Channel structure and evolutionary stability analysis between traditional and green service supply chains

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Abstract: This paper aims to explore the long-term Evolutionary Stability Strategy (ESS) of vertical channel structure strategic interaction between Traditional and Green Service Supply Chains (TSSC and GSSC) and figure out the optimal pricing and green service decisions. Considering that two types of supply chains could choose between centralized (C) and decentralized channel structures (D), we first establish four channel structure models based on optimization theory, namely, Models DD, DC, CD, and CC. Wherein Model DD(CC) means that two supply chains adopt the channel structure D(C) simultaneously and Model DC(CD) refers to GSSC adopting the channel structure D(C) while TSSC using the channel structure C(D). Further, we develop an evolutionary game to discuss the ESSs of the dynamic competitive system under different market environment. The research results show that the stronger the integration between upstream and downstream firms of GSSC is, the supply chain would more likely provide higher green service when the TSSC has a decentralized channel structure. Moreover, when the competition between two supply chains is sufficiently low, only point (0,0) is the ESS; when it is moderate, there are two ESSs, i.e., ESS (0,0) and ESS (1,1); when it is very high, only point (1,1) is the ESS. Numerical studies are conducted to examine the effects of competition coefficient on prices, demands and profits, as well as the roles of initial states of two supply chains' channel strategies on their ESSs.

Keywords: Channel structure · Chain-to-chain competition · Green service supply chain · Evolutionary stability analysis

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1. Introduction

With the rapid and continuous increase of consumers' environmental awareness, more and more enterprises begin to develop and provide green services/products to meet the standard of sustainable development (Zhang and Liu, 2013; Tian et al., 2014; Zhu and He., 2017), especially driven by many environmental legislations promulgated by countries all over the world. For instance, China has proposed the goals of "Carbon Peak, Carbon Neutralization" in May 2021 and Japan also has promised to meet carbon neutrality by 2050. So far, there exist many papers showing that firms engaging in green activities would generate a core competitiveness enhancement and help them to capture more market shares (Xing et al., 2017; He et al., 2018). On the opposite side, some companies are unwilling to take the green program due to the high cost of implementing greening operations. As a consequence, it is not uncommon to see competition between traditional and green service firms during the early stage of promoting sustainable development. Further, the competition between enterprises has increasingly become a chain-to-chain competition with the popularity of the global supply chain (Li and Li, 2016b; Wang et al., 2020). Therefore, this paper will explore the chain-to-chain competition problem between the traditional and green service supply chains in the context of sustainable development.

In the meantime, it is well known that supply chain vertical channel structure would be used as a strategic tool to fight against competitors and seize larger market shares (Moorthy, 1988; Zhao et al., 2009; Liu et al., 2021). Therefore, it is of great significance to investigate the strategic interaction of channel structure choice between traditional and green service supply chains. So far, some scholars have investigated the vertical channel structure selection under a chain-to-chain competition from a static perspective (Xiao et al., 2014; Huang et al., 2018; Moradinasab et al., 2018). They have underlined that the competition between two supply chains plays an important role in chain members' decision-makings of pricing and channel structure choice. Particularly, when the competition is relatively low, both supply chains may select a centralized channel structure; while they would like to adopt a decentralized one under a stronger competitive situation. By contrast, this paper focuses on exploring the long-term evolutionary stability strategy of a competitive system comprised of a traditional service supply chain (TSSC) and a green service supply chain (GSSC). Specifically, this study is different from previous research at least from the following two aspects. On the one hand, we consider two asymmetric supply chains. The members of GSSC would provide not only basic products but also green service (e.g., carbon emission reduction; pollutant discharge pretreatment), which can stimulate the environmental needs of consumers. By contrast, the TSSC's members just sell basic products without any environmental protection service. On the other hand, we discuss different channel structure combinations of two supply chains with considering the effect of green service on demands. In this context, the following research questions of great importance and practice arise.

(1) What are the optimal pricing and green service decisions for these two types of supply chains?

(2) Under what conditions do the supply chains should adopt a centralized or decentralized channel structure?

(3) How does the competition between two supply chains influence the pricing decisions, demands and profits of two supply chains, as well as the ESSs of the competitive system?

To capture these questions, we first develop four channel structure models according to different channel structure choices in two types of supply chains. We solve the optimization problems by backward induction and compare the optimal green service and profits of the two supply chains. The main research results indicate that for the GSSC, no matter which channel structure the TSSC selects, there always exists a threshold of competition between the two supply chains that can distinguish the GSSC's optimal channel structure choice. To be more specific, when that competition is relatively low, the centralized channel structure is better for GSSC, whereas the decentralized channel structure performs better under a stronger competitive situation. Different from prior papers, it is worthy of noting that when the GSSC adopts a centralized channel structure, the TSSC always prefers the centralized channel structure. From a long-term perspective, the evolutionary stable strategy of the competitive system varies with the competition coefficient. Particularly, the initial states of two types of supply chains' strategies would largely affect the evolution paths and ESSs when the competition coefficient is moderate. In this setting, when both the GSSC and TSSC have lower initial probabilities to select the channel structure D, the system would last evolve to ESS (0,0), and vice versa.

The rest of this paper can be organized as follows. Next section discusses the background literature. Section 3 describes the research problem and presents the market demand functions. The model development, optimal solutions and comparative analysis under the one-shot game are conducted in Section 4. In Section 5, we further consider the repeated game case and identify the ESSs of the competitive system, followed by Section 6, which illustrates some main results and presents the effects of competition coefficient. We conclude this paper and propose some potential future research avenues in Section 7.

2. Literature review

The current study is closely related to three areas of existing literature: chain-to-chain competition, green supply chain management and channel structure management. In what follows, we mainly review the closest literature in these areas.

2.1. Chain-to-chain competition

When it comes to chain-to-chain competition, a considerable number of papers have studied the effects of price and/or quality competition (Jafarian et al., 2019; Wang et al., 2020; Nematollahi et al., 2021). Hafezalkotob (2015) incorporates government policies into the competition between the green and regular supply chains. They underscore that the environmental protection and social responsibility tendencies of the government can significantly affect the green supply chain's revenue and its rival's profit. Li and Li (2016b) investigate the product sustainability between two fully symmetrical reverse supply chains. They uncover that vertical integration channel structure is not an equilibrium strategy unless the two sustainable supply chains are completely independent. Wu and Chen (2016) focus on exploring the channel structure choice of two competitive supply chains under uncertain demand. They demonstrate that the double decentralized structure is the equilibrium for substitutable products, whereas the double integrated structure is the equilibrium for complementary products. Goodarzi et al. (2017) study why the cash flow bullwhip effect happens and its influences on the integrated or decentralized supply chains' operational performance. Wang and Liu (2019) explore the vertical contract selections of competitive shipping supply chains between the wholesale-price contract and revenue-sharing contract and identify the conditions for different contracts equilibrium. Li et al. (2020a) examine the effects of partial vertical centralization on the performance of competitive supply chains. They show that this channel structure would be the equilibrium unless the product substitutability is very high. Some other papers study chain-to-chain competition by considering more factors or strategies such as vertical and horizontal information sharing (Chen et al., 2019), product sustainability strategy (Deng et al., 2020), carbon emission (Wang et al., 2020), technology up-gradation and financing risk (Wu and Kung, 2020) and clean development mechanisms (Liu et al., 2021).

