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Towards Zero-Carbon Cities: Optimal Sales Strategies of Green Building Materials Considering Consumer Purchasing Behaviors

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Abstract: The adoption of green building materials (GBMs) has become increasingly important in reducing carbon emissions and realizing zero-carbon cities. Although some scholars have investigated the decision-making of GBMs adoption in markets, they mainly focused on the impact factors of GBMs adoption without considering consumers' multi-channel purchasing behavior. Thus motivated, this paper aims to develop a theoretical game model incorporating consumers' multi-channel purchasing behavior and study the optimal sales strategies of GBMs manufacturers and retailers in markets for promoting GBMs adoption. To do this, not only the equilibrium outcome on sales strategy is examined, but also the effects of different GBMs sales strategies on urban environments and social welfare are theoretically verified. It is found that (1) the equilibrium sales strategy relies on two core parameters, namely matching rate and online return cost. Only when the matching rate is low and the online return cost is at a medium level can the GBMs manufacturer and retailer achieve a strategic consensus, and the equilibrium sales strategy is S (i.e., selling GBMs through the online channel, offline channel, and store-to-online channel). (2) When pursuing total profits of manufacturers and retailers in GBMs markets, the S sales strategy is 100% superior to the D sales strategy (i.e., selling GBMs only through online and offline channels). This is because the introduction of a store-to-online channel can reduce online return losses by providing consumers with physical experiences. (3) When pursuing social welfare (refers to public benefits including consumer surplus, urban environmental impacts, and others), the D sales strategy is optimal if the matching rate is relatively large and the return cost is low. (4) Under certain conditions, governments should incentivize GBMs manufacturers and retailers to adopt the D sales strategy through regulatory instruments, so as to achieve a balance between economic benefits and social benefits.

Keywords: consumer purchasing behaviors; dynamic game model; green building materials; zero-carbon cities



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1. Introduction

Over the past few decades, the emission of carbon dioxide (CO₂) has become a highly concerning issue on a global scale. More than 700 cities in 53 countries around the world have committed to reducing emissions by 50% by 2030 and achieving zero emissions by 2050. These cities include Chongqing, China; Bangkok, Thailand; Chuncheon, South Korea; Miami Beach, USA; Mumbai, India; and Rabat, Morocco, etc. (<https://www.c40.org/news/cities-committed-race-to-zero/>, accessed on 22 May 2025). From the perspective of city development, carbon dioxide (CO₂) emissions from buildings are quite concerning [1]. With the rise of mega cities, the building sector is facing issues of excessive energy consumption created by rapid industrialization and urbanization [2,3].

Traditional building materials not only exacerbate environmental pollution but also pose serious health risks to communities nearby [4]. To reduce carbon emissions and realize zero-carbon cities, many countries have encouraged green building materials (GBMs) adoption in urban building renovation [5]. GBMs, such as recycled materials (such as reclaimed wood salvaged from old buildings or fallen trees), natural/renewable materials (such as green flooring made from sustainably grown lumber), energy-efficient materials (such as photovoltaic glass that generates solar energy while acting as windows), and low-VOC materials (such as zero-VOC paints, natural clay plaster, formaldehyde-free plywood), are beneficial for environmental protection and human health [6–9]. Along with the implementation of the Greenest City Action Plan in the world's nations, the promotion and adoption of GBMs have become increasingly important.

However, the promotion and adoption of GBMs in markets face considerable challenges due to the presence of multiple stakeholders such as GBMs manufacturers, GBMs retailers, and consumers [3,10]. Among them, the GBMs manufacturers not only produce sustainable materials but recently have also set up online channels to directly sell them. The GBMs retailers, meanwhile, sell the manufacturers' products, which compete with the GBMs manufacturers' online channel [11,12]. As for the consumers, they can buy GBMs from the manufacturers' online channel or the retailers' offline channel but may face the problems of online returns or offline stockouts. Specifically, the suitability of GBMs cannot be experienced in the online channel and may cause consumers' returns, and the inventories in the offline channel are limited by storage space and may cause stockouts. As a result, the integration of online and offline channels has begun to emerge, which allows consumers to experience the GBMs offline and then buy them through the online channel if offline stockouts occur. In reality, the integration of online and offline channels is accelerating, creating an important new sales channel for the promotion of GBMs [13].

Facing operations with multiple purchasing channels (including online channel, offline channel, and the integration of online and offline channels), the GBMs manufacturers and retailers generate both cooperative and competitive interest relationships based on consumer purchasing behaviors [3]. During the sales process of GBMs, multi-agent participants will make optimal decisions based on the maximization of their own interests [4,13]. For this multi-stakeholder scenario, each game subject will be restricted by power struggles in the complex decision-making process [14,15]. These would lead to irrational behavior in the sales strategies of GBMs and may further cause a decline in the demand for GBMs. Therefore, developing optimal sales strategies based on consumer purchasing behaviors is crucial for GBMs manufacturers and retailers, which is also essential to promote the sales and adoption of GBMs. However, considering consumer purchasing preferences, the optimal sales strategies of GBMs in the market are still unknown.

Until now, the study of the optimal sales strategies of GBMs considering consumer purchasing preferences has thus far received little attention. Based on these premises, the objectives of this study are to respond to the following questions: (1) What are the optimal sales strategies of GBMs among the alliance-based manufacturers and retailers? (2) How do consumer purchasing behaviors under different channels affect the optimal prices and profits of alliance-based manufacturers and retailers? (3) For promoting the development of zero-carbon cities, how can the government guide decision-makers to accelerate the adoption and promotion of GBMs in setting strategic plans towards greener buildings? Upon these questions, the research framework of this paper can be briefly expressed as shown Figure 1.

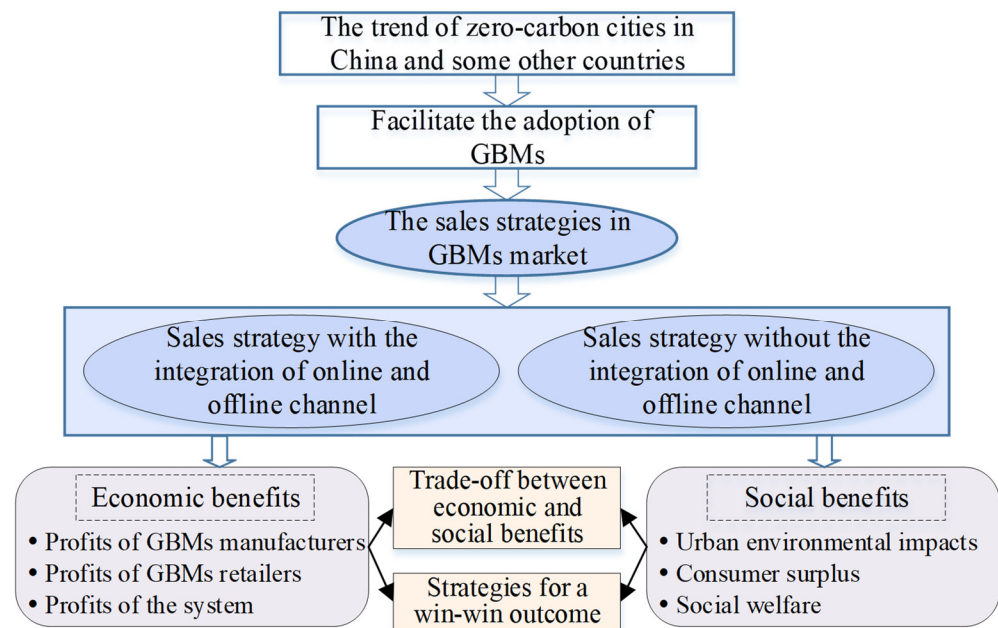


Figure 1. The research framework of this paper.

To resolve this dilemma, game theory is an important tool in mathematical modeling, which has been widely used to explore conflict and cooperation among stakeholders [13,16–18]. This suggests that using game theory for resolving strategic interactions between GBMs manufacturers, GBMs retailers and consumers, considering the preferences and behaviors of each party, is fruitful. Along this line, optimal sales strategies of GBMs considering consumer purchasing behavior are explored by building a dynamic game model. Based on this, the research gaps of this paper are as follows.

