_m^{N*} = \frac{\lambda(q-s)^2}{4q} - \frac{q}{8} - k(\lambda-1)$. Because $k > 0$, $q > 0$, $\lambda > 1$, $s < 0$, and $\frac{\lambda\left[(q-s)^2 - 4kq\right]}{4q} > 0$ (to ensure the equilibrium profit of the manufacturer is positive under Strategy S), we have $\Delta\pi_m^{SN*} > 0$ always holds.

② When $q+s < 0$:

From Table 2, we have $\Delta\pi_m^{SN*} = \pi_m^{S*} - \pi_m^{N*} = -k(\lambda-1) - s\lambda - \frac{q}{8}$. Because $k > 0$, $q > 0$, $\lambda > 1$, $s < 0$,

and $-\lambda(k+s) > 0$ (to ensure the equilibrium profit of the manufacturer is positive under Strategy S), we have $\Delta\pi_m^{SN*} > 0$ always holds.

A.4 Proof of Proposition 2

From Table 2, we have

$$\Delta\pi_m^{EN*}(s) = \pi_m^{E*}(s) - \pi_m^{N*}(s) = \frac{1}{8}\left[q(2\lambda-1) - 4\lambda(2k+s) + \frac{2\lambda\tau_2 s^2}{q\tau_1}\right],$$

where $\tau_1 = (\lambda-1)(1+8\lambda) > 0$ and $\tau_2 = -1-3\lambda+8\lambda^2 > 0$.

Let $\Delta\pi_m^{EN*}(s) = 0$, we get the two positive roots of s, i.e., $\hat{s_0}(\lambda) = \frac{q\tau_1}{\tau_2} + \frac{q\tau_1}{2\lambda\tau_2}\sqrt{\frac{2\lambda[8k\lambda\tau_2 - q(1+3\lambda)]}{q\tau_1}}$ and $\hat{s}_1(\lambda) = \frac{q\tau_1}{\tau_2} - \frac{q\tau_1}{2\lambda\tau_2}\sqrt{\frac{2\lambda[8k\lambda\tau_2 - q(1+3\lambda)]}{q\tau_1}}$. However, the root $\hat{s_0}(\lambda)$ can not ensure both $s = \hat{s_0}(\lambda) > 0$ and $d_m^{E*} = \frac{s+s\lambda(1-8\lambda)+q\tau_1}{2q\tau_1} > 0$ (i.e., the equilibrium demand in the direct digital channel is positive) simultaneously. So, there is only one eligible root $\hat{s}_1(\lambda)$.

Taking the first-order derivative of $\Delta\pi_m^{EN*}(s)$ with regard to s, we get $\frac{\partial\Delta\pi_m^{EN*}(s)}{\partial s} = \frac{\lambda}{2}(\frac{s\tau_3}{q\tau_6} - 1)$.We have $\frac{s+s\lambda(1-8\lambda)+q\tau_1}{2q\tau_1} > 0$ to ensure the equilibrium demand in the direct digital channel is positive. In addition, $\lambda > 1$ and $s > 0$, we get $\frac{\partial\Delta\pi_m^{EN*}(s)}{\partial s} < 0$. Therefore, there exists a threshold $\hat{s}_1(\lambda)$ satisfying $\Delta\pi_m^{EN*} > 0$ if $0 < s < \hat{s}_1(\lambda)$; and $\Delta\pi_m^{EN*} < 0$ if $s > \hat{s}_1(\lambda)$.

Moreover, $\frac{2\lambda[8k\lambda\tau_2 - q(1+3\lambda)]}{q\tau_1} > 0$ needs to be satisfied to ensure that $\hat{s}_1(\lambda)$ is real. Let $\frac{2\lambda[8k\lambda\tau_2 - q(1+3\lambda)]}{q\tau_1} = 0$, we obtain the unique positive root of q, i.e., $q = \frac{8k\lambda\tau_2}{1+3\lambda}$. Then, we get $\frac{\partial\left[\frac{2\lambda[8k\lambda\tau_2 - q(1+3\lambda)]}{q\tau_1}\right]}{\partial q} = \frac{-8k\tau_2\lambda^2}{\tau_1 q^2} < 0$, because $k > 0$, $\lambda > 1$, and $q > 0$. So, when $q \in \left(0, \frac{8k\lambda\tau_2}{1+3\lambda}\right)$, the threshold $\hat{s}_1(\lambda)$ is real.

In summary, $\Delta\pi_m^{EN*} > 0$ if $0 < s < \hat{s}_1(\lambda)$ and $q \in \left(0, \frac{8k\lambda\tau_2}{1+3\lambda}\right)$; $\Delta\pi_m^{EN*} < 0$ if $s > \hat{s}_1(\lambda)$ and $q \in \left(0, \frac{8k\lambda\tau_2}{1+3\lambda}\right)$.