2.2. Green supply chain management

There have existed a large number of studies on green supply chain management (Chan et al., 2016; Hong et al., 2018; Dehghan-Bonari et al., 2021). Most previous works have confirmed that research and development of new green products could enhance firms' core competitiveness and expand their market shares. Chen and Sheu (2009) develop a differential game model consisting of Vidale–Wolfe equation to design an environmental-regulation pricing policy that can promote green supply chain firms' Extended Product Responsibility. Chu and Chung (2016) develop an integrated balanced score card by combining the analytic network process model to establish the indicators for green tourism supply chain management. They confirm that choosing their framework can help tour firms to find the key factors and balance the revenues and their environmental protection responsibility. Sinayi and Rasti-Barzoki (2018) investigate the effects of government intervention on supply chain members' pricing, greening, and social welfare policies. Their findings show that different government policies have significant impacts on supply chain members' profits and the environment. Song and Gao (2018) confirm that the revenue-sharing contract plays a significant role in coordinating the distribution of benefits between the manufacturer and retailer in a green supply chain and it indeed improves the whole supply chain's performance. Hong and Guo (2019) compare three coordination contracts, namely, price-only, green marketing cost sharing, and two-part tariff contracts in a green supply chain. They find a counterintuitive result that compared to a price-only contract, the manufacturer sharing the green marketing cost with the retailer is always more profitable for the manufacturer but not for the retailer. Ma et al. (2020) take the uncertain information into account and propose an alternative decision rule on the basic of firms' confidence level to coordinate the green supply chain with cost sharing contract. Besides, some papers take the service into green supply chain management (Laari et al., 2018; He et al., 2019; Chen et al., 2021; Hong and Liu., 2022). Particularly, Tseng et al. (2018) employ the fuzzy delphi method and analytical network process to design a framework to examine the sustainable service supply chain's performance by considering uncertainty. Ma et al. (2021) take the tourists' green tourism experience into account and explore the joint decisions of tourism firms' service, pricing and advertising. They show that the green tourism preferences and the green tourism experience of consumers largely affect the tour firms' pricing, service and advertising decisions.

2.3. Channel structure management

As for the vertical channel structure management, a lot of researchers focus on investigating the advantages and disadvantages of decentralized or centralized channel structures in different types of supply chains (Schmitt et al., 2015; Li et al., 2020b; Bendadou et al., 2021). Most prior studies indicate that vertically cooperation can reduce the double marginalization effect and some scholars argue that decentralization may be a better strategy when the competition is high enough (Peng et al., 2018; Heydari et al., 2021; Li et al., 2022; Yang et al., 2022). Zhao et al. (2009) study the issue that how channel structure impacts the quality and pricing decisions and how they in turn influence the supply chain members' profits and consumer welfare. Their findings reveal that decentralization would decrease consumer welfare, while the decentralization of high-quality channel hurts consumers more than the low-quality channel. Ghosh and Shah (2012) discuss the problem of how channel structures influence the greening levels, prices and profits of chain members and examine the effects of greening costs and consumer sensitivity towards green apparel. Xiao et al. (2014) establish a retailer-Stackelberg pricing model to explore the manufacturer's product variety and channel structure strategies in a circular spatial market. The results show that unit production cost can reduce the motivation of manufacture using dual channels while marginal cost of variety, the retailer's marginal selling cost, and the customer's fit cost would encourage him to adopt the dual channels. Zhu and He (2017) investigate the problem of how supply chain structures, green product types, and competition types impact supply chains' decisions on product greenness. They indicate that competition can increase products' green level while the greenness competition would reduce the green degree of products. Huang et al. (2018) extend the chain-to-chain competition to the channel structure and quality selections. They find that the follower with cost asymmetry can strategically decentralize its channel structure to affect the leader's quality choice. Yang and Yu (2019) analyze how integrated logistics and procurement service jointly provided by a third-party logistics company affect a supply chain's operational performance. Further, He et al. (2022) propose a partial integrated logistics service strategy for a platform service supply chain and confirm that this strategy would perform better than the completely integrated or decentralize channel structure from the perspective of the whole supply chain.

Differently from the previous studies, this paper first extends the symmetric chain-to-chain competition to the asymmetric chain-to-chain competition by considering GSSC's green service decisions. Secondly, our study takes the time factor and learning ability of members into consideration and aims to explore the long-term evolutionary stability strategy of strategic channel structure interaction between traditional and green service supply chains from a repeated game perspective. Lastly, we examine how the supply chain competition and initial states of different types of supply chains' channel structure strategies affect the evolution path, evolution speed and last ESSs of the competitive dynamic system through numerical experiment.

3. Model setting

This paper considers two competitive traditional and green service supply chains, both of which could utilize a Decentralized or a Centralized vertical channel structure (hereafter channel structure D or C). One of them is a Green Service Supply Chain (GSSC) where the supply chain member(s) would provide environment friendly (green) service products. However, the other one is a Traditional Service Supply Chain (TSSC) in which the supply chain members just provide non-green service products. We focus on discussing four possible channel structure models, namely, Model DD in which both supply chains adopt the channel structure D; Model DC(CD) where the GSSC adopts the channel structure D(C) while the TSSC adopts the channel structure C(D); Model CC where both the GSSC and TSSC adopt the channel structure C. Under different channel structure combinations, the manufacturers or retailers make their pricing and/or service decisions to maximize their individual profits. It is supposed that when supply chains adopt a structure D, the manufacturer and retailer within the same supply chain play a Stackelberg game where the manufacturer is the leader and the retailer is the follower. Under competition from outside supply chains, the two supply chains play a Nash game. In addition, we assume that information is apparent for all chain members and all players are risk neutral and in the purse of self-interest maximization.

Following the majority of works (Li et al., 2019b; Zhang and Li, 2020; Fan et al., 2022), we model the demand function as a linear function of retail price p_i $(i = 1, 2)$ and the service level s_i. We regard the service of supply chain 2 as the green service benchmark (i.e., $s_2 = 0$). Accordingly, the demand functions of the two supply chains can be given as follows.

$$\begin{cases} d_1 = a - (p_1 - s_1) + \beta p_2 \\ d_2 = a - p_2 + \beta(p_1 - s_1) \end{cases} \tag{1}$$

where the parameter a represents the basic market share and β denotes the competition between two types of supply chains. As for the green service cost, we employ a quadratic function $ks_1^2/2$ to reflect the feature of marginal cost efficiency diminishing, wherein k denotes the service cost coefficient (Tsay and Agrawal, 2000; Dan et al., 2012; Li and Li, 2016a). Without loss of generality, we follow many previous studies to normalize the k to 1 (Zhang et al., 2018; Li et al., 2019a). We also employ notation $\Pi_{ji}, j = r, m, sc$ and $i = 1,2$ to denote the profit functions of retailers, manufacturers and the whole supply chains in i supply chain and notation w_i to denote the wholesale prices. The superscript "*" and $l = DD, DC, CD, CC$ refers to the optimal solutions under different channel structure combinations.