- (1) To explore optimal sales strategies of alliance-based GBMs manufacturers and retailers considering consumer purchasing behavior, a dynamic game model containing an online channel, an offline channel, and a store-to-online channel is proposed. We believe that this modeling approach can better measure the evolution of optimal GBMs sales strategies with heterogeneous consumer preferences.
- (2) Based on the goal of maximizing their interests among the group in terms of decision-making, the effects of different sales strategies on the urban environment and social welfare have been theoretically verified. In this framework, the contribution of this paper is to increase the understanding of the effect of different selected GBMs sales strategies on the urban environment and social welfare, which is of significant value in filling a gap in the synergistic effect of urban environment and social welfare by optimizing sales strategies in GBMs markets.
- (3) With regard to the goal of achieving zero-carbon cities in the future, the results of this paper can help governments better understand the positive role of GBMs manufacturers and GBMs retailers in formulating optimal sales strategies. Therefore, the results of this paper not only help GBMs enterprises in the market find optimal sales strategies considering different channels but also provide practical guidance in realizing the Greenest City Action Plan of China and some other countries.

The remainder of this paper is structured as follows: Section 2 provides a literature review. In Section 3, a dynamic game model considering the online channel, offline channel, and store-to-online channel is proposed. Section 4 gives analytical results and discussions. Section 5 provides theoretical and practical implications.

2. Literature Review

As a critical goal in the fight against climate change, urban areas are significant contributors to global carbon emissions, and innovative strategies are required to mitigate their impact [2,19,20]. Therefore, the development of zero-carbon cities plays a critical role in achieving the goals of carbon peaking and carbon neutralization in the future [21]. There are various studies that discuss drivers, challenges, and barriers to the development of zero-carbon cities in promoting green innovation, low carbon emissions, and green buildings [3,22,23]. Along this line, research on zero-carbon cities has attracted widespread attention from scholars in related fields. In numerous studies, the objectives at the city level were to reduce building energy use [24], to mitigate global warming [25], to reduce carbon footprint pressure [26], and so on. Because GBMs can significantly reduce the carbon footprint pressure of urban development, the adoption and application of GBMs are increasingly becoming focal points in achieving zero-carbon cities ([27]). For example, Chen et al. [6] demonstrated that reducing urban carbon emissions requires adapted government policies, carbon emission analysis, and sustainable materials. Liang et al. [28] pointed out that the application and certification of GBMs need to be rapidly promoted in the development of zero-carbon cities.

GBMs, as materials that are environmentally responsible and resource-efficient, are of vital importance for reducing the carbon footprint of buildings and have already contributed to the development of zero-carbon cities [29–32]. This has also attracted widespread attention from scholars in different fields [6,33]. To meet the growing demand for green building solutions, the sales strategies of GBMs are essential for both manufacturers and retailers in green supply chain management practices [13,15,34]. For the literature in this field, existing studies provided many findings on the barriers, drivers, certification, and supply and demand of GBMs adoption. For example, Feng et al. [35] argued that effective subsidy and penalty policies can motivate the adoption of GBMs between manufacturers and developers in the market. Qian et al. [13] provided the application scenario of the GBMs supply chain in encouraging the promotion of GBMs by formulating government policies. Guo et al. [36] explored the significant obstacles and key factors of GBMs promotion in China's green building evaluation. Eze et al. [37] revealed that the green construction market is unsaturated and under-tapped based on an assessment of the benefits of GBMs incorporation.

In the process of GBMs promotion, some scholars are paying attention to optimal sales strategies of GBMs among multiple stakeholders (i.e., manufacturers, retailers, and consumers) [4,38]. However, consumer purchasing preferences are increasingly influenced by the diversification of choices of purchasing channels (online or offline channels) in selecting and purchasing GBMs. To date, the existing literature has only focused on one aspect in supply chain management. From the perspective of manufacturers and retailers, He et al. [39] tackled the issue of green building betrayal within a two-tier green building supply chain comprising developers and contractors; Qian et al. [13] investigated the decision-making behavior of GBMs players (general contractors and manufacturers) by constructing a Stackelberg model. Guo et al. [36] examined strategy changes from the production of green building materials to the purchase and use of homes among multiple stakeholders (suppliers, developers, and homebuyers). From the perspective of consumers, Chen et al. [6] investigated whether and how different price premium display strategies adopted by companies influence consumers' preferences for green products. Rajendra et al. [40] suggested that the lack of a uniform rating system and certification system is the most critical challenge affecting GBMs adoption from the consumer behavior perspective. Yongbo and Zhang [41] found that the development of a green building market correlates with increased consumer willingness to purchase GBMs. Tsai [42] examines

whether city residents' willingness to pay for GBMs changed after the outbreak of the COVID-19 pandemic.

To sum up, previous studies relating to GBMs adoption have either explored the effect of GBMs on the development of green buildings and zero-carbon cities or focused on the role of one market entity in the green building supply chain. Many scholars have also studied the drivers, challenges, and barriers to the development of GBMs adoption or the green construction market. Although some scholars have investigated the decision-making behavior of GBMs adoption by different players, the existing literature has only focused on the impact factor of GBMs adoption. As mentioned above, the adoption and promotion of GBMs have involved multiple stakeholders in sales markets. With the development of the digital economy, the integration of online and offline spaces is accelerating, becoming an essential channel for the sales of GBMs. By reviewing the relevant literature, we found that optimal sales strategies of GBMs considering consumer purchasing behaviors for different purchasing channels have not yet been investigated. Further, we spotted a gap in the literature, consisting of the fact that, while consumer purchasing behaviors rely on the online channel, offline channel, and store-to-online channel, the optimal sales strategies of GBMs among manufacturers and retailers under a multi-channel background are still not adequately treated.

To intuitively present the position of our work in literature, we use Table 1 to summarize the methodology and key results of the most relevant studies.

Table 1. Summary of the most related studies.

Related Studies	Methodology	Key Results
Liu et al. [22]; Tian et al. [23]	Questionnaire survey and empirical research	Discussing drivers and barriers of green building development.
Eze et al. [37]	Questionnaire survey approach and snowball sampling techniques	Assessing the benefits of GBMs incorporation in the green construction market.
Feng et al. [35]	Evolutionary game model	Effective subsidy and penalty policies can motivate the adoption of GBMs.
Qian et al. [13]	Stackelberg model	Investigating the promotion of green building materials production through technology subsidies.
Guo et al. [36]	Multi-agent modeling	Examining strategy changes from the production of GBMs to the purchase and use of homes.
Liu et al. [8]	Text mining	Investigating consumers' preferences and attention to different attributes of green build products.
Ak et al. [38]	Semi-structured interviews and case study	Providing weight and normalization reference information for declaring the environmental information of building materials produced and exported.
Yongbo & Zhang [41]	Evolutionary game	The development of the green building market correlates with increased consumer willingness to purchase green buildings.
Tsai [42]	Empirical research	Examining whether city residents' willingness to pay for green buildings changed after the outbreak of the COVID-19 pandemic.
Iwuanyanwu et al. [30]	Literature research	Reviewing the latest innovations in green building materials and highlighting advances.

3. Research Method

3.1. Problem Description

In sales markets of green building materials (GBMs), GBMs manufacturers prevalently sell the same GBMs (e.g., eco-wood panels, eco-milk paint, photovoltaic glass, etc.) through both their online direct channel and offline retailers. For the offline channel, the GBMs manufacturer offers its green products to the retailer at wholesale price w ; and the GBMs retailer will order Q quantities of products from the GBMs manufacturer based on market demand. After that, the manufacturer and retailer will sell GBMs at retail price p for online and offline channels.