A.5 Proof of Corollary 1

There are two cases based on consumers' privacy preferences.

(1) Case 1: $s > 0$

From Table 2, we have $\Delta d^{EN*} = d_m^{E*} + d_r^{E*} - d_r^{N*} = \frac{q(1+8\lambda)-2s(1+4\lambda)}{4q(1+8\lambda)}$. Because $k > 0$, $q > 0$, $\lambda > 1$, $s > 0$, and $\frac{1}{2} + \frac{s+\lambda s(1-8\lambda)}{2q\tau_1} > 0$ (to ensure the optimal sales volume in the direct digital channel is positive under Strategy E, where $\tau_1 = (\lambda-1)(1+8\lambda) > 0$), we have $\Delta d^{EN*} > 0$ always holds.

(2) Case 2: $s < 0$

① When $q + s \geq 0$: From Table 2, we have $\Delta d^{SN*} = d_m^{S*} - d_r^{N*} = \frac{q-2s}{4q}$. Because $k > 0$, $q > 0$, $\lambda > 1$, and $s > 0$, we have $\Delta d^{SN*} > 0$ always holds.

② When $q + s < 0$: From Table 2, we have $\Delta d^{SN*} = d_m^{S*} - d_r^{N*} = \frac{3}{4} > 0$. Thus, we have $\Delta d^{SN*} > 0$ always holds.

A.6 Proof of Lemma 2

From Table 2, we have $\Delta w^{EN*} = w^{E*} - w^{N*} = \frac{-s}{2+16\lambda}$. Because $k > 0$, $q > 0$, $\lambda > 1$, and $s > 0$, we have $\Delta w^{EN*} < 0$ always holds.

From Table 2, we have $\Delta p_r^{EN*} = p_r^{E*} - p_r^{N*} = \frac{1}{4}(-q + s + \frac{s}{1+8\lambda})$. Because $k > 0$, $q > 0$, $\lambda > 1$, $s > 0$, and $\frac{1}{2} + \frac{s+\lambda s(1-8\lambda)}{2q\tau_1} > 0$ (to ensure the optimal sales volume in the direct digital channel is positive under Strategy E, where $\tau_1 = (\lambda-1)(1+8\lambda) > 0$), we have $\Delta p_r^{EN*} < 0$ always holds.

A.7 Proof of Lemma 3

From Table 2, we have

$$\Delta d_r^{EN*}(s) = d_r^{E*}(s) - d_r^{N*}(s) = -\frac{1}{4} + \frac{s\lambda(1+2\lambda)}{q\tau_1},$$

where $\tau_1 = (\lambda-1)(1+8\lambda) > 0$.

Let $\Delta d_r^{EN*}(s) = 0$, we get only one positive root of s, i.e., $\hat{s_2}(\lambda) = \frac{q\tau_1}{4\lambda(1+2\lambda)}$. Taking the first-order derivative of $\Delta d_r^{EN*}(s)$ with regard to s, we get $\frac{\partial \Delta d_r^{EN*}(s)}{\partial s} = \frac{\lambda(1+2\lambda)}{q\tau_6}$, where $\tau_6 = -1-7\lambda+8\lambda^2 > 0$. Because $k > 0$, $q > 0$, $\lambda > 1$ and $s > 0$, we have $\frac{\partial \Delta d_r^{EN*}(s)}{\partial s} > 0$. Therefore, there exists a threshold $\hat{s}_2(\lambda)$ satisfying $\Delta d_r^{EN*} < 0$ if $0 < s < \hat{s}_2(\lambda)$; and $\Delta d_r^{EN*} > 0$ if $s > \hat{s}_2(\lambda) > 0$.

A.8 Proof of Proposition 3

From Table 2, we have $\Delta\pi_r^{EN*}(s) = \pi_r^{E*}(s) - \pi_r^{N*}(s) = \frac{\lambda s^2(1+2\lambda)^2}{q\tau_1(1+8\lambda)} - \frac{q}{16}$, where $\tau_1 = (\lambda-1)(1+8\lambda) > 0$. Let $\Delta\pi_r^{EN*}(s) = 0$, we get the unique positive root of s, i.e., $\hat{s}_3(\lambda) = \frac{q(1+8\lambda)\sqrt{(-1+\lambda)}}{4(1+2\lambda)\sqrt{\lambda}}$. Taking the first-order derivative of $\Delta\pi_r^{EN*}(s)$ with regard to s, we have $\frac{\partial \Delta\pi_r^{EN*}(s)}{\partial s} = \frac{2s\lambda(1+2\lambda)^2}{q\tau_1(1+8\lambda)} > 0$, because $q > 0$, $s > 0$, and $\lambda > 1$. Therefore, there exists a threshold value of $\hat{s}_3(\lambda)$. Specifically, $\Delta\pi_r^{EN*} < 0$ if $0 < s < \hat{s}_3(\lambda)$, and $\Delta\pi_r^{EN*} > 0$ if $s > \hat{s}_3(\lambda)$.