4. One-shot game

We next develop and solve the vertical channel structure models of two supply chains with different channel structure combinations based on one-shot game.

4.1. Model DD

We start by modeling the channel structure combination DD where both the GSSC and TSSC have a decentralized channel structure. In each supply chain, the retailer with a rational pricing anticipation sets its own retail price p_i under given wholesale price w_i and the green service level s_1. According to the demand functions, the optimization problems of two retailers under Model DD can be expressed as follows.

$$\max_{p_1} \Pi_{r1} = (p_1 - w_1)[a - (p_1 - s_1) + \beta p_2] \tag{2}$$

$$\max_{p_2} \Pi_{r2} = (p_2 - w_2)[a - p_2 + \beta(p_1 - s_1)] \tag{3}$$

It can be derived that the profitability function Π_{ri} is concave in p_i due to $\partial^2\Pi_{r1}/\partial p_1^2 = \partial^2\Pi_{r2}/\partial p_2^2 = -2 < 0$. Hence, solving the first-order conditions for $p_i, p_j, i = 1, 2$ and $j = 3 - i$

yield the following optimal response results.

$$\begin{cases} p_1(w_1, w_2, s_1) = (2a + a\beta + 2s_1 - \beta^2 s_1 + 2w_1 + \beta w_2)/(4 - \beta^2) \\ p_2(w_1, w_2, s_1) = (2a + a\beta - \beta s_1 + \beta w_1 + 2w_2)/(4 - \beta^2) \end{cases} \tag{4}$$

As the Stackelberg leader, the manufacturer i can foresee the retailers' optimum responses and sets its own corresponding wholesale price and green service level simultaneously to maximize its own profit. Hence, the optimization problems of two manufactures are given by:

$$\max_{w_1, s_1} \Pi_{m1} = w_1[a - (p_1 - s_1) + \beta p_2] - s_1^2/2 \tag{5}$$

$$\max_{w_2} \Pi_{m2} = w_2[a - p_2 + \beta(p_1 - s_1)] \tag{6}$$

By plugging Eq. (4) into Eq. (5) and Eq. (6), we can obtain $\partial^2\Pi_{m2}/\partial w_2^2 = -2(2 - \beta^2)/(4 - \beta^2) < 0$ and the Hessian matrix of Π_{m1} with respect to w_1 and s_1 as shown as Eq. (7) by taking the second-order derivatives of Π_{mi} with respect to w_1, s_1, and w_2.

$$H_1 = \begin{vmatrix} \frac{2(2-\beta^2)}{-(4-\beta^2)} & \frac{2-\beta^2}{4-\beta^2} \\ \frac{2-\beta^2}{4-\beta^2} & -1 \end{vmatrix} = \frac{(6-\beta^2)(2-\beta^2)}{(4-\beta^2)^2} > 0 \tag{7}$$

Therefore, we can get the optimal wholesale prices and service level according to the first-order conditions. Further, we can take them into the optimal retail price response functions to obtain the optimal retailer prices, demands and profits. Since the following solving processes of other three models are similar to Model DD, we omit their concrete proofs to save space and just summarize their optimal solutions in Table 1.

4.2. Model DC

In this model, GSSC adopts the channel structure D while TSSC conducts the channel structure C. The timeline of this game can be described as follows. The green manufacturer first determines the wholesale price and green service level at the same time. Afterward, both the green retailer and the TSSC decide the sale prices simultaneously. We can get the optimization problem and show as the following equations. With the similar solving method, the optimal outcomes are listed in Table 1.

$$\begin{cases} \max_{w_1, s_1} \Pi_{m1} = w_1[a - (p_1 - s_1) + \beta p_2] - s_1^2/2 \\ \max_{p_1} \Pi_{r1} = (p_1 - w_1)[a - (p_1 - s_1) + \beta p_2] \end{cases} \tag{8}$$

$$\max_{p_2} \Pi_{SC2} = p_2[a - p_2 + \beta(p_1 - s_1)] \tag{9}$$

4.3. Model CD

In contrast to Model DC, GSSC uses the channel structure C while TSSC adopts the channel structure D in model CD. In this case, the traditional manufacturer first determines her wholesale price. Then, both the GSSC and the traditional retailer set their own retail prices and green service level simultaneously. The optimization problem under Model CD can be given by:

$$\max_{p_1,s_1} \Pi_{SC1} = p_1[a-(p_1-s_1)+\beta p_2]-s_1^2/2 \tag{10}$$

$$\begin{cases} \max\limits_{w_2} \Pi_{m2} = w_2[a-p_2+\beta(p_1-s_1)] \\ \max\limits_{p_2} \Pi_{r2} = (p_2-w_2)[a-p_2+\beta(p_1-s_1)] \end{cases} \tag{11}$$

4.4. Model CC

In the channel combination CC, the two supply chains' members use the centralized channel structure. The timing of this game is: the GSSC determines his retail price and green service level and the TSSC decides her retail price simultaneously. We can present their optimization problems under Model CC as shown as follows.

$$\max_{p_1,s_1} \Pi_{SC1} = p_1[a-(p_1-s_1)+\beta p_2]-s_1^2/2 \tag{12}$$

$$\max_{p_2} \Pi_{SC2} = p_2[a-p_2+\beta(p_1-s_1)] \tag{13}$$

Table1. Equilibrium solutions under different channel structure combinations.