Consumers in the market cannot accurately identify the characteristics of GBMs in the online direct channel, such as color, model, and smell. Therefore, the GBMs manufacturer can cooperate with the GBMs retailer by introducing a “store-to-online” channel, which can allow consumers to touch and feel the GBMs offline and then purchase them online. Under this cooperation mode, the offline retailer not only sells GBMs to consumers, but also places non-sale exhibits in the store. When the store is out of stock, the GBMs retailer will guide consumers to touch and feel the exhibits and then go to the online ordering and purchasing GBMs. This will lead to a reduction in the number of online returns because of the physical experience, which helps the GBMs manufacturer save on return costs. Additionally, the GBMs retailer can also earn unit diversion revenue k from the GBMs manufacturer.

3.2. Utility Function and Cost Function

This subsection first presents the utility functions for consumers to purchase GBMs through the online channel, offline channel, and store-to-online channel, and then introduces the costs generated by the GBMs manufacturer or retailer during their multi-channel operations.

(1) Utility function

The GBMs market size is denoted by X and follows a uniform distribution from 0 to a [43,44]. When consumers buy GBMs through the online channel, they are usually unable to determine whether these products meet their purchasing preferences. Thus, the paper assumes that the probability of products matching consumers’ purchasing preferences in the GBMs market is θ (hereinafter referred to as the “matching rate”). If consumers’ purchasing preferences are matched, the consumers in the GBMs market can obtain a positive value v ; and the value is zero if it does not match.

When consumers purchase GBMs from the online channel, they will incur online hassle costs h_o , such as online search costs and waiting costs for purchasing GBMs. At the same time, considering that some merchants provide transportation insurance, this paper assumes that the logistics cost of consumer returns is borne by GBMs manufacturers. Therefore, the expected utility of consumers choosing the online channel for purchasing GBMs is expressed as Equation (1).

$$u_o = \theta(v - p) - h_o \quad (1)$$

When consumers choose the offline channel, they will incur offline hassle costs h_r , such as transportation costs to the physical store of GBMs. Considering the different transportation costs to the physical store when purchasing GBMs, this paper assumes that h_r follows a uniform distribution on the interval $[0, 1]$ [45]. Consumers will purchase GBMs only when these green products match their needs after visiting the physical store. As a result, the expected utility of consumers choosing the offline channel in purchasing GBMs is expressed as Equation (2).

$$u_r = \theta(v - p) - h_r \quad (2)$$

When the “store-to-online” channel is introduced by the GBMs manufacturer and the GBMs retailer, consumers can also purchase GBMs through this channel. That is, they can touch and feel the green building materials through exhibits in the store and then transfer to the online channel to make a purchase. In this process, consumers first incur offline hassle costs and then need to bear the online hassle costs h_o . Therefore, the expected utility of consumers choosing the “store-to-online” channel is obtained as Equation (3).

$$u_s = \theta(v - p - h_o) - h_r \quad (3)$$

(2) Cost function

When GBMs are returned using the online channel, the GBMs manufacturer will incur a unit return cost t , including the logistics and inventory costs caused by the return, as well as labor processing costs, etc. If the “store-to-online” channel is introduced, the retailer needs to place GBM exhibits in the store, which mainly incurs a fixed cost and does not affect decision-making, so we do not consider it in the model. Additionally, due to changes in market demand, the offline channel may run out of stock of products and not be able to meet consumer demand, whereas the online channel can readily meet consumer demand as the delivery lead time allows the manufacturer enough time to fulfill all online GBMs orders [46].

Based on the above description, this paper makes the following assumptions:

Assumption 1. The GBMs retailer’s diversion revenue k obtained from the GBMs manufacturer does not exceed $p/2$, because of the GBMs manufacturer’s stronger market power.

Assumption 2. The market size X follows a uniform distribution from 0 to a .

Assumption 3. The offline hassle cost h_r follows a uniform distribution on the interval $[0, 1]$.

Assumption 4. There is a delivery lead time for the online channel, which allows the manufacturer enough time to fulfill all online GBMs orders.

Additionally, the notations used in this article are summarized in Table 2.

Table 2. Model variables.

Variables	Explanation
Decision variables	
w	The wholesale price
Q	The product quality level
Other variables	
p	The retail price
k	Unit diversion revenue
X	The GBMs market size
θ	The probability of product matching consumers’ purchasing preferences in the GBMs market
v	The initial utility of consumers obtained from the GBMs
h_o, h_r	The hassle cost of the online channel and offline channel
u_o, u_r, u_s	The expected utility of consumers purchasing from the online channel, offline channel, and store-to-online channel
t	The unit return cost
d_o, d_r, d_s	The expected number of consumers who choose the online channel, offline channel, and store-to-online channel
π_m, π_r	The expected profit of the GBMs manufacturer and retailer
D, S	The sales strategy with and without the store-to-online channel

3.3. Model Construction and Analysis

(1) Dual-channel sales strategy (D)

When the GBMs manufacturer and retailer refuse to cooperate to introduce the “store-to-online” channel (hereinafter referred to as sales strategy D for convenience), consumers can only purchase GBMs through online or offline channels. Particularly if the offline channel is out of stock, consumers can purchase GBMs from the online channel. In reality, some retailers display real-time information about in-store GBMs inventory through WeChat malls [47], and thus, in this paper, we assume that consumers can learn about the GBMs retailer’s inventory information before going to the store.

Consumers in the GBMs market will choose purchase channels based on the principle of maximizing their utility. Accordingly, the following results can be obtained: ① when $u_o < u_r$ (i.e., $0 \leq h_r \leq h_o$), if there are GBMs inventories in the store, consumers will choose the offline channel to purchase GBMs, otherwise they will choose the online channel; ② when $u_o > u_r$ (i.e., $h_o < h_r \leq 1$), consumers always choose the online channel to buy GBMs. Therefore, consumers’ purchase behavior in the GBMs market under the D sales strategy is characterized in Figure 2.

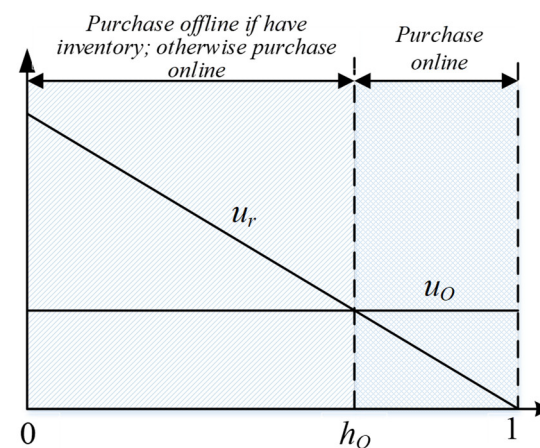


Figure 2. Consumers’ purchase behavior in the GBMs market under D sales strategy.

In the GBMs market, consumers who go offline will buy GBMs only if these green products match their preferences. Thus, if the inventory level of the offline channel is Q , the number of consumers who will learn that the offline channel is in stock can be expressed as Q/θ . Further, the number of consumers who learn that the offline channel is in stock and also decide to purchase GBMs from this channel is $\min(h_o X, Q/\theta)$. Accordingly, the number of consumers who decide to purchase GBMs from the offline channel but learn that this channel is out of stock is $(h_o X - Q/\theta)^+$.

