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OPTIMAL DECISIONS OF ELDERLY CARE SERVICE SUPPLY CHAIN WITH GOVERNMENT INTERVENTION

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Abstract. Government intervention plays an indispensable role in the development of the elderly care service supply chain (ECSSC). However, no research has focused on the optimal decision-making of the ECSSC considering government intervention under different channel power structures. This study establishes a three-stage ECSSC model, including the government sector, elderly care service provider and elderly care service integrator, while considering different government intervention measures and channel power structures. The service-level elasticity coefficient is defined as an uncertain variable, that can affect service demand and ESI service costs. This study explores the optimal decisions and market performance of the government and ECSSC under different channel power structures and government intervention, providing guidance for the ECSSC development and government decision-making. The results show that, first, government intervention is beneficial for the ECSSC, customers, and social welfare. Compared with the subsidy and service-level regulation scenario, only the former is beneficial for the supply chain, social welfare, and unit customer expenditure, but at the cost of lower service level and higher government expenditure. Second, different channel power structures do not affect service level, social welfare, and unit customer expenditure. However, the ESI-dominated structure favors ECSSC development. Third, the setting of the reward-penalty factor should not be too high, as, in this case, supply chain members, customers, and social welfare will benefit from the increased expected value of service level elasticity. At last, managerial insights are presented.

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1. Introduction

In recent years, the issue of aging has escalated worldwide, presenting increasingly pressing challenges. With the continuous increase in demand for elderly care services, the market for such services has experienced new developments. For instance, the community care model originating from the UK has influenced the development of the Chinese community-based elderly care service model (CESM) [51]. Currently, the emerging CESM in China is primarily led by the government and involves the participation of social organizations and market-oriented operations. This mode offers a wide range of services to older adults in a more comfortable and

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convenient manner [47]. Furthermore, with the in-depth integration of the Internet and elderly care service system, various online platforms are emerging, including, "Care.com" and "Kindlycare" in the US, "Daum Kaka" in Korea [26], and "Youkang" in China[1]. These online platforms integrate a series of elderly care providers (ESP), allowing older adults to conveniently access and purchase services. These emerging systems for elderly service provision can be considered the ECSSC, with CESMs (online platforms) serving as the elderly care service integrators (ESI) and service providers serving as the ESPs [50]. ESIs integrate various services and offer them to older adults, whereas ESPs serve older adults directly upon order placement. Unlike other service supply chains (such as logistics and tourism service supply chains), elderly care services possess a public service nature because of the unique characteristics of their recipients, and the government sector plays an essential role in the provision process. Various countries offer subsidies to support older adults in accessing elderly care services. For instance, the Italian government provides subsidies for older adults based on their health conditions [4]. In Japan, older adults aged 70–75 pay 20% of the elderly care service costs, and the remaining expenses are covered by the public system [1]. In China, by the end of 2020, a total of 38.537 million senior citizens nationwide were entitled to old-age subsidies[2]. With the continuous development of the economy, older adults' requirements for quality care services have also increased. In addition to providing subsidies, government sectors must make efforts in service quality supervision. For instance, in Scotland, the Care Inspectorate was established to regulate the service sector to provide higher-quality services to older adults [26]. In Jiangsu, China, basic standards for the level of services have been established. Elderly care service institutions that offer substandard services face penalties, while those with higher ratings receive additional subsidies[3]. Therefore, considering the emerging ECSSC model, it is of great significance to explore the optimal decision-making under government intervention and the impact of government intervention on the ECSSC in promoting the development of the ECSSC and providing sustained high-quality services for older adults.

In addition to the ECSSC under government intervention, the type of supply chain structure that is most suitable for sustainable ECSSC development is also of concern. Channel power structure significantly affects supply chain performance [9]. Manufacturers in traditional product supply chains often have the power to serve as channel leaders and capture higher profits. However, the gradual strengthening of retailers, such as Walmart and Taobao, has resulted in a retailer-dominated structure [12]. In the context of the ECSSC, for instance, in its early stages, ESPs occupied the main market share in China [50], and ESIs presented challenges in controlling decision-making processes. However, as ESIs continue to grow and reach a certain scale, an ESI-dominated structure may emerge. Scholars have extensively analyzed the impact of different channel power structures on supply chain performance and explored advantageous channel structures [8, 25, 42]. Therefore, understanding the impact of channel power structures on optimal decisions and market performance under government intervention, and identifying the most profitable channel structure for the ECSSC are necessary and intriguing. In addition to channel power structures, scholars have often considered uncertainty in the analysis of supply chains [8, 38, 41]. In the ECSSC system, the seller of services, ESI, has the opportunity to influence the final demand by selecting appropriate service levels. For example, providing convenient purchasing experiences [50] and training for service personnel[4] can enhance the ESI service level. Generally, different ESIs may have varying degrees of impact on demand because they may adopt different measures to enhance their service levels, leading to uncertainty in service demand and costs. By considering the uncertainty of the ESI service-level elasticity coefficient, analyzing the impact of uncertain parameter on the optimal decisions and market performance of the ECSSC and government sector can make our research more realistic.

Research on the optimal decision-making and coordination of service supply chains is increasing, but research on the ECSSC remains scarce. One of the most significant differences between the research on the ECSSC and general service supply chains is that elderly care services have a public service nature, and the role of the government cannot be ignored. Considerations of government intervention are more common in sustainable or

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[1] https://www.sohu.com/a/333214303_481760

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low-carbon supply chains [7, 11, 20, 31, 35], but models considering the government sector as a decision-making participant are limited [20,30,40,53], among these studies, no research has considered both subsidy and service-level regulations. Previous studies on the ECSSC have mainly focused on the optimal decision-making and coordination of dual-channel supply chains [50, 52], ECSSC under information asymmetry [6, 48], and ECSSC under demand uncertainty [49]. These models are two-echelon, neglecting the role of government intervention. Government involvement can affect the interaction between ESIs and ESPs. Solving the optimal decisions of the government and supply chain members can provide suggestions for the government to formulate appropriate policies to promote the sustainable development of the ECSSC, which has not been specifically analyzed from a quantitative perspective.

Based on the analysis above, the research gaps are summarized as follows:

(1) Previous research on the ECSSC did not consider the role of government intervention, nor did they consider the government sector as a decision-making participant. By considering government intervention measures (subsidy and service-level regulations), our study is more compatible with the actual situation. By considering the decision-making of the government sector, the formulation of appropriate government strategies can help promote the improvement of service level and the sustainable development of the ECSSC.
(2) Comparative analysis of the optimal decisions and market performance of the ECSSC under different government interventions (non-intervention, subsidy, subsidy and service-level regulation) has not been conducted in previous research. Through comparative analysis, we can better understand the applicability of different government intervention measures and provide guidance for government policy-making.
(3) Previous research has not focused on the influence of channel power structures on the ECSSC. However, it is worth studying to select suitable channel power structure for the ECSSC under government intervention.

Our study addresses the aforementioned research gaps. A three-stage ECSSC model is established that considers the government as a decision-making participant and analyzes the optimal decisions and market performance of supply chain members and the government under different channel power structures and government interventions. Based on systematic analysis, the main contributions of this study are summarized as follows: First, this study provides a novel perspective for ECSSC studies, as a three-stage ECSSC model that considers government intervention is established. Second, by considering the government sector as a decision-maker, the optimal decisions of the government and supply chain members under government intervention are analyzed. Third, the optimal decisions and market performance of the ECSSC under different channel power structures with government intervention are compared and analyzed to seek a more favorable supply chain structure model. Finally, to promote the sustainable development of the ECSSC, suggestions are provided for supply chain members, and the policy-making of the government sector in different situations is discussed.

The rest of the study is organized as follows. Section 2 reviews the related literature. Model description is described in Section 3. In Section 4, optimal decisions of the ECSSC are obtained and comparative analyses are carried out. In Section 5, numerical experiments and sensitive analysis are conducted. Managerial insights are discussed in Section 6. Section 7 concludes the study.

2. Literature review

In this section, an in-depth review of the relevant literature is conducted to emphasize the research gaps and specific research priorities of our study.