Channel	DD	DC	CD	CC
w_1^*	$\frac{a(2-\beta)(2+\beta)^2(4+\beta-2\beta^2)}{2(24-29\beta^2+10\beta^4-\beta^6)}$	$\frac{a(2-\beta)(2+\beta)^2}{(6-\beta^2)(2-\beta^2)}$	N/A	N/A
s_1^*	$\frac{a(2+\beta)(2-\beta^2)(4+\beta-2\beta^2)}{2(24-29\beta^2+10\beta^4-\beta^6)}$	$\frac{a(2+\beta)}{6-\beta^2}$	$\frac{4a+3a\beta}{4}$	$\frac{a(2+\beta)}{2}$
w_2^*	$\frac{a(2+\beta)(12+2\beta-8\beta^2+\beta^4)}{2(24-29\beta^2+10\beta^4-\beta^6)}$	N/A	$\frac{a}{2}$	N/A
p_1^*	$\frac{a(2+\beta)(4+\beta-2\beta^2)}{8-7\beta^2+\beta^4}$	$\frac{2a(2+\beta)(3-\beta^2)}{12-8\beta^2+\beta^4}$	$\frac{4a+3a\beta}{4}$	$\frac{a(2+\beta)}{2}$
p_2^*	$\frac{a(6+4\beta-2\beta^2-\beta^3)}{8-7\beta^2+\beta^4}$	$\frac{a(6+4\beta-2\beta^2-\beta^3)}{12-8\beta^2+\beta^4}$	$\frac{3a}{4}$	$\frac{a}{2}$
q_1^*	$\frac{a(16+12\beta-14\beta^2-10\beta^3+3\beta^4+2\beta^5)}{2(24-29\beta^2+10\beta^4-\beta^6)}$	$\frac{a(2+\beta)}{6-\beta^2}$	$\frac{4a+3a\beta}{4}$	$\frac{a(2+\beta)}{2}$
q_2^*	$\frac{a(12+8\beta-10\beta^2-6\beta^3+2\beta^4+\beta^5)}{2(3-\beta^2)(8-7\beta^2+\beta^4)}$	$\frac{a(6+4\beta-2\beta^2-\beta^3)}{12-8\beta^2+\beta^4}$	$\frac{a}{4}$	$\frac{a}{2}$
Π_{SC1}^*	$\frac{a^2(2+\beta)^2(4+\beta-2\beta^2)^2(20-16\beta^2+3\beta^4)}{8(3-\beta^2)^2(8-7\beta^2+\beta^4)^2}$	$\frac{a^2(2+\beta)^2(10-3\beta^2)}{2(6-\beta^2)^2(2-\beta^2)}$	$\frac{a^2(4+3\beta)^2}{32}$	$\frac{a^2(2+\beta)^2}{8}$
Π_{SC2}^*	$\frac{a^2(2-\beta^2)(6+4\beta-2\beta^2-\beta^3)^2}{2(3-\beta^2)(8-7\beta^2+\beta^4)^2}$	$\frac{a^2(6+4\beta-2\beta^2-\beta^3)^2}{(12-8\beta^2+\beta^4)^2}$	$\frac{3a^2}{16}$	$\frac{a^2}{4}$

4.5. Equilibrium analysis

Based on the optimal solutions as shown in Table 1, we next conduct equilibrium analysis. Firstly, we explore the green service decisions of GSSC by comparing the optimal green service levels under four models, leading to the following findings.

Proposition 1. The green service levels under different models follow the relationship: $s_1^{CD*} > s_1^{CC*} > s_1^{DD*} > s_1^{DC*}$.

Proposition 1 shows that channel structures of the two supply chains play a significant role in green service decisions. Particularly, the GSSC would set the highest green service level when he adopts a centralized channel structure but the TSSC uses a decentralized one, followed by, channel structure CC, and then by channel structure DD. When the GSSC applies the decentralized channel structure, he would set the lowest green service level if the TSSC has a centralized channel structure. Put it differently, the lower the integration between upstream and downstream enterprises in a TSSC, the higher the green service level the GSSC with a centralized channel structure needs to provide, so that he can maintain his competitive advantage and obtain more benefits. By contrast, when the GSSC has a channel structure D, he would like to provide higher green service level if his rival also has a channel structure D. This suggests that encouraging the highly integrated industries with different channel structures to implement green service operations can better promote the implementation of green development policies.

We next aim to explore the vertical channel structure preferences of GSSC by comparing his equilibrium profits under given the TSSC's channel structure, resulting in the thresholds $\overline{\beta}_1$ and $\overline{\beta}_2 = \sqrt{5-\sqrt{17}}$, wherein $\overline{\beta}_1$ as the unique root can be solved by the function $f_1(\beta) = 4096 + 6144\beta - 12032\beta^2 - 21824\beta^3 + 8272\beta^4 + 25240\beta^5 + 705\beta^6 - 13488\beta^7 - 2688\beta^8 + 3648\beta^9 + 1054\beta^{10} - 480\beta^{11} - 164\beta^{12} + 24\beta^{13} + 9\beta^{14}$.

Proposition 2. For the GSSC, there exist thresholds $\overline{\beta}_1$ and $\overline{\beta}_2$,

(1) When TSSC adopts a decentralized structure, if $0 < \beta \leq \overline{\beta}_1$, GSSC prefers a centralized structure, otherwise a decentralized one if $\overline{\beta}_1 < \beta < 1$.

(2) When TSSC adopts a centralized structure, if $0 < \beta \leq \overline{\beta}_2$, GSSC prefers a centralized channel structure, otherwise a decentralized one if $\overline{\beta}_2 < \beta < 1$.

Proposition 2 indicates that no matter which vertical channel structure the TSSC adopts, there always exists a threshold for GSSC to make better channel structure decisions. Namely, the GSSC can gain more from a specific channel structure under different market competition environment. To be more specific, when the competition between two supply chains is relatively low, the GSSC would like to adopt a centralized channel structure. On the contrary, the channel structure D is performing better than channel structure C when the competition between them is relatively high.

This implies that when two supply chains compete fiercely, the decentralized channel structure is beneficial to the GSSC. This result is similar to some traditional research results. It is worth noting that the first threshold is smaller than the second (i.e., $\overline{\beta}_1 < \overline{\beta}_2$), which means that the rival adopting a centralized channel structure would decrease the incentive of GSSC to adopt a decentralized channel structure.

In what follows, we are to analyze the vertical channel structure preference of TSSC by comparing her profits under given GSSC's channel structure, resulting in Proposition 3, wherein $\overline{\beta}_3$ can be solved by $f_3(\beta) = 6 - 14\beta^2 + 8\beta^4 - \beta^6$ uniquely.

Proposition 3. For the TSSC, there exists a threshold $\overline{\beta}_3$,

(1) When GSSC adopts a decentralized channel structure, if $0 < \beta \le \overline{\beta}_3$, the TSSC prefers a centralized channel structure, otherwise a decentralized one if $\overline{\beta}_3 < \beta < 1$.

(2) When GSSC adopts a centralized channel structure, the TSSC always prefers a centralized one.

Proposition 3 shows the competition between two supply chains also significantly affects the channel structure preferences of TSSC. Similarly, it can be found from Proposition 3(1) that when the competition is relatively low, the TSSC likes the centralized channel structure more than the decentralized one, and vice versa. In contrast to GSSC's channel structure preference, we find that when the GSSC uses a centralized channel structure, there is no incentive for the TSSC to adopt the channel structure D. This implies when a supply chain facing a competition of a green service supply chain, the decentralized channel structure advantage disappears completely. This is because the TSSC is relatively weaker without providing green service, so that she has to use the channel structure C to enhance her market competitiveness and strive for more consumers while facing a stronger GSSC. This result suggests that a traditional supply chain can introduce green service to enhance the chance of conducting a channel structure D. Furthermore, we can find $\overline{\beta}_1 < \overline{\beta}_3 < \overline{\beta}_2$. This means, GSSC can widen the region of his decentralized channel structure advantage compared to the TSSC. Note that although the GSSC can keep his decentralized channel structure advantage under Model DC, it would not be too high. Namely, this advantage cannot be over than the TSSC's decentralized channel structure advantage under GSSC adopting a channel structure D. In other words, the decentralized channel advantage of investing in green activity is lower than that of a supply chain adopting a centralized channel structure.