From the above analysis, the expected number of consumers who choose the online channel to purchase GBMs d_o^D , and the expected number of consumers who choose the offline channel to purchase GBMs d_r^D are defined as Equations (4) and (5).

$$d_o^D = E((1 - h_o)X) + E\left(h_o X - \frac{Q}{\theta}\right)^+ \quad (4)$$

$$d_r^D = E\min\left(h_o X, \frac{Q}{\theta}\right) \quad (5)$$

In this case, the GBM manufacturer determines the wholesale price w first; then, the GBMs retailer determines the order quantity Q . Thus, optimization problems faced by the GBMs manufacturer and retailer are shown as Equations (6) and (7).

$$\max_w \pi_m^D = (p\theta - t(1 - \theta))d_o^D + wQ \quad (6)$$

$$\max_Q \pi_r^D = p\theta d_r^D - wQ \quad (7)$$

Theorem 1. When the GBMs manufacturer and retailer adopt the D sales strategy, equilibrium decisions and expected profits of each participant are shown as Equations (8)–(11).

$$w^{D*} = p \int_{\frac{Q^{D*}}{\theta h_o}}^{\infty} f(x) dx = \frac{p^2 \theta}{p\theta + t - t\theta} \quad (8)$$

$$Q^{D*} = \frac{t(1 - \theta)\theta h_o a}{p\theta + t - t\theta} \quad (9)$$

$$\pi_m^{D*} = \frac{(t^2(1 - \theta)^2 h_o + (p\theta - t\theta + t)(p\theta + t\theta + t))a}{2(p\theta - t\theta + t)} \quad (10)$$

$$\pi_r^{D*} = \frac{pt^2(1 - \theta)^2 \theta a h_o}{2(p\theta - t\theta + t)^2} \quad (11)$$

From Theorem 1, we can observe that the decisions of each participant are affected by the return cost t . Further, we derive that $\partial w^{D*} / \partial t < 0$ and $\partial Q^{D*} / \partial t > 0$, suggesting that the GBMs manufacturer will reduce its wholesale price if the return cost of GBMs becomes higher; and the retailer will increase its GBMs order quantity accordingly.

Furthermore, to examine the impact of the matching rate on the GBMs retailer's order quantity, we conduct a sensitivity analysis, as shown in Corollary 1.

Corollary 1. When the GBMs manufacturer and retailer adopt the D sales strategy of GBMs, the effect of matching rate on the GBMs retailer's order quantity is $\frac{\partial Q^{D*}}{\partial \theta} > 0$ if $\theta < \frac{\sqrt{pt} - t}{p - t}$ and $\frac{\partial Q^{D*}}{\partial \theta} < 0$ otherwise.

Corollary 1 shows that the effect of matching rate on the GBMs' order quantity is not monotonic. As the matching rate increases, the effect of matching rate on the GBMs order quantity is first positive and then negative. This is because, given the wholesale price w , the GBMs retailer's optimal order quantity is $(p - w)\theta a h_o / p$. From $\partial w^{D*} / \partial \theta > 0$, we know that an increase in the matching rate leads to a higher wholesale price for the GBMs manufacturer and a consequent decrease in the GBMs retailer's order quantity. However, on the other hand, an increased matching rate means that more consumers who come into the store will eventually make a purchase, and in response to this change, the GBMs retailer will increase its order quantity. When the product matching rate is relatively small, the latter has a greater impact, so an increase in the matching rate will stimulate the GBMs retailer to order more; conversely, the former has a greater impact, and an increase in the matching rate will inhibit the GBMs retailer's ordering behavior.

(2) Introducing a store-to-online channel (S)

When the GBMs manufacturer cooperates with the GBMs retailer in introducing a "store-to-online" channel (hereafter referred to as sales strategy S for ease of presentation), consumers have more channel choices to purchase GBMs. Under this condition, when

$u_o < u_s$ (i.e., $0 \leq h_r \leq (1 - \theta)h_o$), consumers will choose the offline channel to purchase GBMs if there are in-store inventories and choose the store-to-online channel otherwise. When $u_s < u_o < u_r$ (i.e., $(1 - \theta)h_o < h_r \leq h_o$), consumers will choose the offline channel to purchase GBMs if there are in-store inventories and choose the online channel otherwise. If $u_o > u_r$ (i.e., $h_o < h_r \leq 1$), no matter whether there are GBMs inventories in the store, consumers always choose the online channel. Therefore, consumers' purchase behavior in the GBMs market under S sales strategy is characterized in Figure 3.

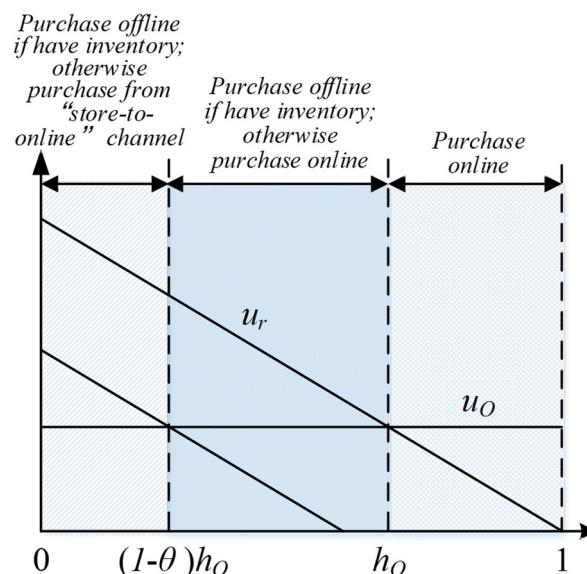


Figure 3. Consumers' purchase behavior in the GBMs market under S sales strategy.

Based on the above analysis, the expected number of consumers choosing the online channel d_o^S , the expected number of consumers choosing the offline channel d_r^S , and the expected number of consumers choosing the "store-to-online" channel d_s^S are computed by Equations (12)–(14).

$$d_o^S = E((1 - h_o)X) + E\left(\theta\left(h_o X - \frac{Q}{\theta}\right)^+\right) \quad (12)$$

$$d_r^S = E\min\left(h_o X, \frac{Q}{\theta}\right) \quad (13)$$

$$d_s^S = E\left((1 - \theta)\left(h_o X - \frac{Q}{\theta}\right)^+\right) \quad (14)$$

Similar to case D, the GBMs manufacturer determines the wholesale price w firstly; then, the GBMs retailer determines the order quantity Q . Accordingly, optimization problems of the GBMs manufacturer and retailer are shown as Equations (15) and (16).

$$\max_w \pi_m^S = (p\theta - t(1 - \theta))d_o^S + (p - k)\theta d_s^S + wQ \quad (15)$$

$$\max_Q \pi_r^S = p\theta d_r^S + k\theta d_s^S - wQ \quad (16)$$

Theorem 2. When the GBMs manufacturer and retailer adopt the S sales strategy, equilibrium decisions and expected profits of each participant are expressed as Equations (17)–(20).

$$w^{S*} = (p - k(1 - \theta)) \int_{\frac{Q^{S*}}{\theta h_0}}^{\infty} f(x) dx = \frac{(p - k + k\theta)^2}{p - k + k\theta + t - t\theta} \quad (17)$$

$$Q^{S*} = \frac{t\theta(1 - \theta)ah_0}{p - k + k\theta + t - t\theta} \quad (18)$$

$$\pi_m^{S*} = \frac{((p\theta + t\theta - t)A_1 - (1 - \theta)(-(1 - \theta)t^2 - (1 - \theta)(p - k)t + k\theta(k\theta + p - k))h_0)a}{2A_1} \quad (19)$$

$$\pi_r^{S*} = \frac{(1 - \theta)(p(1 - \theta)t^2 + 2k(1 - \theta)(k\theta + p - k)t + k(k\theta + p - k)^2)\theta ah_0}{2A_1^2} \quad (20)$$

where $A_1 = p - k + k\theta + t - t\theta$.

From Theorem 2, we derive that $\partial w^{S*}/\partial t < 0$, $\partial Q^{S*}/\partial t > 0$, and $\partial w^{S*}/\partial \theta > 0$, which are similar to those under the D sales strategy. Further, we obtain that when $(\sqrt{p(p - k)} - p + k)/k < \theta < (2p - k - \sqrt{2p^2 - kp})/(p - k)$ and $t < (k\theta^2 + (2\theta - 1)(p - k))/(1 - \theta)^2$, or when $\theta > (2p - k - \sqrt{2p^2 - kp})/(p - k)$, then $\partial Q^{S*}/\partial \theta < 0$. This means that a higher matching rate will induce the GBMs retailer to set a lower inventory level under certain conditions. The reason lies in that the GBMs manufacturer's wholesale price increases in matching rate and then leads to higher ordering costs of the GBMs retailer.