2.1. Service supply chain management

Services play a crucial role in supply chain systems [45]. In recent years, the number of studies on service supply chains has been increasing [5,10,13,17,18,23,24,27,29]. Some scholars have focused on optimal decision-making in service supply chains. For instance, Han *et al.* [18] focused on the optimal decision-making and coordination strategies of the port and shipping service supply chain. He *et al.* [21] explored optimal decision-making for the low-carbon service supply chain. Concerning the optimal decisions of the supply chain, we focus on service quality (level), in addition to the optimal price. The acquisition of optimal product quality and the enhancement of product quality have been widely studied in product supply chains. For example, Sarkar *et al.* [39] developed a three-echelon sustainable supply chain model that simultaneously considered controlling carbon emissions and improving product quality. Taleizadeh *et al.* [43] assigned different qualities to manufacturing and remanufacturing products. Regarding the service supply chain, service level is also a research focus. He *et al.* [21] developed a service supply chain model that considered corporate social responsibility (CSR) and emission reduction to determine the optimal service level. Liu *et al.* [28] focused on the optimal decisions when service providers provided quality defect assurance in the logistics service supply chain. Bian *et al.* [3] studied the impact of service outsourcing and found that service outsourcing could reduce the retail price or improve the service level under Manufacture-Stackelberg (MS) or Retailer-Stackelberg (RS). Although the above research involved service level, their focus was not primarily on government intervention, or the service level was not a decision variable.

At present, merely a few studies have focused on the ECSSC. Zhao *et al.* [52] used time perception to refine the demand for elderly care services and analyzed the optimal decisions of a dual-channel smart ECSSC. Service level is also their concern. Chen [6] focused on the information asymmetry between the ESI and ESP and constructed an ECSSC model based on trust incentives. Zhao [48] analyzed the optimal ordering decisions of a two-echelon ECSSC with asymmetric demand information. Zhao [50] employed a game-theoretic framework to analyze the coordination of the ECSSC within a dual-channel setting. The optimal strategies and supply chain coordination for the ESI and ESP were studied under three decision forms. Zhao [49] analyzed the supply chain coordination of the ECSSC, while considering a combination of options and loss-sharing contracts. The above-mentioned articles focused on the optimal decision-making and coordination of the ECSSC; however, they ignored the important role of the government in providing elderly care services. They neither considered government intervention, let alone the optimal decision-making of the government, nor did they reflect on the influence of different channel power structures on the optimal decision-making of the ECSSC, all of which constitute the focus of our study.

2.2. Government intervention in supply chain management

Government intervention in supply chain management is often observed in research on green supply chains, whereby methods such as taxation or subsidies are commonly employed. For instance, Ma *et al.* [31] investigated the impact of consumption subsidies on a closed-loop supply chain (CLSC). Fu *et al.* [11] analyzed the influence of different government subsidies on an electric vehicle supply chain, categorizing government subsidies into fixed and linear types. Yang and Xiao [46] analyzed the optimal decisions considering different channel power structures and government interventions. Barman *et al.* [2] analyzed the optimal decision-making of the green supply chain under different channel power structures and various carbon tax policies. Sarkar *et al.* [37] analyzed the optimal decision-making process in the green supply chain considering asymmetry under the government's carbon policies. Han *et al.* [18] focused on the decision-making of the port and shipping service supply chain under government subsidy and showed that government subsidies directly impacted the profits. Peng *et al.* [35] analyzed optimal decision-making under government supervision and found that government service supervision was conducive to incentivizing platforms to improve service levels and social welfare. However, the aforementioned research did not consider the government as a decision-making participant. By contrast, some studies have focused on incorporating the government as a decision-maker. Sheu [40] explored the negotiation of cooperation agreements under government intervention and found that excessive intervention may yield negative consequences. Liu *et al.* [30] analyzed optimal decision-making considering CSR under government subsidies. He *et al.* [20] focused on the optimal channel structure, pricing, and government subsidy within a CLSC. Zhang *et al.* [53] established a three-stage differential game model to analyze the optimal decision-making of the CLSC, to facilitate the government in formulating emission reduction and recycling subsidies. Although the aforementioned studies treated the government sector as a decision-making participant, they did not simultaneously consider government subsidies and service-level regulation.

In summary, many scholars have discussed optimal decision-making in supply chains under government intervention. However, few studies have considered the government as a decision-maker. Furthermore, studies that consider the government as a decision-maker do not simultaneously consider subsidy and service-level regulations.

2.3. Uncertainty and channel power structure in supply chain management

Uncertainty and channel power structures are often involved in supply chain management. Considering these factors in the optimal decision-making of supply chains can make our analysis more realistic. The impact of uncertainty and channel power structures on supply chains has attracted the attention of numerous researchers. For instance, He *et al.* [19] studied the channel coordination problem with stochastic demand. Ullah *et al.* [44] considered the uncertainty of demand and returns in a CLSC. Sarkar *et al.* [38] focused on uncertainty costs and represented such costs using a signed distance formula. Hu and Feng [22] explored supply chain coordination and considered the uncertainties from both supply and demand. He *et al.* [20] investigated the optimal channel power structure and pricing decisions. Sun *et al.* [42] studied the recycling, emission reduction, and pricing decisions of low-carbon CLSC under three channel power structures. Shi *et al.* [41] investigated the impact of power structures on market performance when facing uncertain demand. Chen *et al.* [8] studied optimal pricing and effort decisions under cost uncertainty and different channel power structures. Yang and Xiao [46] analyzed the pricing and green-level decisions under different channel power structures. By summarizing the abovementioned literature, we can find that research on uncertainty in supply chain management has largely focused on demand and cost uncertainties. Inspired by Chen *et al.* [8], we assume the uncertainty of the service-level elasticity coefficient in this study. Additionally, the influence of channel power structure is also one of our concerns.

A survey of the aforementioned literature reveals that, in most studies involving the impact of government intervention, only subsidies or tax-related policies are considered, with few articles simultaneously considering the regulation of service (product) level. Additionally, most studies overlook the government sector as a decision-maker. Considering the involvement of the government can help the decision-making of the government and benefit the sustainable development of the ECSSC. To fill these gaps and consider the uncertainty and channel structures involved in the actual provision process of elderly care services, we establish a three-stage ECSSC model. To the best of our knowledge, no study has simultaneously addressed all of these factors in an ECSSC context. Some relevant studies from different backgrounds are listed and compared with this study in Table 1.

3. Model description

In this study, we examine an ECSSC system comprising an ESI, an ESP, and the government sector. The government is considered the leader of the entire supply chain, offering subsidies to older adults, while enforcing service-level regulations on the ESI. We consider two types of channel power structures: ESP and ESI-dominated. Subsequently, a three-stage Stackelberg game model is established.

The ESI pays the ESP a wholesale price w per unit of elderly care services and sells the services to older adults at a price of p. It is widely recognized that $p > w$ [8]. The ESI provides services with a service level of e while being subject to a government-imposed restriction e_0 thereon. If $e < e_0$, the ESI will face penalties; otherwise, the ESI will receive rewards from the government sector. Notably, h represents a reward-penalty factor that quantifies the amount of punishment or reward granted by the government sector to the ESI [35]. Furthermore, delivering services at a level of e incurs additional costs for the ESI, including expenses related to instrument and equipment purchases, personnel training, and so on. In terms of the ESP, we assume that the marginal cost of providing a unit of service is c, and $w > c$. The government sector offers subsidies to older adults with unit subsidy amounts of s.

Based on the aforementioned assumptions, customer demand is influenced by purchase price and ESI service level, and the linear demand function can be defined as follows:

$$D\left(p,e\right) = a - (p - s) + \gamma e \tag{1}$$

TABLE 1. Summary of some relevant literature.

Authors	Model type	Decision system structure	Government policy	Service level	Channel power structure
Chen *et al.* [8]	SC	manufacture, retailer	–	sales effort	MS; RS; VN
Fu *et al.* [11]	SSC	supplier, manufacture	subsidy	–	supplier-dominated
Sarkar *et al.* [37]	GSC	manufacture, n-buyers	CAPT; CT	–	–
Sarkar *et al.* [39]	SSC	supplier, one manufacture and n-retailers	–	product quality	–
Barman *et al.* [2]	DCGSC	manufacture, retailer	CCT; CT	–	MS; RS
Gao *et al.* [12]	CLSC	manufacture, retailer	–	sales effort	MS; RS; VN
He *et al.* [20]	CLSC	government sector, manufacture and retailer	subsidy	–	MS
Liu *et al.* [30]	SSC	government sector, one retailer; n-suppliers	subsidy	CSR-effort	RS
Peng *et al.* [35]	LCSC	manufacture, platform	service supervision	service level	platform-dominated
Yang *et al.* [46]	GSC	manufacture and retailer	government intervention	green level	MS; RS; VN
Zhao [52]	DCECSSC	online provider and offline provider	–	service level	online provider-dominated
Zhao [48]	ECSSC	ESI and ESP	–	–	ESP-dominated
Zhao [49]	ECSSC	ESI and ESP	–	sales effort	ESP-dominated
Zhao [50]	DCECSSC	ESI and ESP	–	service enhancement effort	ESP-dominated
This paper	ECSSC	government sector, one ESI, one ESP	subsidy; service level regulation	service level	ESI-dominated; ESP-dominated