5. Evolutionary stability analysis

In reality, the decision makers often don't make a decision-making once but constantly adjust their organizational structure by keeping learning and imitating their competitors' tactics over time by repeated game. Accordingly, we employ the evolutionary game theory to explore the long-term stable strategies of this system. Based on the optimal profits of the two supply chains in Table 1, we can obtain the payoff matrix as follows.

Table2. Payoff matrix of asymmetric two supply chains.

Supply chain 1	**Supply chain 2**	
	Structure D (y)	Structure C $(1-y)$
Structure D (x)	$(\Pi_{SC1}^{DD*}, \Pi_{SC2}^{DD*})$	$(\Pi_{SC1}^{DC*}, \Pi_{SC2}^{DC*})$
Structure C $(1-x)$	$(\Pi_{SC1}^{CD*}, \Pi_{SC2}^{DD*})$	$(\Pi_{SC1}^{CC*}, \Pi_{SC2}^{CC*})$

It assumes that the proportion of GSSC adopting a channel structure D is x, then that of GSSC utilizing a channel structure C is $(1-x)$. Similarly, we employ y and $(1-y)$ represent the proportion of TSSC adopting channel structure D and C, respectively. According to the works of Yi and Yang (2017) and He et al. (2019), the increasing rate $(dx/dt)/x$ of GSSC adopting a channel structure D equals to the difference between earnings $\boldsymbol{a} \bullet A_1 \bullet (y, 1-y)^T$ and the average revenue of two supply chains $(x, 1-x) \bullet A_1 \bullet (y, 1-y)^T$, wherein $\boldsymbol{a} = (1,0)$ indicates that GSSC adopts a channel structure D with a probability 1, and A_1 denotes the profit matrix $\begin{bmatrix} \Pi_{SC1}^{DD*} & \Pi_{SC1}^{DC*} \\ \Pi_{SC1}^{CD*} & \Pi_{SC1}^{DD*} \end{bmatrix}$ of GSSC. Therefore, the replicator dynamic equation of GSSC can be given by

$$F(x) = \frac{dx}{dt} = x\big(\boldsymbol{a} - (x, 1-x)\big) \cdot A_1 \cdot (y, 1-y)^T \tag{14}$$

To facilitate following statements, we hereafter define $\Delta m \equiv \Pi_{SC1}^{DD*} + \Pi_{SC1}^{CC*} - \Pi_{SC1}^{DC*} - \Pi_{SC1}^{CD*}$ and $\Delta n \equiv \Pi_{SC1}^{DC*} - \Pi_{SC1}^{CC*}$, so $\Delta L \equiv \Delta m + \Delta n$. Similarly, $\Delta\overline{m} = \Pi_{SC2}^{DD*} + \Pi_{SC2}^{CC*} - \Pi_{SC2}^{DC*} - \Pi_{SC2}^{CD*}$ and $\Delta\overline{n} = \Pi_{SC2}^{CD*} - \Pi_{SC2}^{CC*}$ as well as $\Delta\overline{L} = \Delta\overline{m} + \Delta\overline{n}$. Furthermore, we can obtain the replicator dynamic equations of GSSC and TSSC based on Tables 1 and 2 as below.

$$\begin{cases} F(x) = \frac{dx}{dt} = x(1-x)[\Delta m y + \Delta n] \\ F(y) = \frac{dy}{dt} = y(1-y)[\Delta\overline{m} x + \Delta\overline{n}] \end{cases} \tag{15}$$

From Eq. (15), we can derive the Jacobi matrix J of replicator dynamic equations of the competitive supply chain system, as well as the TrJ and $DetJ$ as below:

$$J = \begin{bmatrix} (1-2x)(\Delta m y + \Delta n) & x(1-x)\Delta m \\ y(1-y)\Delta\overline{m} & (1-2y)(\Delta\overline{m} x + \Delta\overline{n}) \end{bmatrix} \tag{16}$$

$$\begin{cases} TrJ = (1-2x)(\Delta my + \Delta n) + (1-2y)(\Delta \overline{m}x + \Delta \overline{n}) \\ DetJ = -x(1-x)\Delta my(1-y)\Delta \overline{m} + (1-2x)(\Delta my + \Delta n)(1-2y)(\Delta \overline{m}x + \Delta \overline{n}) \end{cases} \tag{17}$$

From Eq. (17) and Friedman (1991), we can deduce the system's ESSs under different conditions in terms of competition coefficient β, which are presented in Proposition 4. To save space, we omit some proofs in the main text and just provide the representative conditions of Proposition 4(3) in Table 3.

Proposition 4. For the dynamic system of two competitive supply chains,
(1) When $0 < \beta \leq \overline{\beta}_3$, $(x, y) = (0,0)$ is the ESS;
(2) When $\overline{\beta}_3 < \beta \leq \overline{\beta}_2$, $(x, y) = (0,0)$ or $(1,1)$ is the ESS;
(3) When $\overline{\beta}_2 < \beta \leq 1$, $(x, y) = (1,1)$ is the ESS.

Table 3. The stability of points when $\overline{\beta}_3 < \beta \leq \overline{\beta}_2$.

	$\boldsymbol{DetJ}$	**Sign**	$\boldsymbol{TrJ}$	**Sign**	**Stability**
(0,0)	$\Delta n \cdot \Delta \overline{n}$	$+$	$\Delta n + \Delta \overline{n}$	$-$	ESS
(0,1)	$-\Delta L \cdot \Delta \overline{n}$	$+$	$\Delta L - \Delta \overline{n}$	$+$	Unstable
(1,0)	$-\Delta \overline{L} \cdot \Delta n$	$+$	$\Delta \overline{L} - \Delta n$	$+$	Unstable
(1,1)	$\Delta L \cdot \Delta \overline{L}$	$+$	$-(\Delta L + \Delta \overline{L})$	$-$	ESS

Proposition 4 demonstrates the evolutionary stability strategy of the competitive service supply chain system. It can be shown that when the competition between two types of supply chains is sufficiently low (i.e., $\beta \leq \overline{\beta}_3$), only the point (0,0) is an evolutionary stability strategy; when it is moderate, both the points (0,0) and (1,1) may be the evolutionary stability strategies (i.e., $\overline{\beta}_3 < \beta \leq \overline{\beta}_2$); when it is extremely high, only the point (1,1) is an evolutionary stability strategy (i.e., $\overline{\beta}_2 < \beta < 1$). Put it differently, both the GSSC and TSSC would adopt a centralized channel structure when the competition coefficient is very low. On the contrary, when the two supply chains compete heavily, the decentralized channel structure is a stable equilibrium channel structure over time. The reason behind this is that supply chain internal integration often increases their competitiveness. Accordingly, when the market competition is fierce, both types of supply chains can reduce their chain-to-chain competition by reducing the degree of supply chain integration. It is noteworthy that when the competition coefficient is moderate, the evolutionary stability strategy of this system may be the ESS (0,0) or ESS (1.1), which is significantly affected by the initial states of two supply chains adopting the centralized channel structure. In particular, when two types of supply chains have lower initial willingness to adopt decentralized channel structure, the dynamic service system will lastly evolve to ESS (0,0), otherwise to ESS (1,1).