Further, we know that under case S, the optimal decisions of the GBMs manufacturer and retailer are also affected by the diversion revenues k . We derive that $\partial w^{C*}/\partial k < 0$ and $\partial Q^{C*}/\partial k > 0$, suggesting that, as k increases, the GBMs manufacturer will reduce the wholesale price and the GBMs retailer will increase the order quantity. This is because, under case S, if the store is out of stock, the GBMs retailer will obtain a unit expected revenue $(1 - \theta)k$ from the GBMs manufacturer by recommending consumers to the online channel. As a result, the GBMs retailer's stockout cost becomes $p - w - (1 - \theta)k$. Moreover, the higher the value of k , the lower the stockout cost of the GBMs retailer, which will reduce the GBMs retailer's incentives for stocking up. In order to avoid the GBMs retailer holding inventory too low, the GBMs manufacturer will appropriately reduce the wholesale price. Under the effect of wholesale price, the GBMs retailer will choose to increase the order quantity.

Under the S sales strategy, the online hassle cost will affect the GBMs manufacturer's profit through both the online channel and store-to-online channel. Thus, we make Corollary 2 to study this effect in detail.

Corollary 2. The effect of online hassle cost h_0 on the GBMs manufacturer's profit is as follows:

- ① When $0 < \theta < \theta_h$ and $0 < t < t_h$, or when $\theta_h < \theta < 1$, we have $\frac{\partial \pi_m^{S*}}{\partial h_0} < 0$.
- ② When $0 < \theta < \theta_h$ and $t > t_h$, we have $\frac{\partial \pi_m^{S*}}{\partial h_0} > 0$.

$$\text{where } \theta_h = \frac{-2p^2 + k^2 + \sqrt{4p^4 + 4p^2k^2 - 4pk^3 + k^4}}{2k^2}, \text{ and}$$

$$t_h = \frac{p\theta - k\theta - p + k + \sqrt{-4k^2\theta^3 + (p - 3k)^2\theta^2 - 2(p - k)(p - 3k)\theta + (p - k)^2}}{2(1 - \theta)}.$$

Corollary 2 shows an interesting result. When the matching rate is relatively low and the return costs are large, the reduction in online hassle cost will hurt the GBMs manufacturer's profit. This is because, although the reduction of online hassle cost will attract more consumers to purchase from the online channel, when $0 < \theta < \theta_h$ and $t > t_h$,

the unit expected revenue obtained by the GBMs manufacturer from the online channel is greatly reduced, and may even be lower than the expected revenue brought by other channels. And thus, the GBMs manufacturer will lose profits when more consumers shift from other channels to the online channel. Corollary 2 suggests that the GBMs manufacturer does not necessarily benefit from providing more convenience to the online consumers (i.e., reducing online hassle costs h_o), and they should adjust the online hassle cost based on considering the impact of the matching rate and return cost.

(3) Equilibrium decisions comparison between D and S sales strategies

By comparing the equilibrium wholesale price and order quantity under D and S sales strategies, we obtain Proposition 1.

Proposition 1. *The equilibrium decision changes of the GBMs manufacturer and retailer under the two sales strategies (i.e., D and S sales strategies) are as follows:*

① When $0 < \theta < \underline{\theta}$ and $0 < t < t_1$, or when $\underline{\theta} < \theta < 1$, we have $w^{S*} < w^{D*}$ and $Q^{S*} < Q^{D*}$.

② When $0 < \theta < \underline{\theta}$ and $t > t_1$, we have $w^{S*} > w^{D*}$ and $Q^{S*} < Q^{D*}$.

Where $\underline{\theta} = \min\left(\frac{p^2-2pk+k^2}{p^2-pk+k^2}, \frac{p^2-3pk+2k^2}{2k^2}\right)$, and $t_1 = \frac{pk\theta(k\theta+p-k)}{(1-\theta)(-k^2\theta+p^2-2pk+k^2)}$.

Proposition 1 indicates that the GBMs manufacturer will raise or lower the wholesale price according to different matching rates and return costs, while the GBMs retailer will always reduce the order quantity. Particularly, Proposition 1 (1) shows that, when the sales strategy adopted changes from D to S, the GBMs manufacturer will reduce the wholesale price; however, this does not cause the GBMs retailer to increase its order quantity. The reason is as follows. Under strategy S, the GBMs manufacturer and retailer cooperate to introduce the “store-to-online” channel. At this time, the retailer’s stockout cost changes from $p - w^{D*}$ to $p - w^{B*} - (1 - \theta)k$, and the difference is $(w^{D*} - w^{B*}) - (1 - \theta)k$. When both the matching rate and the return cost are small or the matching rate is high, after the introduction of a “store-to-online” channel, the GBMs manufacturer will reduce the wholesale price and lead to an increase in the stockout cost of the GBMs retailer, but the existence of diversion revenue k will lower the GBMs retailer’s stockout cost. The effect of the diversion revenue outweighs the effect of the wholesale price, so the GBMs retailer will reduce its order quantity. Proposition 1 states that the introduction of store-to-online channels always leads the GBMs retailer to reduce in-store inventory holdings, which explains the real-life phenomenon that GBMs retailers with showroom functions normally tend to hold less inventory.

4. Results and Discussions

4.1. Optimal Sales Strategy of GBMs Considering Inventory Risk

(1) Equilibrium GBMs sales strategy

Before examining the equilibrium GBMs sales strategy, we first analyze the profit differences of each participating member as well as the whole system under S and D sales strategies. Based on Equations (10), (11), (19) and (20), the profit differences can be obtained, as shown in Equations (21)–(23).

$$\pi_m^{S*} - \pi_m^{D*} = (t(1 - \theta) - k\theta)(d_o^{D*} - d_o^{S*}) + (p - k)\theta(d_r^{D*} - d_r^{S*}) + G \quad (21)$$

$$\pi_r^{S*} - \pi_r^{D*} = k\theta(d_o^{D*} - d_o^{S*}) - (p - k)\theta(d_r^{D*} - d_r^{S*}) - G \quad (22)$$

$$(\pi_m^{S*} + \pi_r^{S*}) - (\pi_m^{D*} + \pi_r^{D*}) = t(1 - \theta)(d_o^{D*} - d_o^{S*}) \quad (23)$$

where $G = w^{S*}Q^{S*} - w^{D*}Q^{D*}$, representing the change in the wholesale income of the GBMs manufacturer under D and S sales strategies. For the GBMs retailer, G also represents the difference in the order cost under the two sales strategies.

From Equation (23), the S sales strategy with a store-to-online channel will bring more benefit to the alliance-based system compared to the D sales strategy, i.e., $(\pi_m^{S*} + \pi_r^{S*}) - (\pi_m^{D*} + \pi_r^{D*}) > 0$. This is because the store-to-online channel provides consumers with a better product experience than the online channel, which reduces GBMs returns from the consumers who have “shifted from online to store-to-online channel”. According to Equations (21) and (22), the introduction of a store-to-online channel under the S strategy will generate two effects: One is that it will cause adjustments in the GBMs manufacturer’s and retailer’s equilibrium decisions, and the other is that it will result in the shifting behavior of consumers, both of which will affect the GBMs manufacturer’s and retailer’s profits. Since $G < 0$, it means that the adjustment of equilibrium decisions will lead to a decrease in wholesale revenue for GBMs manufacturer and the decrease in GBMs retailer’s ordering cost. Therefore, optimal sales strategies of GBMs considering consumer purchasing behavior need to be further analyzed, as shown in Proposition 2.

Proposition 2. *The equilibrium sales strategies of GBMs between the manufacturer and retailer considering consumer purchasing behavior are shown in Table 3.*

Table 3. The equilibrium sales strategies of GBMs.