Notes. DCGSC: Dual-channel green supply chain; SSC: Sustainable supply chain; LCSC: Low-carbon supply chain; VN: Vertical Nash; CAPT: Carbon tax & cap and trade; CCT: Carbon cap-and-trade; CT: Carbon tax.

where a represents the total potential market demand, the elasticity of price to demand is assumed to be 1 [35], and γ represents the elasticity coefficient of service level to demand. We assume that γ is a linear uncertain variable and denote the distribution of γ by $\Phi(x)$ with $x \in [0,1]$. Thus, the customer demand D is also an uncertain variable. For the sake of the present study's length, specific introductions of linear uncertain variables can be reviewed in Chen *et al.*'s paper [8]. Consistent with the assumptions made by Chen *et al.* [8], we establish a linkage between service level cost and ESI type. Specifically, the ESI service-level cost is assumed to be

$$C(e) = \frac{(1-\gamma)^2 e^2}{2}. \tag{2}$$

Similar to the description in Chen *et al.*'s paper [8], in our model, γ takes a value from interval [0,1], and when $\gamma = 0$, the cost of maintaining the same service level for the ESI is high, resulting in its reluctance to enhance the service level to influence the demand; when $\gamma = 1$, a small investment may affect service demand, making the ESI more motivated to provide high-level services. Furthermore, in our model, service-level elasticity meets the condition $E[\gamma] \in [0, 0.5)$, which means that the service-level elasticity has an expected boundary. This range is derived from the essential requirements that the model must satisfy to ensure meaningful results.

Next, we present the objective functions for each participant. The government sector aims to maximize social welfare, comprising producers' surpluses, customers' surpluses, and government revenue and expenditure [30]. Producers' surpluses are the sum of the benefits of the ESI and ESP. Customers' surpluses are commonly expressed as $D^2/2$ [7]. The revenue and expenditure of the government sector can be expressed as $hD(e_0 - e) - sD$. ESI's profits comprise three parts: total income, service wholesale costs and service-level costs, and gains and losses brought about by government service-level regulation. ESP's profits comprise two parts: income and expenses of providing services.

The social welfare of the government sector is expressed as

$$SW = \Pi_{ESI} + \Pi_{ESP} + \frac{D^2}{2} + hD(e_0 - e) - sD. \tag{3}$$

The profits of the ESI and ESP are, respectively, expressed as

$$\Pi_{ESI} = (p-w)(a-(p-s)+\gamma e) - \frac{e^2(1-\gamma)^2}{2} - h(e_0-e)(a-(p-s)+\gamma e) \tag{4}$$

$$\Pi_{ESP} = (w-c)(a-(p-s)+\gamma e). \tag{5}$$

The profits of the supply chain is described as

$$\Pi_{SC} = \Pi_{ESI} + \Pi_{ESP} = (p-c)(a-(p-s)+\gamma e) - h(e_0-e)(a-(p-s)+\gamma e) - \frac{e^2(1-\gamma)^2}{2}. \tag{6}$$

The sequence of events unfolds as follows: (1) The government sector announces the subsidy level provided to the customers. (2) The ESI sets the retail price and service level (in the ESI-dominated scenario) or the ESP sets the wholesale price (in the ESP-dominated scenario). (3) The ESP sets the wholesale price (in the ESP-dominated scenario) or the ESI sets the retail price and service level (in the ESI-dominated scenario). The decision sequence is illustrated in Figure 1 and the notations are listed in Table 2.

4. Decision model analysis of the ECSSC

In this section, we focus on analyze the optimal decision-making of the ECSSC under different scenarios and the comparison of results between different scenarios.

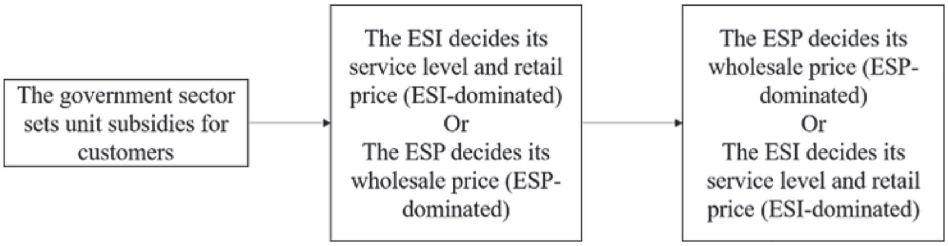

Figure 1. Sequence of decisions.

Table 2. Basic parameters for models.

Symbols	Description
c	Per unit cost of service capacity for the ESP
w	Wholesale price of per unit service capacity for the ESP
e	Service level for the ESI
p	Retail price of per unit service capacity to the customers for the ESI
D	Customer demand for service
γ	Elasticity coefficient of service level to demand
a	Total potential market demand
Π_i	Profits of the ESI/ESP/supply chain (i=ESI/ESP/SC)
SW	Social welfare
s	Per unit government subsidy to customers
h	Reward-penalty factor of service level for the ESI
e_0	Service level threshold set by the government sector
m	Marginal profits of the ESI

Notes. Note that SC includes the ESI and ESP.

4.1. The optimal decisions without government intervention

In this section, we examine the optimal decisions of the ECSSC without government intervention under two channel power structures as a benchmark. The ESI-dominated Stackelberg (IS) game, wherein the ESI acts as the Stackelberg leader, while the ESP acts as the follower. The ESP-dominated Stackelberg (PS) game, wherein the ESP has more bargaining power than the ESI. The ECSSC model without government intervention is formulated as follows:

The customer demand function can be expressed as

$$D\left(p,e\right)=a-p+\gamma e. \tag{7}$$

The profits of the ESI and ESP can be, respectively, expressed as

$$\Pi_{ESI}=\left(p-w\right)\left(a-p+\gamma e\right)-\frac{e^2\left(1-\gamma\right)^2}{2} \tag{8}$$

$$\Pi_{ESP}=\left(w-c\right)\left(a-p+\gamma e\right). \tag{9}$$

4.1.1. IS game model

When the ESI has more bargaining power, the game process unfolds as follows: (1) The ESI determines the retail price and its service level; (2) The ESP determines its wholesale price.

$$\begin{cases} \max\limits_{(p,e)} E\left[\Pi_{ESI}\left(p,e,w_{IS}^{*}\right)\right] \\ \qquad where\ \left(w_{IS}^{*}\right)\ is\, derived\, from\, solving\, the\ following\ problem \\ \qquad \begin{cases} \max\limits_{(w)}\ E\left[\Pi_{ESP}\left(w\right)\right] \end{cases} \end{cases} \tag{10}$$

Note that $E\left[\prod_i^k\right]$ is the expected value of i's profits under scenario k (where $i = ESI, ESP$; $k = IS, PS$); p_k^*,e_k^*, and w_k^* represent the optimal retail price, optimal ESI service level, and optimal wholesale price under scenario k, respectively. SW_k represents the expected social welfare.

As m represents the marginal profits of the ESI, we obtain $p = w + m$. The game is solved by backward induction. First, the ESP's optimal wholesale price w_{IS}^* is acquired. Subsequently, the optimal wholesale price is put into $E\left[\Pi_{ESI}\left(p,e,w_{IS}^*\right)\right]$ to determine the optimal retail price and ESI service level.

Proposition 4.1. *(i) The optimal retail price and service level of the ESI without government intervention are* $p_{IS}^* = \frac{3aE^2[\gamma]+(1-2E[\gamma])(3a+c)}{3E^2[\gamma]-8E[\gamma]+4}$ *and* $e_{IS}^* = \frac{E[\gamma](a-c)}{3E^2[\gamma]-8E[\gamma]+4}$*, respectively. (ii) The optimal wholesale price of the ESP without government intervention is given as* $w_{IS}^* = \frac{aE^2[\gamma]+2cE^2[\gamma]+(1-2E[\gamma])(a+3c)}{3E^2[\gamma]-8E[\gamma]+4}$*. (iii) The expected profits of ESI and ESP are* $\Pi_{ESI}^{IS}=\frac{(a-c)^2(E[\gamma]-1)^2}{2(3E^2[\gamma]-8E[\gamma]+4)}$ *and* $\Pi_{ESP}^{IS}=\frac{(a-c)^2(E[\gamma]-1)^4}{(3E^2[\gamma]-8E[\gamma]+4)^2}$*, respectively. (iv) The expected social welfare is* $SW_{IS}=\frac{(a-c)^2\left(6E^2[\gamma]-14E[\gamma]+7\right)(E[\gamma]-1)^2}{2(3E[\gamma]-2)^2(E[\gamma]-2)^2}$.

All the proofs are in the Appendix.

Consequently, we obtain the following insight:

Insight 1. When the ESI has more bargaining power, the optimal retail price, wholesale price, and service level all increase with the expected value of service level elasticity. The ESI's dominant position within the supply chain enables it to attain higher profits compared with the ESP.