Moreover, we obtain $\hat{s}_3(\lambda) > \hat{s}_2(\lambda)$ always hold because $q > 0$, $k > 0$, $\lambda > 1$, and $s > 0$.

A.9 Proof of Corollary 2

According to Proposition 2 and Proposition 3, let $\frac{\hat{s}_1}{\hat{s}_3} = 1$. Then,we get the unique positive root of k, i.e., $\hat{k}_1 = -\frac{q\left[9+8(1+10\lambda+16\lambda^2)\sqrt{\lambda(\lambda-1)}+\lambda(27-16\lambda-128\lambda^2)\right]}{64\lambda(1+2\lambda)^2}$. Taking the first-order derivative of $\frac{\hat{s}_1}{\hat{s}_3}$ with regard to k, we have $\frac{\partial\left[\frac{\hat{s}_1}{\hat{s}_3}\right]}{\partial k} = -\frac{8\lambda(1+2\lambda)\sqrt{2\lambda}}{q(1+8\lambda)\sqrt{\frac{\lambda[8k\lambda\tau_2 - q(1+3\lambda)]}{q(1+8\lambda)}}} < 0$, because $k > 0$, $q > 0$, and $\lambda > 1$. Therefore, there exists a threshold value of $\hat{k}_1$. Specifically, $\hat{s}_1 > \hat{s}_3$ if $0 < k < \hat{k}_1$, and $\hat{s}_1 < \hat{s}_3$ if $k > \hat{k}_1$.

Based on Proposition 2 and Proposition 3, there exists three situations between the manufacturer and the retailer (i.e., win-win, win-lose, and lose-win) if $\hat{s}_1 > \hat{s}_3$ (i.e., $0 < k < \hat{k}_1$). Otherwise, there exist three situations between the manufacturer and the retailer (i.e., lose-lose, win-lose, and lose-win) if $\hat{s}_1 < \hat{s}_3$ (i.e., $k > \hat{k}_1$).

A.10 Proof of Proposition 4

(1) Case 1: $q + s \geq 0$

From Table 2, we have $\pi_{sc}^{S*} = \pi_m^{S*} + \pi_r^{S*} = \frac{\lambda\left[(q-s)^2-4kq\right]}{4q}$ and $\pi_{sc}^{N*} = \pi_m^{N*} + \pi_r^{N*} = \frac{q-8k}{8} + \frac{q}{16}$. Thus, we get $\Delta\pi_{sc}^{SN*} = \pi_{sc}^{S*} - \pi_{sc}^{N*} = k(1-\lambda) - \frac{3q}{16} + \frac{\lambda(q-s)^2}{4q}$. Because $k > 0$, $q > 0$, $\lambda > 1$, $s < 0$, and $\frac{\lambda\left[(q-s)^2-4kq\right]}{4q} > 0$ (to ensure the equilibrium profit of the manufacturer is positive under Strategy S), we have $\Delta\pi_{sc}^{SN*} > 0$ always holds.

(2) Case 2: $q + s < 0$

From Table 2, we have $\pi_{sc}^{S*} = \pi_m^{S*} + \pi_r^{S*} = -\lambda(k+s)$ and $\pi_{sc}^{N*} = \pi_m^{N*} + \pi_r^{N*} = \frac{q-8k}{8} + \frac{q}{16}$. Thus, we get $\Delta\pi_{sc}^{SN*} = \pi_{sc}^{S*} - \pi_{sc}^{N*} = k(1-\lambda) - \frac{3q}{16} - s\lambda$. Because $k > 0$, $q > 0$, $\lambda > 1$, $s < 0$, $q + s < 0$, and $-\lambda(k+s) > 0$ (to ensure the equilibrium profit of the manufacturer is positive under Strategy S), we have $\Delta\pi_{sc}^{SN*} > 0$ always holds.

A.11 Proof of Proposition 5

From Table 2, we have $\pi_{sc}^{E*} = \pi_m^{E*} + \pi_r^{E*} = -k(1+\lambda) + \frac{\lambda\left[q^2\tau_1 + 2qs(4\lambda-\tau_2)+s^2\tau_2\right]}{4q\tau_1} + \frac{\lambda s^2(1+2\lambda)^2}{q\tau_1(1+8\lambda)}$ and $\pi_{sc}^{N*} = \pi_m^{N*} + \pi_r^{N*} = -k + \frac{3q}{16}$. Thus, we get

$$\Delta\pi_{sc}^{EN*}(s) = \pi_{sc}^{E*}(s) - \pi_{sc}^{N*}(s) = \frac{1}{16}\left[-8\lambda(2k+s) + q(4\lambda-3) + \frac{4\lambda\tau_9 s^2}{q\tau_1(1+8\lambda)}\right],$$

where $\tau_1 = (\lambda-1)(1+8\lambda) > 0$, $\tau_2 = -1-3\lambda+8\lambda^2 > 0$, and $\tau_9 = 3+5\lambda+64\lambda^3 > 0$.