Conditions		Preference of the GBMs Manufacturer	Preference of the GBMs Retailer	Consistent?	Equilibrium GBMs Sales Strategy
$0 < \theta < \underline{\theta}$	$0 < t < t_1$	$\pi_m^{S*} < \pi_m^{D*}$	$\pi_r^{S*} > \pi_r^{D*}$	No	/
	$t_1 < t < \min(t_2, \bar{t})$	$\pi_m^{S*} > \pi_m^{D*}$	$\pi_r^{S*} > \pi_r^{D*}$	Yes	S
	$t_2 < t < \bar{t}$	$\pi_m^{S*} > \pi_m^{D*}$	$\pi_r^{S*} < \pi_r^{D*}$	No	/
$\underline{\theta} < \theta < 1$	$0 < t < \bar{t}$	$\pi_m^{S*} < \pi_m^{D*}$	$\pi_r^{S*} > \pi_r^{D*}$	No	/

Where $\underline{\theta} = \min(\theta_4, \theta_5)$, $\theta_4 = \frac{p^2 - 2pk + k^2}{p^2 - pk + k^2}$, and $\theta_5 = \frac{p^2 - 3pk + 2k^2}{2k^2}$; t_2 satisfies $\pi_r^{S*} - \pi_r^{D*} = 0$, $\bar{t} = \min(t_3, p)$, and $t_3 = \frac{p\theta}{1-\theta}$.

Proposition 2 gives the sales strategy preferences of the GBMs manufacturer and retailer, as shown in Figure 4a,b. The specific analysis is as follows.

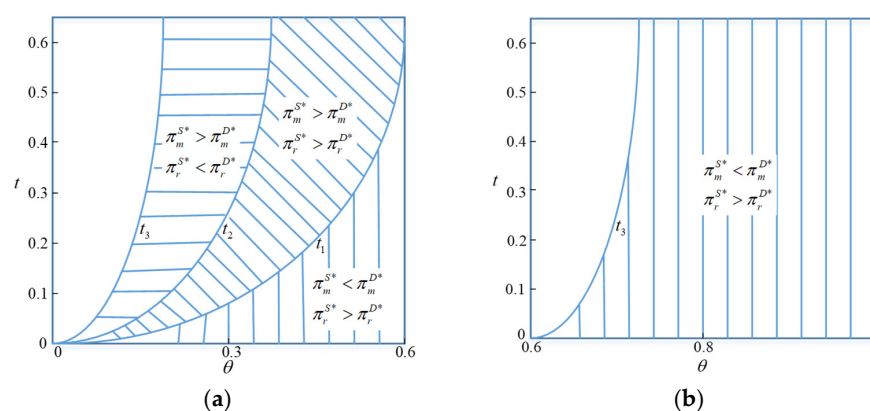


Figure 4. (a) The sales strategy preferences when $0 < \theta < \underline{\theta}$. (b) The sales strategy preferences when $\underline{\theta} < \theta < 1$.

For the GBMs manufacturer, when the matching rate is small ($0 < \theta < \underline{\theta}$), as the return cost of the online channel increases, the GBMs manufacturer’s strategic preference changes

from D to S. This is because a low matching rate implies a large return volume in the online channel. When the return cost of GBMs is not very high, there are limited return losses from the online channel, and the GBMs manufacturer prefers the D sales strategy. However, when the return cost is above a certain threshold, the GBMs manufacturer's return loss becomes so high that it has to introduce a store-to-online channel, so that some consumers can experience the GBMs offline and then buy them online. As a result, the optimal GBMs sales strategy becomes S. When the matching rate is relatively large ($\underline{\theta} < \theta < 1$), the GBMs manufacturer does not have a large number of returns in the online channel, so the GBMs manufacturer always prefers the D sales strategy.

For the GBMs retailer, when the matching rate is relatively small ($0 < \theta < \underline{\theta}$), the GBMs retailer prefers the S sales strategy if the return cost is below a certain threshold ($0 < t < \min(t_2, \bar{t})$), and prefers the D sales strategy if $t_2 < t < \bar{t}$. This is because, when the matching rate is relatively small, the return losses of the online channel are high, and the GBMs manufacturer will pay more attention to the offline retail channel. Under this condition, if the return cost is low, the GBMs manufacturer will set a higher wholesale price, which hurts the GBMs retailer's offline sales revenue. As a result, the GBMs retailer prefers the S sales strategy to earn additional profit from the store-to-online channel. As the return cost becomes higher, the GBMs manufacturer's wholesale price decreases, and the GBMs retailer prefers the D sales strategy to earn more offline sales revenue. When the matching rate is relatively high ($\underline{\theta} < \theta < 1$), the online return losses are not serious, and the GBMs manufacturer will increase the wholesale price. At this time, the GBMs retailer has to introduce the store-to-online channel to expand revenue streams.

From the above analysis of Proposition 2, both the GBMs manufacturer and retailer prefer the S sales strategy when the matching rate is relatively low and the return cost is at an intermediate level (i.e., $0 < \theta < \underline{\theta}$ and $t_1 < t < \min(t_2, \bar{t})$), and the equilibrium GBMs sales strategy in this scenario is the S sales strategy. When the matching rate is relatively low and the return cost is relatively large ($0 < \theta < \underline{\theta}$ and $t_2 < t < \bar{t}$), the GBMs manufacturer prefers the S sales strategy, but the GBMs retailer does not. For ease of description, this situation is called Scenario I in the following. When both the matching rate and the return cost are low ($0 < \theta < \underline{\theta}$ and $0 < t < t_1$), or when the matching rate is large ($\underline{\theta} < \theta < 1$), the GBMs retailer prefers the S sales strategy, but the GBMs manufacturer does not, which will be referred to as Scenario II in the following. Scenarios I and II are carefully analyzed below.

(2) Pareto improvement of GBMs sales strategy

In this subsection, this paper studies the optimal GBMs sales strategy under Scenarios I and II from the perspective of the alliance-based system.

Proposition 3. *For Scenarios I and II, this paper derives that $(\pi_m^{S*} + \pi_r^{S*}) > (\pi_m^{D*} + \pi_r^{D*})$, so the optimal GBMs sales strategy of the alliance-based system is S strategy. Further, if the GBMs manufacturer gives the GBMs retailer a transfer payment F , both of them are willing to adopt the S sales strategy, where $F_{\min} \leq F \leq F_{\max}$, $F_{\min} = -(\pi_r^{S*} - \pi_r^{D*})$, and $F_{\max} = \pi_m^{S*} - \pi_m^{D*}$.*

Proposition 3 shows that the two parties can successfully cooperate to adopt the S sales strategy and realize a “win-win” outcome when the GBMs manufacturer provides an appropriate transfer payment to the GBMs retailer. It should be noted that, in Scenario I, we have $F_{\min} \geq 0$ and $F_{\max} \geq 0$. To make the GBMs retailer want to adopt the S sales strategy in Scenario I, the GBMs manufacturer needs to provide an appropriate compensatory transfer payment to the GBMs retailer. Differently, we have $F_{\min} \leq 0$ and $F_{\max} \leq 0$ in Scenario II. This means that the GBMs manufacturer needs to charge the GBMs retailer

a certain cooperation fee so that the GBMs manufacturer has an incentive to adopt the S sales strategy.

Corollary 3. Under Scenarios I and II, there exists a threshold t_4 such that $\frac{\partial(F_{max}-F_{min})}{\partial t} > 0$ if $t < t_4$ and $\frac{\partial(F_{max}-F_{min})}{\partial t} < 0$ otherwise.

Where t_4 satisfies $g(t) = 0$,

$$g(t) = (-1 + \theta)^3 \left(k^2(3p - k)\theta^2 + (p - k)(p^2 + 4pk - 2k^2)\theta + (p - k)^3 \right) t^3 \\ + (-1 + \theta)^4 \left(-k^2\theta + (p - k)^2 \right) t^4 - 3p\theta(-1 + \theta)^2(p - k)(p + A_2)A_2t^2 \quad , \quad \text{and} \\ + p^2\theta(-1 + \theta)(p\theta - 4k\theta + A_2)A_2^2t + p^3\theta^2A_2^3 \\ A_2 = p - k + k\theta.$$

Corollary 3 shows that, for both Scenarios I and II, when the return cost is sufficiently small ($t < t_4$), the range of transfer payments increases with the return cost. It indicates that the higher the return cost of GBMs, the more likely the GBMs manufacturer is to cooperate with the GBMs retailer to adopt the S sales strategy under certain conditions. This is because, under the condition $t < t_4$, the increase in GBMs return cost will make the consumers who “move from online to store-to-online channel” under the S sales strategy reduce more return losses for the GBMs manufacturer. For Scenario I, this will enable the GBMs manufacturer to have a sufficient profit increment to compensate for the profit loss of the GBMs retailer. For Scenario II, this makes the profit loss of the GBMs manufacturer less serious after adopting the S sales strategy. Therefore, the difficulty of the GBMs manufacturer and retailer adopting S sales strategy is reduced accordingly.