When the ESI has more bargaining power, it has an incentive to expand the demand of the ECSSC as the expected value of γ increases. The ESI is willing to improve its service level, which leads to increased costs; consequently, the ESI raises its retail price. In the pursuit of higher profits, the ESP also chooses to increase its wholesale price.

4.1.2. PS game model

When the ESP has more bargaining power, the game process unfolds as follows: (1) The ESP determines the wholesale price; (2) the ESI determines the retail price and service level.

$$\begin{cases} \max\limits_{w}\ \ E\left[\Pi_{ESP}\left(w,e_{PS}^{*},p_{PS}^{*}\right)\right] \\ \qquad where\ \left(e_{PS}^{*},p_{PS}^{*}\right)\ is\, derived\, from\, solving\, the\ following\ problem \\ \qquad \begin{cases} \max\limits_{(e,p)}\ E\left[\Pi_{ESI}\left(e,p\right)\right] \end{cases} \end{cases} \tag{11}$$

First, we aim to derive the response function of the ESI. Subsequently, the ESP can use the response function to determine its optimal wholesale price and maximize its expected profit. Thus, we obtain the following proposition.

Proposition 4.2. *(i) The optimal wholesale price of the ESP without government intervention is given as* $w_{PS}^{*} = \frac{a+c}{2}$. *(ii) The optimal retail price and service level of the ESI without government intervention are* $p_{PS}^{*} = \frac{2aE^2[\gamma]+(1-2E[\gamma])(3a+c)}{2(E^2[\gamma]-4E[\gamma]+2)}$ *and* $e_{PS}^{*} = \frac{E[\gamma](a-c)}{2(E^2[\gamma]-4E[\gamma]+2)}$, *respectively. (iii) The expected profits of the ESI and ESP are* $\Pi_{ESI}^{PS}=\frac{(a-c)^2(E[\gamma]-1)^2}{8(E^2[\gamma]-4E[\gamma]+2)}$ *and* $\Pi_{ESP}^{PS}=\frac{(a-c)^2(E[\gamma]-1)^2}{4(E^2[\gamma]-4E[\gamma]+2)}$, *respectively. (iv) The expected social welfare is* $SW_{PS}=\frac{(a-c)^2\left(4E^2[\gamma]-14E[\gamma]+7\right)(E[\gamma]-1)^2}{8(E^2[\gamma]-4E[\gamma]+2)^2}$.

Consequently, we obtain the following insight:

Insight 2. When the ESP has more bargaining power, both the optimal retail price and the optimal service level increase with the expected value of service level elasticity. However, the optimal wholesale price remains unaffected by the service level elasticity. With a dominant position in the supply chain, the ESP can achieve higher profits than the ESI.

When the ESP has more bargaining power, the optimal wholesale price is not affected by the change of γ. Facing demand uncertainties, the ESI should improve the retail price to resist risks, and the increase in revenue will contribute to the improvement of its service level.

4.1.3. Comparison analysis under no-governmental intervention

By comparing the results in the IS and PS scenarios, we can obtain the following proposition.

Proposition 4.3. *When the ECSSC does not take government intervention into consideration, we obtain* $e_{IS}^{*} < e_{PS}^{*}$, $w_{IS}^{*} < w_{PS}^{*}$, $p_{IS}^{*} > p_{PS}^{*}$, $\Pi_{ESP}^{IS} < \Pi_{ESP}^{PS}$,$\Pi_{ESI}^{IS} > \Pi_{ESI}^{PS}$,$\Pi_{SC}^{IS} < \Pi_{SC}^{PS}$, *and* $SW^{IS} < SW^{PS}$.

When the ESP has more bargaining power, customers can obtain higher levels of service at lower prices, and the overall profit of the ECSSC is higher than that of the ESI-dominated structure. Moreover, this scenario enables the government sector to achieve higher social welfare. In the absence of governmental intervention, an ESP-dominated structure proves to be more advantageous for the government, the entire supply chain, and customers.

4.2. The optimal decisions of the ESI-dominated ECSSC with government intervention

In this section, we consider the government sector as a decision-maker that provides subsidies and regulates the service level of the ESI. We proceed to solve and analyze the optimal decisions under an ESI-dominated structure. We refer to the ESI-dominated supply chain with government intervention as GSI. The game process is as follows: (1) The government sector determines the subsidy level; (2) The ESI determines the retail price and service level; (3) The ESP determines its wholesale price.

$$\begin{cases} \max\limits_{s} \; E\left[SW_{GSI}\left(s, w_{GSI}^{*}, e_{GSI}^{*}, p_{GSI}^{*}\right)\right] \\ \quad where\ (p_{GSI}^{*}, e_{GSI}^{*})\ is\ derived\ from\ solving\ the\ following\ problem \\ \quad \begin{cases} \max\limits_{(p,e)} E\left[\Pi_{ESI}\left(p, e, w_{GSI}^{*}\right)\right] \\ \quad where\ (w_{GSI}^{*})\ is\ derived\ from\ solving\ the\ following\ problem \\ \quad \begin{cases} \max\limits_{(w)} E\left[\Pi_{ESP}\left(w\right)\right] \end{cases} \end{cases} \end{cases} \tag{12}$$

Through backward induction, first, the ESP's optimal wholesale price w_{GSI}^{*} is acquired. Afterward, the optimal wholesale price is put into $E\left[\Pi_{ESI}\left(p, e, w_{GSI}^{*}\right)\right]$ to determine the optimal retail price and service level of the ESI. Next, the value of w_{GSI}^{*}, p_{GSI}^{*} and e_{GSI}^{*} are replaced into $E\left[SW_{GSI}\left(s, w_{GSI}^{*}, e_{GSI}^{*}, p_{GSI}^{*}\right)\right]$ to achieve the optimal s_{GSI}^{*}. Then, we obtain Proposition 4.4.

Note that $E\left[\prod_i^k\right]$ is the expected value of i's profits under scenario k (where $i = ESI, ESP, SC; k = GSI, GSP$); p_k^*, e_k^*, s_k^*, and w_k^* represent the optimal retail price, optimal service level of the ESI, optimal subsidy level, and optimal wholesale price under scenario k, respectively.

Proposition 4.4. *(i) The optimal subsidy level of the government sector for customers is* $s_{GSI}^* = \frac{(a-c)\left(3E^2[\gamma]-2E[\gamma]h-2h^2-6E[\gamma]+3\right)+e_0h\left(h^2+1-2E[\gamma]\right)}{h^2+1-2E[\gamma]}$. *The optimal service level and retail price of the ESI are* $e_{GSI}^* = \frac{(a-c)(h+E[\gamma])}{h^2+1-2E[\gamma]}$ *and* $p_{GSI}^* = \frac{(a-c)\left(3E^2[\gamma]-hE[\gamma]\right)+(3a-2c)(1-2E[\gamma])-h^2(a-2c)+e_0h\left(h^2+1-2E[\gamma]\right)}{h^2+1-2E[\gamma]}$, *respectively. The optimal wholesale price of the ESP is* $w_{GSI}^* = \frac{a(E[\gamma]-1)^2+c\left(h^2-E^2[\gamma]\right)}{h^2+1-2E[\gamma]}$. *(ii) The expected profits of ESI and ESP are* $\Pi_{ESI}^{GSI} = \frac{(E[\gamma]-1)^2(a-c)^2(3E[\gamma]+h-2)(E[\gamma]-h-2)}{2(h^2+1-2E[\gamma])^2}$ *and* $\Pi_{ESP}^{GSI} = \frac{(E[\gamma]-1)^4(a-c)^2}{(h^2-2E[\gamma]+1)^2}$, *respectively. The expected total profit of the ECSSC is* $\Pi_{SC}^{GSI} = \frac{(a-c)^2(E[\gamma]-1)^2\left(5E^2[\gamma]-2hE[\gamma]-h^2-12E[\gamma]+6\right)}{2(h^2-2E[\gamma]+1)^2}$. *(iii) The expected social welfare is* $SW_{GSI} = \frac{(a-c)^2(E[\gamma]-1)^2}{2h^2-4E[\gamma]+2}$.

Consequently, we derive the following insight:

Insight 3. Under an ESI-dominated structure, the optimal subsidy level and retail price increase with the improvement of the service-level regulation threshold. However, the optimal service level and wholesale price are not affected by this threshold. The optimal service level of the ESI increases with the expected value of the service-level elasticity.

The above insight can be easily obtained by taking derivatives. The higher the service-level threshold, the higher the service costs to avoid fines, and the higher the retail price. The government sector may increase subsidies to encourage customers to purchase services.