Let $\Delta\pi_{sc}^{EN*}(s) = 0$, we get the two positive roots of s, i.e., $\hat{s}_4(\lambda) = \frac{2q\lambda\tau_1(1+8\lambda) - q\tau_1\sqrt{\frac{\lambda(16k\lambda\tau_9 - q\tau_8)}{q(\lambda-1))}}}{2\lambda\tau_9}$ and $\hat{s}_5(\lambda) = \frac{2q\lambda\tau_1(1+8\lambda) + q\tau_1\sqrt{\frac{\lambda(16k\lambda\tau_9 - q\tau_8)}{q(\lambda-1))}}}{2\lambda\tau_9}$, where $\tau_8 = -9+\lambda+80\lambda^2 > 0$. Additionally, $16k\lambda\tau_9 - q\tau_8 > 0$ needs to be satisfied to ensure that $\hat{s}_4(\lambda)$ and $\hat{s}_5(\lambda)$ are real. Let $16k\lambda\tau_9 - q\tau_8 = 0$, we obtain the unique positive root of q, i.e., $q = \frac{16k\lambda\tau_9}{\tau_8}$. Then, we get $\frac{\partial[16k\lambda\tau_9 - q\tau_8]}{\partial q} = 9 - \lambda(1+80\lambda) < 0$, because $k > 0$, $\lambda > 1$, $s > 0$, and $q > 0$. So, when $q \in \left(0, \frac{16k\lambda\tau_9}{\tau_8}\right)$, the threshold $\hat{s}_4(\lambda)$ and $\hat{s}_5(\lambda)$ are real.

Moreover, we obtain $\hat{s}_4(\lambda) < \hat{s}_5(\lambda)$ because $0 < q < \frac{16k\lambda\tau_9}{\tau_8}$, $s > 0$, $\lambda > 1$, and $k > 0$. According to $0 < q < \frac{16k\lambda\tau_9}{\tau_8}$, $\lambda > 1$, and $k > 0$, we get $\Delta\pi_{sc}^{EN*} > 0$ always hold if $0 < s < \hat{s}_4(\lambda)$. Similarly, because $0 < q < \frac{16k\lambda\tau_9}{\tau_8}$, $\lambda > 1$, and $k > 0$, we get $\Delta\pi_{sc}^{EN*} < 0$ always hold if $\hat{s}_4(\lambda) < s < \hat{s}_5(\lambda)$. Analogously, because $0 < q < \frac{16k\lambda\tau_9}{\tau_8}$, $\lambda > 1$, and $k > 0$, we get $\Delta\pi_{sc}^{EN*} > 0$ always hold if $s > \hat{s}_5(\lambda) > 0$. Therefore, there exists thresholds satisfying $\Delta\pi_{sc}^{EN*} > 0$ if $0 < s < \hat{s}_4(\lambda)$; $\Delta\pi_{sc}^{EN*} < 0$ if $\hat{s}_4(\lambda) < s < \hat{s}_5(\lambda)$; and $\Delta\pi_{sc}^{EN*} > 0$ if $s > \hat{s}_5(\lambda) > 0$.

A.12 Proof of Proposition 6

There are two cases based on consumers' privacy preferences.

(1) Case 1: $s > 0$

From Table 2, we have $\Delta CS^{EN*} = CS^{E*} - CS^{N*} = \frac{q(4\lambda-1)}{32} - \frac{s\lambda(3+8\lambda)}{4(1+8\lambda)} + \frac{\lambda\tau_3 s^2}{8q\tau_1(1+8\lambda)}$, where $\tau_1 = (-1+\lambda)(1+8\lambda) > 0$ and $\tau_3 = -5-23\lambda+64\lambda^3 > 0$. Because $q > 0$, $\lambda > 1$, and $s > 0$, we have $\Delta CS^{EN*} > 0$ always holds.

(2) Case 2: $s < 0$

① When $q + s \geq 0$:

From Table 2, we have $\Delta CS^{SN*} = CS^{S*} - CS^{N*} = \frac{\lambda(q-s)^2}{8q} - \frac{q}{32}$. Because $q > 0$, $\lambda > 1$, and $s > 0$, we have $\Delta CS^{SN*} > 0$ always holds.

② When $q + s < 0$:

From Table 2, we have $\Delta CS^{SN*} = CS^{S*} - CS^{N*} = \frac{q(16\lambda-1)}{32}$. Because $q > 0$, and $\lambda > 1$, we have $\Delta CS^{SN*} > 0$ always holds.