6. Numerical study

6.1. Sensitivity analysis

In this subsection, the effects of competition coefficient on individual or supply chains' optimal prices, green service levels, demands and profits under different channel structure combinations are examined numerically. We regard the tourism service market as a case and set the basic market share $a = 100$ and let the factor β change over from 0 to 1. Then, the effects of competition coefficient can be illustrated by Figs. 1-4.

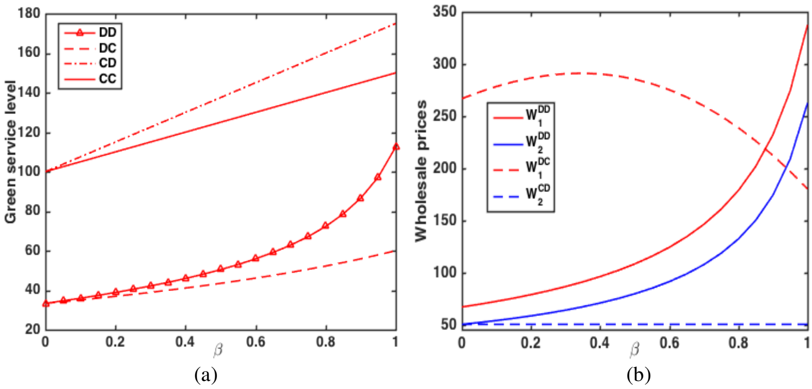

Fig. 1. The effects of factor β on green service levels and wholesale prices.

Fig. 1 shows that the green service level under each model is always increasing with the increase of competition between two types of supply chains. Moreover, it verifies that the ranking relationship of green service levels under four models is in line with our prior findings (i.e., $s_1^{CD*} > s_1^{CC*} > s_1^{DD*} > s_1^{DC*}$). By contrast, the effects of β on wholesale prices are not all monotonously increasing (see Fig. 1(b)). To be more specific, it can be found that both wholesale prices of the two supply chains under Model DD increase in competition, while the wholesale price of GSSC under Model DC first increases then decreases as β increases, showing an inverted U-shaped structure. Note that the competition coefficient wouldn't affect the wholesale price of TSSC under Model CD.

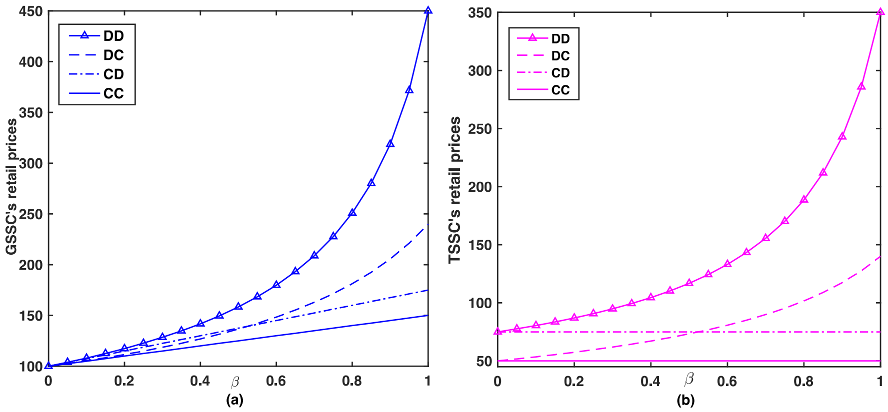

Fig. 2. The effects of factor β on two supply chains' retail prices.

We can find from Fig. 2 that almost retail prices of two supply chains under four models are increasing with the rise of competition coefficient except for the p_2^{CD*} and p_2^{CC*}, which are not affected by it. More interestingly, it is a general trend that retail prices of the two supply chains under Model DD is the highest while the lowest under Model CC. The reason behind that the double marginalization effect under Model DD is the fiercest while lowest under Model CC. The two supply chains with channel structure C can set lower retail prices due to no price increase by upstream enterprises. It is noteworthy that the retail prices of two supply chains under Model CD are higher than that under model DC when the competition is relatively low, and vice versa.

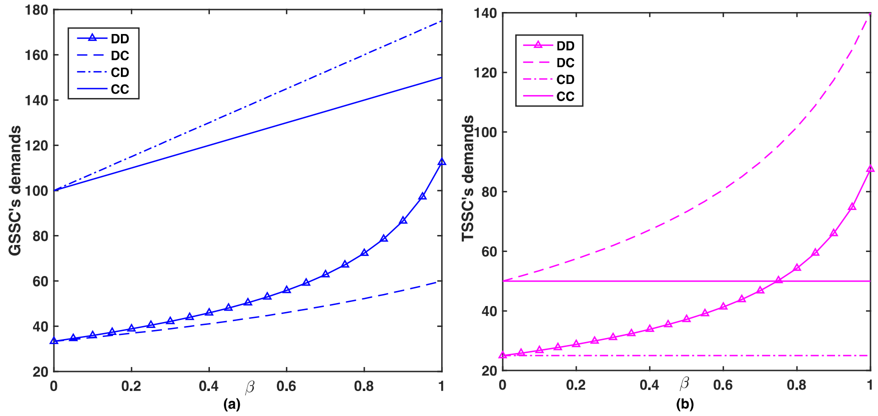

Fig. 3. The effects of factor β on two supply chains' demands.

From Fig. 3, we can find that almost demands of two supply chains increase in β except for d_2^{CD*} and d_2^{CC*}, which cannot be influenced by it. Furthermore, it can be found that the demands of GSSC under four models always satisfy the relationship $d_1^{CD*} > d_1^{CC*} > d_1^{DD*} > d_1^{DC*}$. By contrast, it is worth noting that when the competition between two supply chains is relatively low, the demands of TSSC under four models satisfy $d_1^{DC*} > d_1^{CC*} > d_1^{DD*} > d_1^{DC*}$; however, the TSSC's demands follow the relationship $d_1^{DC*} > d_1^{DD*} > d_1^{CC*} > d_1^{DC*}$ when that competition is relatively high. This implies that supply chain with a centralized channel structure can acquire more market shares than with a decentralized one, especially when its rival has a decentralized one.