Furthermore, according to the optimal response functions presented in the proof of Proposition 4.4 in the Appendix, it can be concluded that when the ESI has more bargaining power, government subsidy is positively correlated with the optimal service level of the ESI but negatively correlated with the optimal retail and wholesale prices ($\frac{\partial e_{GSI}^*}{\partial s} > 0$, $\frac{\partial p_{GSI}^*}{\partial s} < 0$, $\frac{\partial w_{GSI}^*}{\partial s} < 0$).

4.3. The optimal decisions of the ESP-dominated ECSSC with government intervention

In this section, we aim to solve and analyze the optimal decisions of the ECSSC under an ESP-dominated structure (GSP). The game process is as follows: (1) The government sector sets the subsidy level; (2) The ESP determines its wholesale price; (3) The ESI decides on the retail price and service level.

$$\begin{cases} \max\limits_{s} \; E\left[SW_{GSP}\left(s, w_{GSP}^*, e_{GSP}^*, p_{GSP}^*\right)\right] \\ \qquad where\ \left(w_{GSP}^*\right)\ is\ derived\ from\ solving\ the\ following\ problem \\ \qquad \begin{cases} \max\limits_{(w)} \; E\left[\Pi_{ESP}\left(w, e_{GSP}^*, p_{GSP}^*\right)\right] \\ \qquad where\ \left(p_{GSP}^*, e_{GSP}^*\right)\ is\ derived\ from\ solving\ the\ following\ problem \\ \qquad \begin{cases} \max\limits_{(p,e)} \; E\left[\Pi_{ESI}\left(p, e\right)\right] \end{cases} \end{cases} \end{cases} \tag{13}$$

First, we aim to derive the response function of the ESI; the ESP can utilize this to determine its optimal wholesale price and maximize its expected profit. Next, the government sector can utilize the above information to maximize social welfare and obtain the optimal subsidy level. Thus, we obtain the following proposition.

Proposition 4.5. *(i) The optimal subsidy level of the government sector for customers is* $s_{GSP}^* = \frac{(a-c)\left(2E^2[\gamma]-4hE[\gamma]-3h^2-6E[\gamma]+3\right)+e_0h\left(h^2-2E[\gamma]+1\right)}{h^2-2E[\gamma]+1}$. *The optimal wholesale price of the ESP is* $w_{GSP}^* =$

$\frac{(a-c)\left(E^2[\gamma]-2hE[\gamma]\right)+(1-2E[\gamma])(2a-c)-h^2(a-2c)}{h^2-2E[\gamma]+1}$. *The optimal service level and retail price of the ESI are* $e^*_{GSP} = \frac{(a-c)(E[\gamma]+h)}{h^2-2E[\gamma]+1}$ *and* $p^*_{GSP} = \frac{(a-c)\left(2E^2[\gamma]-3hE[\gamma]\right)-h^2(2a-3c)+(3a-2c)(1-2E[\gamma])+e_0h\left(h^2-2E[\gamma]+1\right)}{h^2-2E[\gamma]+1}$, *respectively. (ii) The expected profits of ESI and ESP are* $\Pi^{GSP}_{ESI}=\frac{(E[\gamma]-1)^2(a-c)^2\left(E^2[\gamma]-2hE[\gamma]-4E[\gamma]-h^2+2\right)}{2(-h^2+2E[\gamma]-1)^2}$ *and* $\Pi^{GSP}_{ESP}=\frac{(E[\gamma]-1)^2(a-c)^2\left(E^2[\gamma]-2hE[\gamma]-4E[\gamma]-h^2+2\right)}{(-h^2+2E[\gamma]-1)^2}$, *respectively. The expected total profit of the ECSSC is* $\Pi^{GSP}_{SC}=\frac{3(E[\gamma]-1)^2(a-c)^2\left(E^2[\gamma]-2hE[\gamma]-h^2-4E[\gamma]+2\right)}{2(-h^2+2E[\gamma]-1)^2}$. *(iii) The expected social welfare is* $SW_{GSP}=\frac{(a-c)^2(E[\gamma]-1)^2}{2(h^2+1-2E[\gamma])}$.

Consequently, we derive the following insight:

Insight 4. Under an ESP-dominated structure, the optimal subsidy level and retail price increase with the improvement of the service-level regulation threshold, while the optimal service level and wholesale price remain unaffected. The optimal service level of the ESI increases with the expected value of the service-level elasticity.

The reasons for this are similar to the explanations of Insight 3. Through Insights 3 and 4, we can draw an interesting conclusion that the service-level threshold only affects the optimal subsidy level and retail price. The optimal ESI service level and market performance are not influenced by this threshold. The government can achieve its regulatory goals by adjusting the reward-penalty factor, along with the appropriate subsidy value.

According to the optimal response functions presented in the proof of Proposition 4.5, it can be determined that, when the ESP has more bargaining power, government subsidy is positively correlated with the optimal service level and negatively correlated with the optimal retail and wholesale prices ($\frac{\partial e^*_{GSI}}{\partial s} > 0, \frac{\partial p^*_{GSI}}{\partial s} > 0, \frac{\partial w^*_{GSI}}{\partial s} > 0$).

4.4. Comparative analysis

In the previous analysis, we have derived the optimal decisions of the government and supply chain members under different channel power structures, considering the presence or absence of government intervention. Next, we will perform a comparative analysis of these scenarios.

4.4.1. Comparison with or without government intervention

In this section, we analyze the potential benefits of government intervention in the ECSSC.

Proposition 4.6. *The optimal service level of the ESI is higher with government involvement compared with without government involvement, denoted as* $e^*_{GSI} > e^*_{IS}$ *and* $e^*_{GSP} > e^*_{PS}$, *respectively.*

Thus, it can be inferred that government intervention plays a favorable role in enhancing service level. This conclusion holds even in cases wherein the government only provides subsidies without imposing service-level regulations ($h = 0$).

4.4.2. Comparison between different channel power structures under government intervention

By comparing the two game models under different channel power structures with government intervention, we can derive the following proposition:

Proposition 4.7. *(i)* $p^*_{GSI} > p^*_{GSP}$, $s^*_{GSI} > s^*_{GSP}$, $e^*_{GSI} = e^*_{GSP}$, $\Pi^{GSI}_{ESI} > \Pi^{GSP}_{ESI}$, $\Pi^{GSI}_{SC} > \Pi^{GSP}_{SC}$, $SW_{GSI} = SW_{GSP}$; *(ii) When* $h + 2E[\gamma] - 1 > 0$, $w^*_{GSI} > w^*_{GSP}$ *and* $\Pi^{GSI}_{ESP} > \Pi^{GSP}_{ESP}$, *or else, the results are the opposite.*

When the ESI has more bargaining power, the optimal retail price and optimal subsidy are higher than those in the ESP-dominated structure. The ESI adopts a higher retail price in pursuit of increased profits, while the government's high subsidies precisely compensate for customers' increased expenses. Consequently, the ESI lacks incentives to actively improve its service level. More government subsidies to customers are transferred to the supply chain, benefiting the overall performance, and resulting in higher profits for the ESI. Additionally,

TABLE 3. Comparison of optimal decisions and market performance.

Equilibrium outcomes	ESI-dominated			ESP-dominated		
	NI	OS	SR	NI	OS	SR
p^*	129.6875	722	636.4074	126.7857	618	468.0487
w^*	56.5625	254	235.7676	85	384	283.1766
e^*	40.625	260	317.6579	46.4286	260	317.6579
s^*	–	702	575.1118	–	598	406.7531
Π_{ESI}	2.3766*10^3	9.7344*10^4	7.4948*10^4	1.358*10^3	4.2588*10^4	2.8392*10^4
Π_{ESP}	1.358*10^3	5.4756*10^4	4.6556*10^4	2.7161*10^3	8.5176*10^4	5.6785*10^4
Π_{SC}	3.7134*10^3	1.521*10^5	1.215*10^5	4.0741*10^3	1.2776*10^5	8.5177*10^4
SW	4.3818*10^3	15210	1.4025*10^4	4.9471*10^3	15210	1.4025*10^4
UCE	129.6875	20	61.2956	126.7857	20	61.2956
GE	–	1.6427*10^5	1.3076*10^5	–	1.3993*10^5	9.443*10^4

Notes. "NI" means non-intervention; "OS" means only subsidy; "SR" means subsidy and service level regulation, "UCE" means unit customer expenditure, and "GE" means government expenditure.

different channel power structures do not affect the optimal service level, customer surplus, or social welfare. These conclusions also hold in the case where $h = 0$.

When other conditions remain unchanged, if the expected value of γ is high and exceeds$(1-h)/2$, both the ESI and ESP reap advantages from high government subsidies; otherwise, the ESI benefits more from government subsidies, while customers and the ESP do not. In the case where $h = 0$, the ESI benefits more from government subsidies, while customers and the ESP do not.