4.2. Effects of GBMs Sales Strategy on Urban Environment and Social Welfare

(1) The effect of GBMs sales strategies on urban environment

The adoption of GBMs can reduce carbon emissions and thus have a positive impact on the urban environment. In this subsection, the paper examines the adoption of GBMs among consumers under different sales strategies. Based on this, the impact of different GBMs sales strategies on urban environments is investigated. Furthermore, we explore which sales strategies can increase the GBMs manufacturer's and retailer's profits, and at the same time stimulate the GBMs adoption among consumers to positively impact the urban environment.

Based on the research of Chen et al. [48], this paper uses n to denote the positive impact of unit GBMs adoption on the urban environment. Then, the urban environmental impact of GBMs adoption under D and S sales strategies can be represented as $EI^D = (d_o^D + d_r^D)n$ and $EI^S = (d_o^S + d_r^S + d_s^S)n$, respectively. Analyzing EI^D and EI^S , Proposition 4 can be obtained.

Proposition 4. The effects of different GBMs sales strategies on the urban environment and system profits are $EI^D = EI^S$ and $(\pi_m^{S*} + \pi_r^{S*}) - (\pi_m^{D*} + \pi_r^{D*}) > 0$, respectively.

Proposition 4 shows that the D and S sales strategies have the same positive impact on the urban environment. This is because, when the GBMs manufacturer and retailer cooperate to introduce the store-to-online channel, a portion of the original online and offline consumers will transfer to this channel for purchasing GBMs. And the number of transferred consumers for purchasing GBMs is equal to the number of consumers in the new channel ($d_s^S = (d_o^{D*} - d_o^{S*}) + (d_r^{D*} - d_r^{S*})$). In other words, the introduction of the store-to-online channel will change the channel structure and market demands of the GBMs manufacturer and GBMs retailer. But this will not generate impacts on the system's

total demand. The total amount of GBMs adoption is the same under both sales strategies, thereby having the same positive impact on the urban environment.

Proposition 4 also shows that the S sales strategy will result in an increase in overall GBMs sales profit in the alliance-based system, although D and S sales strategies have the same impact on the urban environment. From the perspective of achieving zero-carbon cities, the GBMs manufacturer and GBMs retailer should choose the S sales strategy. This is because the S sales strategy makes the whole GBMs sales system more profitable without affecting the total amount of GBMs adoption. For the development of zero-carbon cities, government environmental policies (i.e., environmental tax, green subsidy, carbon trading market) have become the driving force of GBMs adoption [13,30,49]. In contrast, this paper provides a new idea that spontaneously promotes the sales of GBMs between manufacturers and retailers by changing the channel structure.

(2) The effect of GBMs sales strategies on social welfare

In this section, this paper analyzes the effect of different GBMs sales strategy on social welfare by incorporating environmental impacts into social welfare.

Following the literature of Krass et al. [50] and Niu et al. [51], this paper measures social welfare by summing up the manufacturer's profit, the retailer's profit, environmental impacts, and consumer surplus. Namely, social welfare is described as $SW^X = \pi_m^{X*} + \pi_r^{X*} + CS^X + EI^X$. Here, $X \in \{D, S\}$, $CS^S = \int_{h_0}^1 u_o dh_r + \left(1 - \frac{a\theta h_0 - Q^S}{a\theta h_0}\right) \int_0^{h_0} u_r dh_r + \frac{\theta(a\theta h_0 - Q^S)}{a\theta h_0} \int_0^{h_0} u_o dh_r + \frac{(1-\theta)(a\theta h_0 - Q^S)}{a\theta h_0} \int_0^{h_0} u_s dh_r$, and $CS^D = \int_{h_0}^1 u_o dh_r + \left(1 - \frac{a\theta h_0 - Q^D}{a\theta h_0}\right) \int_0^{h_0} u_r dh_r + \frac{(a\theta h_0 - Q^D)}{a\theta h_0} \int_0^{h_0} u_o dh_r$, which respectively denote consumer surplus under the S and D sales strategies. By comparing the social welfare under the two sales strategies, Proposition 5 can be obtained.

Proposition 5. *The impacts of different GBMs sales strategies on social welfare are*

- ① *When $\theta < 1/2$, we have $SW^S > SW^D$;*
- ② *When $\theta \geq 1/2$, there exists threshold t_5 such that $SW^S < SW^D$ if $0 < t \leq t_5$ and $SW^S > SW^D$ otherwise.*

Based on Proposition 5, the effects of different GBMs sales strategies on social welfare are shown in Figure 5. The specific analysis is as follows. Proposition 5 ① shows that the S sales strategy will generate greater social welfare when $\theta < 1/2$. This is because social welfare includes the profits of the GBMs manufacturer and GBMs retailer, the urban environmental impacts, and consumer surplus in the GBMs adoption. According to Proposition 4, the urban environmental impacts are the same for both S and D sales strategies. Therefore, which GBMs sales strategy has a greater impact on social welfare depends on the profits of the GBMs manufacturer and retailer, and the consumer surplus under different sales strategies. The paper has derived that the S sales strategy can bring more total profits to the GBMs manufacturer and retailer ($(\pi_m^{S*} + \pi_r^{S*}) > (\pi_m^{D*} + \pi_r^{D*})$). Compared with the D sales strategy, when the matching rate of consumers is relatively small, the GBMs returns can be solved by introducing the store-to-online channel under the S sales strategy, which can lead to a higher consumer surplus in purchasing GBMs. Therefore, the S sales strategy will generate greater social welfare when $\theta < 1/2$.

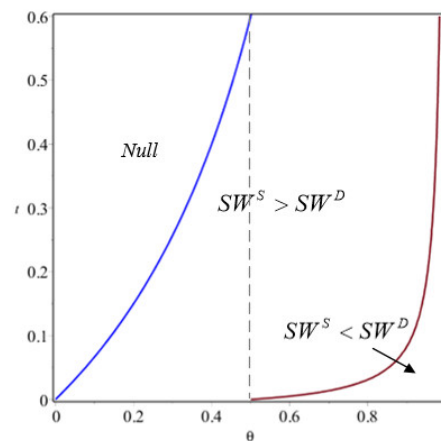


Figure 5. Effects of different GBMs sales strategies on social welfare.

However, Proposition 5 ② presents a different result from 5 ①. When the matching rate of consumers is relatively high ($\theta \geq 1/2$), the D sales strategy will lead to greater social welfare if the return cost of GBMs is lower ($0 < t \leq t_5$). This is because consumers can buy GBMs directly from the online channel without too many returns when the matching rate is relatively high. Under the S sales strategy, the store-to-online channel for purchasing GBMs brings limited convenience to consumers. In addition, the reduction of offline GBMs inventory under the S sales strategy further damages the benefits for some offline consumers, which can significantly decrease consumer surplus in purchasing GBMs. The S sales strategy harms consumer surplus to a greater extent than it adds to the total profits of GBMs manufacturer and retailer, leading to a reduction in overall social welfare. Therefore, the D sales strategy leads to greater social welfare than the S sales strategy.

Comparing Proposition 5 with Proposition 4, as shown in Figure 6a,b, it can be found that many players in the GBMs market aiming to maximize their own profits will choose the S sales strategy in the absence of any government intervention. However, the effect of social welfare brought by the S sales strategy is weaker than the D sales strategy when the matching rate of consumers is relatively large and the return cost of GBMs is relatively low. The reason hinges on the differences in environmental impact and consumer surplus between the D and S sales strategies. Therefore, under certain circumstances, the government should intervene in the market behavior of manufacturers and retailers in GBMs market and guide them to choose the appropriate sales strategy.