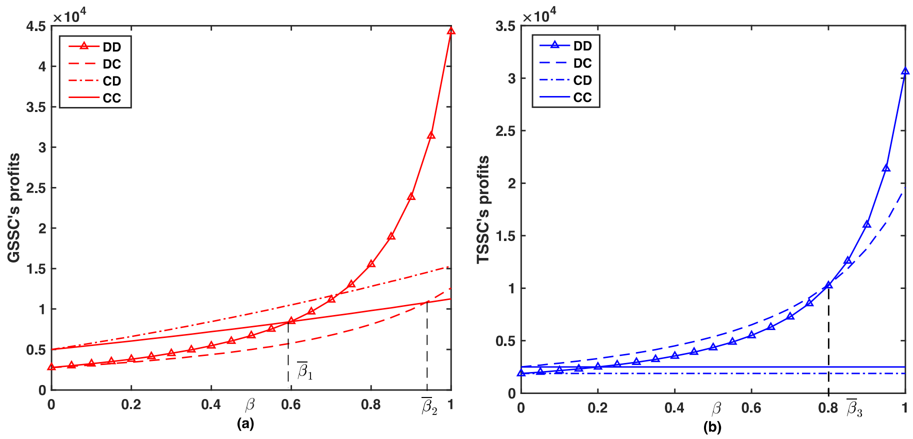

Fig. 4. The effects of factor β on two supply chains' profits.

From Fig. 4, we can find that profits of two supply chains are increasing along with the competition between two supply chains except for Π_{SC2}^{CD*} and Π_{SC2}^{CC*}, which can't be influenced by β. In addition, these illustrations verify our previous propositions that there exist key thresholds for facilitating the two supply chains to make better channel structure decisions. Further, when that competition is relatively high, channel structure DD is more beneficial for two types of supply chains. This suggests that supply chains should reduce their integration degree to increase their retail prices so that they can obtain more consumer surplus value, even if this behavior would compress their total market shares.

6.2. Evolutionary stability strategy analysis

In this subsection, we employ the numerical simulation analysis method to observe the evolution trend of the dynamic competitive system. In order to illustrate the evolution path of the two supply chains' channel strategies more intuitively, we normalize the basic market $a = 1$ and let the competition coefficient β change internal [0, 1] under different initial states of the competitive system, thereby resulting in Fig. 5, wherein the blue, red and green lines represent the three cases $0 < \beta < \overline{\beta}_3$, $\overline{\beta}_3 < \beta < \overline{\beta}_2$ and $\overline{\beta}_2 < \beta < 1$ respectively.

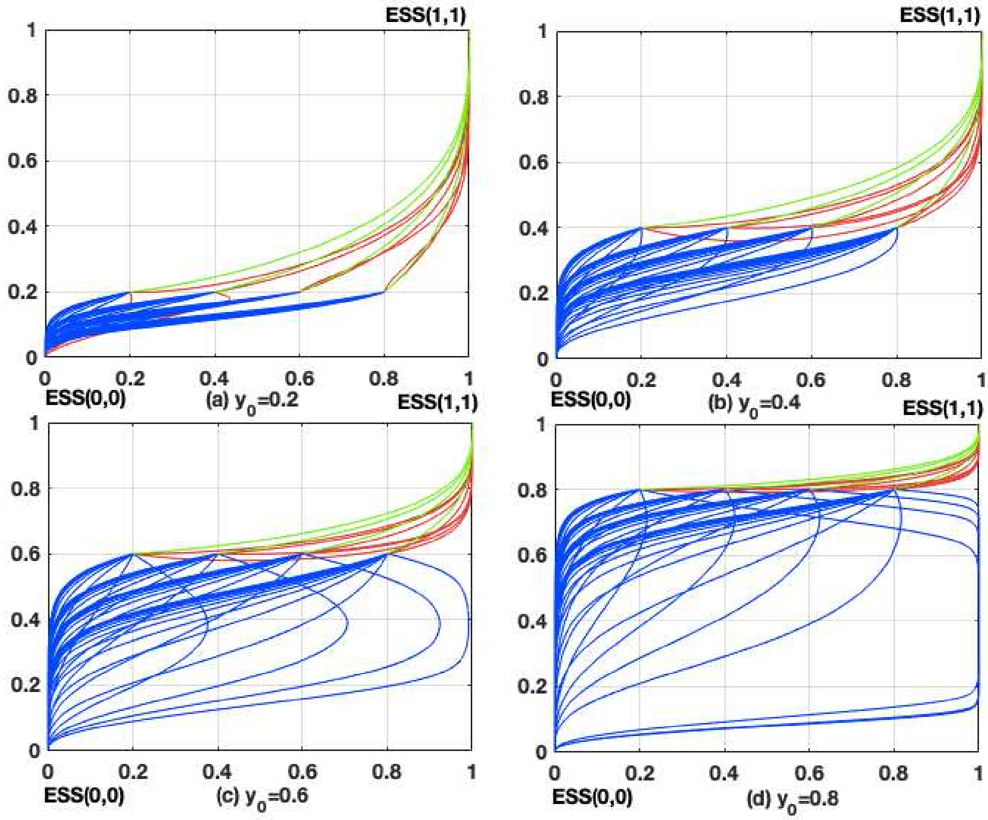

Fig. 5. The effects of factor β on ESSs of the dynamic competitive system.

It can be seen from the above figure that both the competition coefficient and initial states of two supply chains' channel strategies play a significant role in the evolution trends and ESSs of this competitive system. In particular, when the competition coefficient is relatively low, the competitive system lastly evolves to point (0, 0) regardless of the initial states (see the blue lines). Namely, both supply chains will eventually adopt the centralized channel structure. However, it would evolve to point (1, 1) when the competition coefficient is sufficiently high regardless of the initial states (see the green lines). More importantly, the initial states will make sense when the competition coefficient is moderate. In this setting, the competitive system would lastly evolve to point (0, 0) when the initial states are very low, and vice versa (see red lines in Fig. 5(a)). It is also generally concluded that the system evolves to ESS (0, 0) faster when the initial states are smaller while it evolves to ESS (1, 1) faster under the higher initial states.

7. Conclusions and future directions

In this paper, a joint decision problem of channel structure, pricing and green service for traditional and green service supply chains are studied. In each supply chain, the manufacturer and the retailer follow a manufacturer-led Stackelberg game and the two types of supply chains play a Nash game. We first develop four channel structure models to investigate the channel structure and pricing, as well as the green service decisions of GSSC under a one-shot game. Further, we consider the repeated game situation and identify the evolutionary stability strategy of this dynamic competitive system. The main research results are summarized as follows.