5. Numerical analysis and discussions

In this section, we first solve and compare the optimal decisions and market performance under different channel power structures, with or without government intervention, to verify the effectiveness of the model. Furthermore, to gain more managerial insights, we categorize government intervention into two scenarios: solely government subsidy, subsidy and service-level regulation. Second, we conduct a series of sensitivity analyses of the crucial parameters. Finally, a case study of the ECSSC is discussed.

As it is difficult to find a single and comprehensive data source for our input parameters in the existing literature, we obtain the input range of relevant parameters from several papers that are highly correlated with our research, while considering meeting the essential prerequisites. The total potential market demand is set to 150 [8]. The distribution of the service-level elasticity coefficient is assumed to be $\mathbf{L}(0, 0.8)$ with an expected value of $E[\gamma] = 0.4$ [8]. When it comes to the service-level regulation, it is set to 0.13 [35] and the range of it is set to $h \in [0, 0.25)$according to the necessary conditions of this study. The per unit cost of service capacity can be set to 20 according to Zhao's study [49]. Based on the preceding analysis, the parameters are configured as: $a = 150$, $c = 20$, $e_0 = 80$, $E[\gamma] = 0.4$, and $h = 0.13$.

5.1. Comparison of optimal results under different channel power structures with or without government intervention

Table 3 provides the optimal decisions and market performance of the ECSSC under different channel power structures in three government intervention scenarios (non-intervention, subsidy, and subsidy and service-level regulations).

(1) Comparing the results under different channel power structures in scenario NI, under the ESP-dominance structure, the retail price is lower and the service level is higher, which is beneficial to customers. Additionally, the entire supply chain is more profitable, and social welfare is higher. This result verifies the accuracy of Proposition 4.3.

(2) Comparing the results of scenarios SR(OS) and NI, government intervention in the ECSSC can increase the retail price, wholesale price, ESI service level, and ESI and ESP profits. Furthermore, the overall social welfare improves significantly.

(3) Comparing the results under different channel power structures in scenario SR, the optimal service level of the ESI is not affected by the channel power structure. The ESI-dominated structure is more beneficial for the ESI (compared with the ESP-dominance structure for the ESP), as the retail price significantly increases. Additionally, different channel power structures do not impact customers, because they can acquire the same level of service at the same expense. Furthermore, the entire supply chain is more profitable. Regarding the government, an ESI-dominated structure leads to higher government expenditure, without changing the social welfare. This also verifies Proposition 4.7. When the ESP has more bargaining power, the government can save expenses without changing the level of social welfare; however, the overall profit of the supply chain is not high.

(4) Comparing the results between the SR and OS scenarios, customers can obtain services at a lower cost in the latter, but the ESI service level is lower than that in the SR scenario. The ESI and ESP can obtain higher profits. Simultaneously, the government can obtain higher social welfare but at the cost of increased expenditure.

In general, under scenario NI, customers can obtain higher-level services at lower prices under the ESP-dominated structure, while the social welfare and overall profit of the supply chain are higher. With government intervention, the profits of the ECSSC members and social welfare increase significantly compared with scenario NI, and customers can obtain higher-level services at lower costs. Additionally, although different channel power structures do not impact the optimal service level, overall social welfare, and unit expenditure of customers, the ESI-dominated ECSSC exhibits higher overall profits, which is more beneficial for the development of the supply chain. However, government expenditure is simultaneously higher. Under scenario OS, customers have a lower unit expenditure for obtaining services, but government expenditure is higher than that in scenario SR. Meanwhile, the ESI and ESP can obtain relatively high profits, which is beneficial for the sustainable development of the supply chain.

5.2. Sensitive analysis

In this section, we analyze the effects of changes in the expected value of γ and the reward-penalty factor on optimal decisions and market performance. Four reward-penalty factor values are selected: without service-level regulation ($h = 0$), low ($h = 0.03$), medium ($h = 0.13$), and high ($h = 0.23$). The solid lines in the figures indicate ESI-dominance, while the dotted lines represent ESP-dominance.

First, we focus on the impact of parameter changes on the optimal decisions.

(1) Initially, our attention is directly toward exploring the impact of parameters on ESI service level. As the optimal service level is not affected by channel power structures, the curves illustrated in Figure 2 (a) represent the influence of the change in the expected value of γ on e^* under the two channel power structures. As shown in the figure as the expected value of γ increases, the optimal service level tends to rise. Moreover, the higher the expected value of γ, the faster the optimal service level increases.

When the expected value of γ does not exceed a certain value (at a low or moderate level), the service level tends to increase with h. At this point, a higher h is beneficial for customers to access a higher level of service. However, when the expected value of γ exceeds a certain value, the service level of the ESI decreases as h increases. Meanwhile, compared with the scenario wherein $h = 0$, a lower h is advantageous for customers to access a higher level of service.

(2) Next, we examine the impact of the expected value of γ on the retail price. Figure 2 (b) depicts that, when the ESI has more bargaining power, the retail price experiences an upward trend in response to an increase in the expected value of γ. Alternatively, when the ESP has more bargaining power and h remains below a certain threshold, the retail price increases with the expected value of γ. However, when the reward-penalty factor is higher than this threshold, the retail price decreases. In other words, when the ESP has more bargaining power, an excessively high h is not beneficial for the ESI.

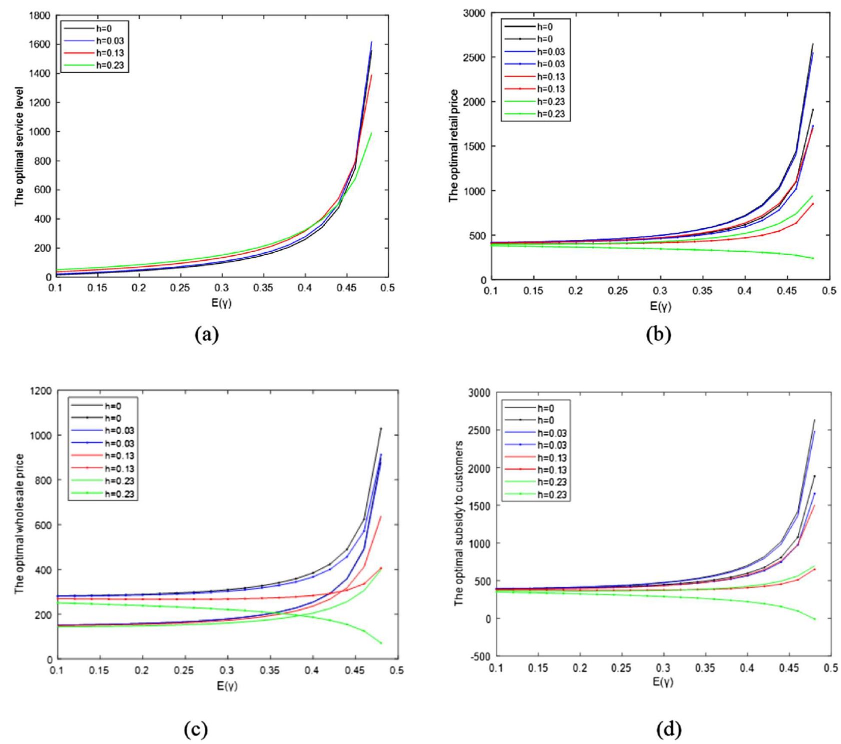

FIGURE 2. Impact of the parameter γ and h on the optimal decisions. (a) Service level. (b) Retail price. (c) Wholesale price. (d) Subsidy.

When considering the impact of h on the retail price, we observe that, as h increases, the retail price tends to decrease, a trend that becomes more pronounced with the increase in the expected value of γ. Therefore, for the ESI, it is unfavorable for the government to set an excessively high h when the expected value of γ is too high.

(3) Combined with Proposition 4.7 (ii), Figure 2 (c) shows that, when $h + 2E[\gamma] - 1 < 0$, $w^*_{GSI} < w^*_{GSP}$; otherwise, the right halves of the red line and the green line in the figure show opposite results. When the ESI has more bargaining power, regardless of variations in h, the optimal wholesale price exhibits an upward trend in response to an increase in the expected value of γ. When the ESP has more bargaining power and h remains below a certain threshold, the optimal wholesale price increases with the expected value of γ. However, once h surpasses this threshold, the optimal wholesale price decreases with the expected value of γ. In this case, an excessively high h is not beneficial for the ESP.

When considering the impact of h on wholesale price, we see that, with the increase in h, the wholesale price decreases, which is unfavorable for the development of the ESP.

(4) When it comes to the impact of the expected value of γ on the optimal subsidy, Figure 2 (d) reveals that, when the ESI has more bargaining power, the optimal subsidy exhibits an upward trend in response to an increase in the expected value of γ. When the ESP has more bargaining power and h is below a certain threshold, the optimal subsidy increases with the expected value of γ. However, when h is higher than this threshold, the optimal subsidy decreases with the increase in the expected value of γ.