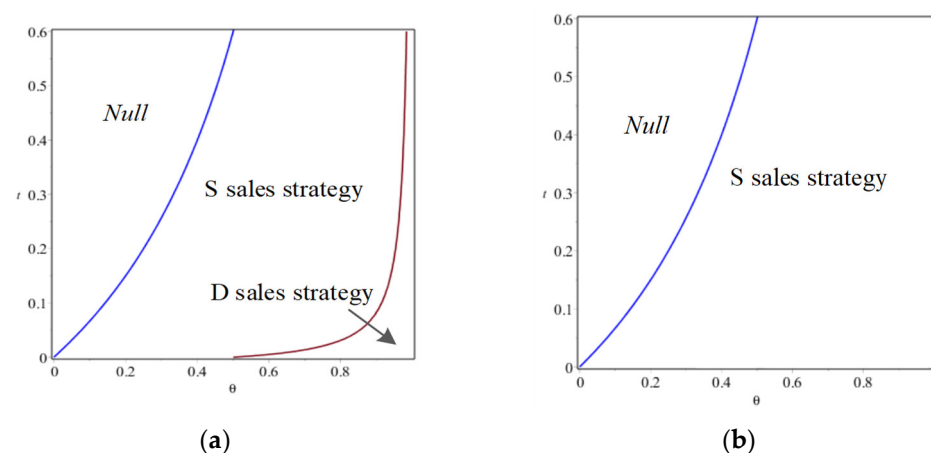


Figure 6. (a) Optimal sales strategy when pursuing market profits. (b) Optimal sales strategy when pursuing social welfare.

Further, we denote $\Delta SW = SW^S - SW^D$, which represents the change in social welfare that occurs when the sales strategy changes from D to S (hereafter referred to as social welfare change for convenience). In the following, we draw Figure 7a,b to show the impacts of t and θ on social welfare change.

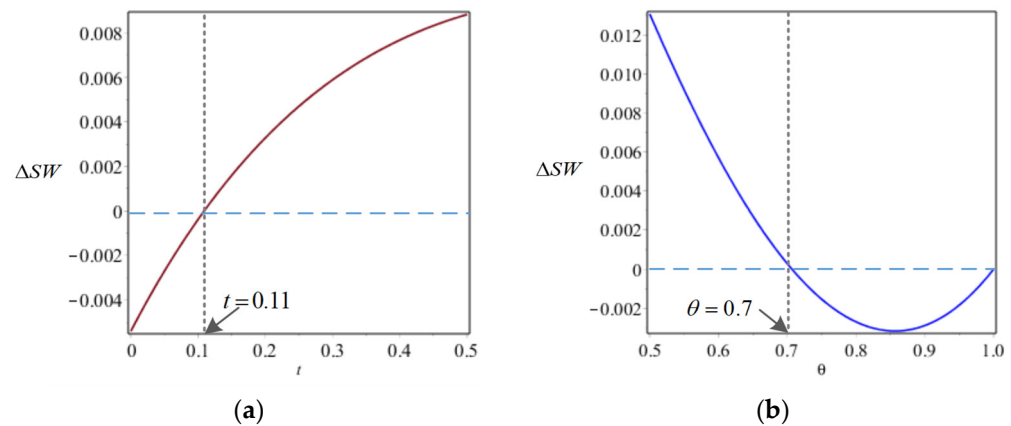


Figure 7. (a) The effect of t on ΔSW . (b) The effect of θ on ΔSW .

Figure 6a shows the effect of return cost t on social welfare change ΔSW . We can observe that the social welfare change increases with the return cost of GBMs, indicating that the S sales strategy generates significantly more social welfare compared to the D strategy when the hassle cost becomes higher. The reason is as follows. When the return cost is higher, the number of online returns will decrease if the sales strategy changes from D to S. This not only helps the GBMs manufacturer save on return costs but also increases consumer surplus. In reality, the return cost of GBMs is related to the volume and weight of GBMs. Therefore, as a key factor in achieving zero-carbon cities, the government should encourage GBMs manufacturers and retailers to actively adopt the S sales strategy regarding GBMs with high volume and weight.

Figure 6b presents the effect of matching rate θ on social welfare change ΔSW . We can observe that ΔSW tends to decrease firstly and then increase as the matching rate becomes higher. This is because, on the one hand, a higher matching rate will weaken the advantage of the S sales strategy in reducing the GBMs manufacturer's returns. On the other hand, a higher matching rate means the probability of consumers making purchases offline will increase, thereby boosting the GBMs retailer's profits under the S sales strategy. When θ is lower, the effect of the former is dominant and causes ΔSW to decrease. In reality, different GBMs have different attribute characteristics, which can result in the different matching rates of consumers. Therefore, the government should encourage GBMs manufacturers and retailers to adopt the S sales strategy for GBMs with lower matching rates.

5. Conclusions

In this paper, we established a dynamic game model to analyze the optimal GBMs sales strategies among alliance-based manufacturers and retailers considering consumer purchasing behavior. Based on model deduction, this paper also explored the effects of different GBMs sales strategies on the urban environment and social welfare. The main conclusions are summarized below:

(1) In the GBMs sales market, the GBMs manufacturers and retailers choose their sales strategy based on profit maximization. Only when the consumers' matching rate is relatively low and the return cost of GBMs is at an intermediate level can the GBMs manufacturer and retailer achieve a strategic consensus, and the equilibrium GBMs sales strategy is S (i.e., the GBMs manufacturer and retailer sell GBMs through an online channel, an of-

fine channel, and a store-to-online channel). In other conditions, the GBMs manufacturer's and retailer's strategy preference is inconsistent, and they can achieve a win-win outcome through choosing the S sales strategy with an additional transfer payment contract.

(2) Stimulated by the alliance-based GBMs manufacturer's and retailer's sales strategies, consumers in the market will use certain quantities of GBMs, which generates positive impacts on the urban environment. Based on mathematical model calculation, this paper finds that the introduction of the store-to-online channel under the S sales strategy will change the channel structure of the alliance-based system, but will not generate impacts on the total quantities of GBMs used in the market. Therefore, the D and S GBMs sales strategies have the same positive impacts on the urban environment.

(3) By incorporating urban environmental impacts, the profits of the alliance-based GBMs manufacturer and retailer, and consumer surplus into social welfare, this paper finds that different sales strategy will generate diverse social welfare. Specifically, the D GBMs sales strategy will generate more social welfare when the matching rate of consumers is relatively large and the return cost of GBMs is relatively low. Otherwise, the S sales strategy will bring strong welfare. Therefore, the government should intervene in the sales behavior of the alliance-based GBMs manufacturers and retailers under certain conditions.

The above results can also bring meaningful enlightenment for different participants. For the alliance-based manufacturers and retailers in the GBMs market, they should choose the S GBMs sales strategy when the consumer matching rate is relatively low and the return cost of GBMs is at an intermediate level. In other conditions, only when a reasonable transfer payment contract is developed, the alliance-based manufacturers and retailers can agree on the S GBMs sales strategy. For governments aiming at achieving zero-carbon cities, in addition to adopting commonly used tools, such as environmental tax and carbon trading markets, they can also use another new approach. Namely, governments can intervene in the sales strategy of the alliance-based GBMs manufacturers and retailers by enacting commercial regulations or providing a specific business environment, which incentivizes the manufacturers and retailers to adopt the S or D sales strategy for GBMs with different consumer matching rates and return costs.

This study mainly explores the optimal GBMs sales strategy in markets considering consumers' multi-channel purchasing behavior. To do this, a game-theoretical model incorporated with decision-making behaviors of the GBMs manufacturer, GBMs retailer, and consumers is established. In future studies, more impact factors of GBMs adoption in sales markets, such as the competition between GBMs supply chains, the participation of GBMs industry associations, and the psychological impact on consumers can be further explored. Additionally, combining interdisciplinary fields, such as urban science and management science, to explore GBMs adoption with new perspectives is a worthwhile research direction.

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