Comparing the optimal solutions across four models under a one-shot game, we find that when it gives the TSSC's channel structure, the GSSC prefers the channel structure C under a relatively low competition coefficient while the channel structure D under a relatively high one. By contrast, it shows that the TSSC always prefers the channel structure C when the GSSC adopts a centralized channel structure. In addition, the GSSC would like to provide the highest green service level when he adopts a channel structure C while the TSSC uses a channel structure D. Moreover, the wholesale price of GSSC under Model DC first increases then decreases as the competition between two supply chains rises. Finally, we find that the ESSs of this system are really dependent of the competition between two supply chains and the initial states of two types of supply chains' channel strategies. Thus, it can be suggested that the managers should adopt different channel structures according to the market competition intensity of their industry and select the appropriate time node to implement large-scale green service investment so that they can obtain better market competitiveness.

Like many prior studies, this paper also has some limitations and could be extended from the following aspects possibly. Firstly, it could extend our models to consider other market environment such as different product competition in the future. Secondly, considering the information asymmetry may be another interesting future research direction (e.g., private cost/demand information). Lastly, this paper focuses on the decentralized and centralized channel structure choices of two supply chains. Similarly, it would be interesting to study the online and offline channel choices of different types of supply chains from a long-term perspective.

Declaration of Competing Interest

The authors report no conflict of interest.

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Appendix

Proof for Proposition 1. Comparing the optimal green service levels under different models yields the following results.

$$S_1^{CC*} - S_1^{CD*} = -\frac{a\beta}{4} < 0$$

$$S_1^{DD*} - S_1^{DC*} = \frac{a\beta(2+\beta)(12+2\beta-8\beta^2+\beta^4)}{2(6-\beta^2)(3-\beta^2)(8-7\beta^2+\beta^4)} > 0$$

$$S_1^{CC*} - S_1^{DD*} = \frac{a(2+\beta)(16-2\beta-21\beta^2+\beta^3+8\beta^4-\beta^6)}{2(3-\beta^2)(8-7\beta^2+\beta^4)} > 0$$

According to the above equations, we can easily derive the Proposition 1.

Proof for Proposition 2. Comparing the optimal profits of green service supply chain under different models yields the following results.

$$\Pi_{SC1}^{DD*} - \Pi_{SC1}^{CD*} = \frac{-a^2}{(32(3-\beta^2)^2(8-7\beta^2+\beta^4)^2)}\{(4096 + 6144\beta - 12032\beta^2 - 21824\beta^3 + 8272\beta^4 + 25240\beta^5 + 705\beta^6 - 13488\beta^7 - 2688\beta^8 + 3648\beta^9 + 1054\beta^{10} - 480\beta^{11} - 164\beta^{12} + 24\beta^{13} + 9\beta^{14})\}$$

$$\Pi_{SC1}^{CC*} - \Pi_{SC1}^{DC*} = \frac{a^2(2-\beta)(2+\beta)^3(8-10\beta^2+\beta^4)}{8(6-\beta^2)^2(2-\beta^2)}$$

Based on the above equations, we define $f_1(\beta) = 4096 + 6144\beta - 12032\beta^2 - 21824\beta^3 +$

$8272\beta^4 + 25240\beta^5 + 705\beta^6 - 13488\beta^7 - 2688\beta^8 + 3648\beta^9 + 1054\beta^{10} - 480\beta^{11} - 164\beta^{12} + 24\beta^{13} + 9\beta^{14}$ and $f_2(\beta) = 8 - 10\beta^2 + \beta^4$. Solving $f_3(\beta) = 0$ and $f_2(\beta) = 0$, we can obtain the key thresholds $\overline{\beta}_1$ and $\overline{\beta}_2$.

Proof for Proposition 3. Comparing the optimal profits of traditional service supply chain under different models yields the following results.

$$\Pi_{SC2}^{DC*} - \Pi_{SC2}^{DD*} = \frac{a^2(4-\beta^2)^2(2\beta^2+\beta^3-6-4\beta)^2(6-14\beta^2+8\beta^4-\beta^6)}{2(3-\beta^2)(12-8\beta^2+\beta^4)^2(8-7\beta^2+\beta^4)^2}$$

$$\Pi_{SC2}^{CC*} - \Pi_{SC2}^{CD*} = \frac{a^2}{16} > 0$$

Based on the above equations, we define $f_3(\beta) = 6 - 14\beta^2 + 8\beta^4 - \beta^6$. Solving $f_3(\beta) = 0$, we can obtain the key threshold $\overline{\beta}_3$.

Proof for Proposition 4. The conditions for different ESSs are presented in Table A.1-A.3.

Table A.1. The stability of points when $0 < \beta \leq \overline{\beta}_1$.

	$\boldsymbol{DetJ}$	**Sign**	$\boldsymbol{TrJ}$	**Sign**	**Stability**
(0,0)	$\Delta n \cdot \Delta \overline{n}$	$+$	$\Delta n + \Delta \overline{n}$	$-$	ESS
(0,1)	$-\Delta L \cdot \Delta \overline{n}$	$-$	$\Delta L - \Delta \overline{n}$	$\pm$	Saddle point
(1,0)	$-\Delta \overline{L} \cdot \Delta n$	$-$	$\Delta \overline{L} - \Delta n$	$\pm$	Saddle point
(1,1)	$\Delta L \cdot \Delta \overline{L}$	$+$	$-(\Delta L + \Delta \overline{L})$	$+$	Unstable

Table A.2. The stability of points when $\overline{\beta}_1 < \beta \leq \overline{\beta}_3$.

	$\boldsymbol{DetJ}$	**Sign**	$\boldsymbol{TrJ}$	**Sign**	**Stability**
(0,0)	$\Delta n \cdot \Delta \overline{n}$	$+$	$\Delta n + \Delta \overline{n}$	$-$	ESS
(0,1)	$-\Delta L \cdot \Delta \overline{n}$	$+$	$\Delta L - \Delta \overline{n}$	$+$	Unstable
(1,0)	$-\Delta \overline{L} \cdot \Delta n$	$-$	$\Delta \overline{L} - \Delta n$	$\pm$	Saddle point
(1,1)	$\Delta L \cdot \Delta \overline{L}$	$-$	$-(\Delta L + \Delta \overline{L})$	$\pm$	Saddle point

Table A.3. The stability of points when $\overline{\beta}_2 < \beta \leq 1$.

	$\boldsymbol{DetJ}$	**Sign**	$\boldsymbol{TrJ}$	**Sign**	**Stability**
(0,0)	$\Delta n \cdot \Delta \overline{n}$	$-$	$\Delta n + \Delta \overline{n}$	$\pm$	Saddle point
(0,1)	$-\Delta L \cdot \Delta \overline{n}$	$+$	$\Delta L - \Delta \overline{n}$	$+$	Unstable
(1,0)	$-\Delta \overline{L} \cdot \Delta n$	$-$	$\Delta \overline{L} - \Delta n$	$\pm$	Saddle point
(1,1)	$\Delta L \cdot \Delta \overline{L}$	$+$	$-(\Delta L + \Delta \overline{L})$	$-$	ESS

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