When considering the impact of h on government subsidy, we can see that with the increase of h, the optimal subsidy decreases. This trend becomes more evident with the increase in the expected value of γ. This means that the government's higher setting of the reward-penalty factor reduces its subsidies to customers.

Second, we focus on the impact of parameter changes on objective functions.

(1) As social welfare remains the same under different channel power structures, the curves depicted in Figure 3 (a) illustrate the influence of the expected value of γ on social welfare under two channel power structures. Upon observing Figure 3 (a), it becomes evident that an increase in the expected value of γ corresponds to an increase in social welfare. When other conditions remain unchanged, social welfare declines as h increases.

(2) As depicted in Figure 3 (b–d), when the ESI has more bargaining power, with the increase of the expected value of γ, the ESI, ESP, and the total profits of the supply chain all increase. Under the ESP-dominated structure, when h is at a low or moderate level, the profits of ESI, ESP, and the entire supply chain all increase with the expected value of γ; otherwise, the results are the opposite.

When considering the impact of h on the profits of the supply chain, we can find that with the increase of h, the profits of supply chain members show a downward trend, and the total profits of the supply chain also decrease. When the expected value of γ is not high, the fluctuation of h does not significantly affect the profits of the supply chain members. When the expected value of γ is high, a relatively high h is detrimental to the development of the ESP.

Finally, we focus on the impact of parameter changes on other market performance.

(1) We can see from Figure 4 (a) that an increase in the expected value of γ leads to an increase in government expenditure. However, government expenditure decreases with an increase in h. Furthermore, when the expected value of γ is not high, the impact of h on government expenditure is not significant.

(2) Customer surplus is not affected by channel power structures. From Figure 4 (b), we can see that customer surplus increases with an increase in the expected value of γ and decreases with an increase in h (when the expected value of γ is not high, the impact of h thereon is not significant).

In general, when the ESI has more bargaining power, the supply chain members will benefit from an increase in the expected value of γ. The increasing expected value of γ leads to higher retail prices, providing the ESI an incentive to improve its service level. The government will also benefit from an increase in the expected value of γ, but at the cost of increased expenditure. Customer surplus also increases with an improvement in the expected value of γ. When the ESP has more bargaining power and the government sets a relatively high reward-penalty factor, the interests of the supply chain will be harmed by an increase in the expected value of γ. When considering the impact of the government's reward-penalty factor setting, for the government, setting a high-level h will not only reduce government expenditure but also lead to a decrease in social welfare. For supply chain members, setting a relatively high h is also not beneficial to their interests. These changes are not significant when the expected value of γ is low. In terms of customers, when the expected value of γ is low, setting a relatively high h is beneficial for them to obtain a higher level of service.

5.3. Case study of the ECSSC

Based on the above, a real case study is conducted on an ECSSC in China. China's elderly care services supply system is in the stage of continuous development, with different regions demonstrating different characteristics. In economically underdeveloped areas, the main goals are to promote the popularization of services and provide convenient elderly care services. The main intervention measures taken by the government sectors are generally subsidies to promote the provision of services and increase the demand for services. In economically developed areas, in addition to the subsidy measures, the government has instituted a series of regulatory measures. For instance, in Jiangsu Province[3], a comprehensive system for rating the service levels of elderly care institutions has been established, and rewards or punishments are implemented based on the evaluation results. Community service centers and online elderly care service platforms that have emerged in economically developed areas are applications of the ECSSC model. Older adults can make service reservations online, receive corresponding services at home, or choose to go to community service centers to receive a series of services such as catering, medical care, healthcare, and psychological services. A specific ECSSC model is shown in Figure 5. Our study corresponds to the developmental status of the ECSSC. Taking an elderly care service community center in a

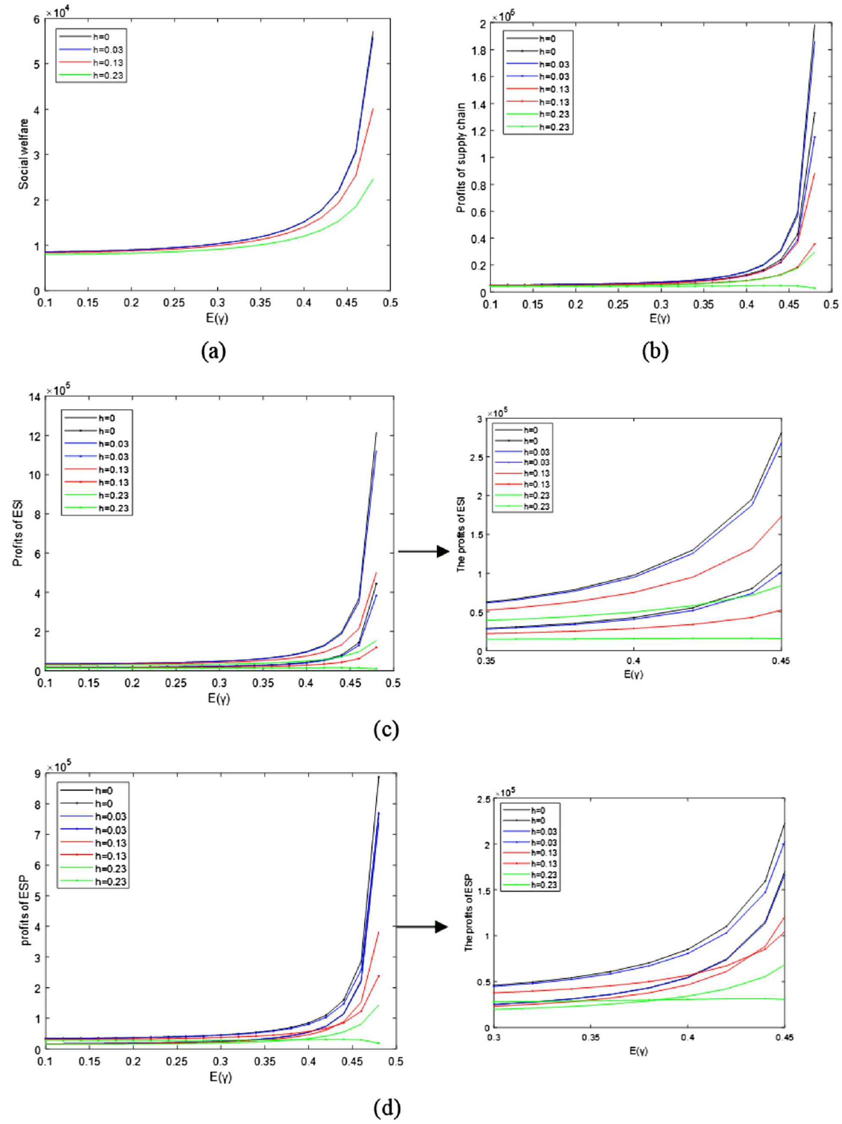

FIGURE 3. Impact of the parameter γ and h on the objective functions. (a) Social welfare. (b) Profits of the SC. (c) Profits of the ESI. (d) Profits of the ESP.

large coastal city in China as an example, there are about 4,000 older adults in the community[5]. According to relevant survey reports, approximately 4% older adults require care services[6]; therefore, the average number of older adults receiving nursing care services at the community service center each week is approximately 160. Additionally, based on relevant surveys, the weekly cost of nursing staff is estimated to be between 78 and 126[7]; therefore, the average unit cost for nursing staff is about 100. When the community service center has

[5] https://www.thepaper.cn/newsDetail_forward_10771496

[6] http://www.ordos.gov.cn/gk_128120/tjxx/tjfx/202206/t20220607_3226828.html

[7] https://mp.weixin.qq.com/s?__biz=MzAxOTA1MDgxMA==&mid=2649527338&idx=1&sn =7999b0744b6575f384a55aa8be75bf27&chksm=83d4cc7fb4a3456961d14a8d426274075736d7af3db c983e4ffd629c54c0b21a4dda6eed628d&scene=27

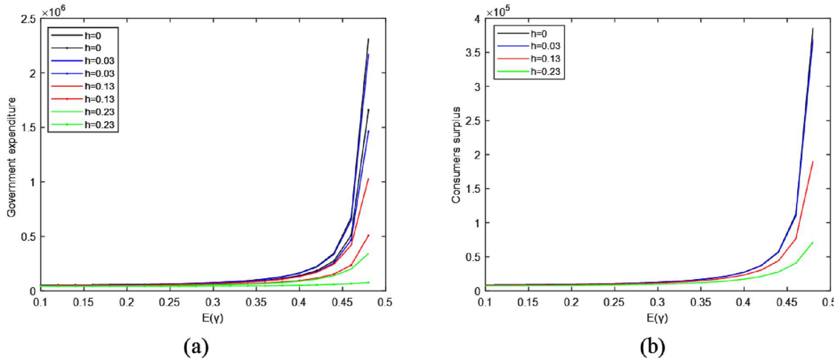

FIGURE 4. Impact of the parameter γ and h on other market performance. (a) Government expenditure. (b) Consumer surplus.

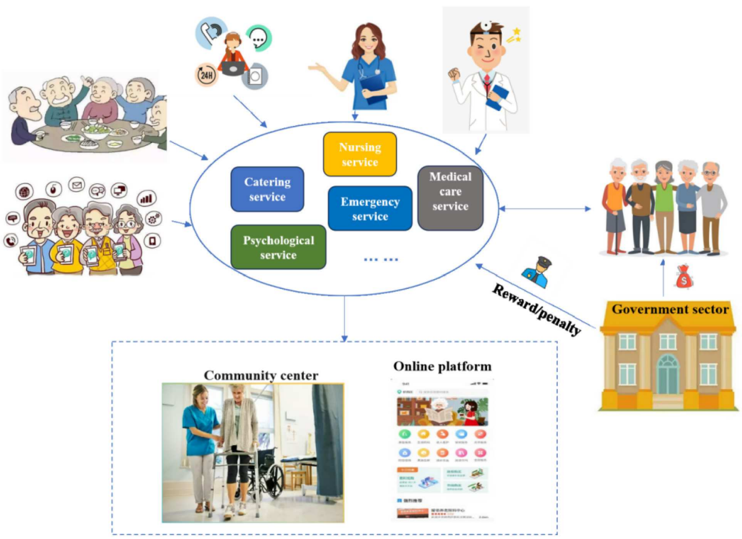

FIGURE 5. The ECSSC system model in China.

more bargaining power, combining the reasonable assumptions in Section 5.1, the optimal retail price for the nursing service is 390.096, the optimal wholesale price for the nursing service is 199.585, the optimal service level of the community center is 146.611, the optimal subsidy of the government sector is 271.036, the expected social welfare value is 2987.6, the expected weekly profit of the community center is 15965, and the expected weekly profit of the nursing service providers is 9917.2. The results verify the applicability and effectiveness of the ECSSC model.

6. Managerial insights

This study proposes a three-stage ECSSC model under government intervention. Our model differs from previous studies [6, 48–52] in that it incorporates government interventions into the ECSSC system, while taking into account the impact of different channel power structures and government intervention. The analysis conducted on this basis is more in line with the actual situation of the ECSSC system. Our model can be used to guide the decision-making process of supply chain members and provide recommendations for the sustainable development of the ECSSC. More importantly, it can be used to assist the government sector in making decisions to solve a series of problems in reality (such as limited budgets, policy-making in different regions). In addition to the ECSSC system under government intervention, our model has broad applicability. Other service supply chain systems involving government intervention can apply our model for relevant analysis. Based on the relevant analysis, the specific management suggestions are presented as follows:

(1) For the government sector, intervention measures in the elderly care service provision system are necessary. In terms of the choice of intervention measures, we believe that providing only subsidies is more suitable for services available to older adults with financial difficulties. In this way, more service providers can be attracted to the system to promote the popularization of services, and customer expenditure can be reduced, which can increase the demand for services and reduce idle service resources. When the service provision system has developed to a certain extent, or for some services that have service-level requirements, adopting a combination of subsidy and service-level regulations can meet consumers' higher-level service demands while reducing government expenditure.

(2) From the perspective of sustainable supply chain development, an ESI-dominated structure is more acceptable. We believe that in the early development stage of the ECSSC, or when the government is not constrained by budget constraints, the government sector can take measures to promote rapid ESI development. This may include strengthening the platform's access and review measures, co-constructing with online platforms, and collaborating on promotion to enhance the scale and reputation of the ESI. This advocacy for an ESI-dominated supply chain structure helps improve the overall performance of the ECSSC without reducing social welfare. However, we believe that an ESP-dominated structure is more suitable for underdeveloped regions with limited government budgets. In this case, the government can adopt relevant policies to increase the economies of scale of the ESP, and thus enhance the ESP's bargaining power.

(3) For the ESI, the question entails how to enhance its competitiveness to gain more bargaining power in the supply chain? We believe that strengthening platform construction, standardizing platform operation regulations, improving the admission criteria for cooperative service providers, enhancing supervision of service providers, and attaching importance to platform evaluation by customers are all beneficial for improving ESI competitiveness. This, in turn, promotes its decision-making position in the supply chain system. For the ESP, controlling its service costs, enhancing its brand effect, improving access standards for service personnel, and expanding its scale contribute to enhancing its bargaining power in the supply chain.

7. Conclusions

In this study, an ECSSC model considering government intervention is established to address the decision-making problems of the ECSSC members and government sector. We consider three scenarios of government intervention, namely, non-intervention, subsidy, subsidy and service level regulation, and obtain optimal decisions along with the corresponding market performance under two different channel power structures. To verify the effectiveness of the model, we conduct numerical experiments and compare and analyze the optimal decisions and market performance of the ECSSC considering different channel power structures and government intervention measures. Simultaneously, we utilize numerical experiments to analyze the impact of the uncertainty parameter and reward-penalty factor. The main conclusions are summarized as follows:

(1) Government interventions in the ECSSC are beneficial to the ESI, ESP, entire supply chain, customers, and overall social welfare.

(2) Considering the impact of different channel power structures on the market performance of the supply chain, we find that, under the non-intervention scenario, the ESP-dominated structure is more powerful in driving the entire supply chain and pursuing social welfare. Additionally, customers can obtain higher levels of service at lower prices. Considering government intervention, although the service level of the ESI, social welfare, and unit customer expenditure are not influenced by different channel power structures, the ESI-

dominated supply chain is more favorable for the development of the entire supply chain. However, when the government is facing limited budgets, an ESP-dominated supply chain may be more appropriate.

(3) Comparing the results under different government intervention scenarios (OS *vs.* SR), we find that considering only subsidy policy is beneficial for social welfare, unit customer expenditure, and profits of supply chain members, but at the cost of higher government expenditure and lower ESI service levels.

(4) Under the ESI-dominated structure, all members of the supply chain and customers benefit from an increase in the expected value of service-level elasticity. The government simultaneously achieves higher social welfare but at the cost of increased government expenditure. Under an ESP-dominated structure, an excessively high reward-penalty factor set by the government harms the interests of supply chain members from the increase in the expected value of service-level elasticity.

(5) A high reward-penalty factor leads to a decrease in social welfare and reduces the profits of supply chain members, but these changes are not significant when the expected value of the elasticity coefficient of the service level is low. However, when the expected value of service-level elasticity coefficient is low, a high reward-penalty factor helps customers to receive a higher level of service. In general, from the perspective of supply chain development, we believe that the reward-penalty setting should not be excessively high.

Although our model is based on an abstraction of an actual elderly care service system, the real-world ECSSC system is much more complicated, with many complex factors overlooked in our model. For instance, the ECSSC may involve more participants, influencing factors, and sales channels, and many uncertainties may be involved in the provision process. Considering these limitations, the single-channel ECSSC model can be expanded to dual channels, including both online and offline service sales [2, 50]. Considering the factors influencing the demand function, in addition to price and service level, customer satisfaction can also be regarded as an influencing factor [37]. Furthermore, there are many uncertainties in the provision process of elderly care services (demand, cost, service time), and the system is subject to various constraints (government constraint, service capacity constraint, service time constraint, etc.). We can use fuzzy numbers to describe the parameter and constraints uncertainties and solve the model using relevant methods for solving the Stackelberg game with fuzzy numbers [32, 33, 36]. The sustainable management of the ECSSC is also a topic to address in our future research. The analysis model of the ECSSC system can also be transformed into a multi-objective optimization model [15,16,34] from economic and social perspective. In addition to considering the factors mentioned above, decision makers' corresponding uncertainty will also impact the supply chain [14]. These are our directions for future research.

Appendix A.

Proof of Proposition 4.1. Through Equations (8) (9) and the linearity of the expected value operator, the expected profits of the ESI and ESP are: $E\left[\Pi_{ESI}\left(m,e\right)\right]$ $=E\left[\left(m+w-w\right)\left(a-\left(m+w\right)+\gamma e\right)-\frac{e^2(1-\gamma)^2}{2}\right] = am-m\left(m+w\right)+E\left[\gamma\right]me-\frac{e^2}{2}+E\left[\gamma\right]e^2-\frac{E^2[\gamma]e^2}{2}$, $E\left[\Pi_{ESP}\left(w\right)\right]=E\left[\left(w-c\right)\left(a-\left(m+w\right)+\gamma e\right)\right] = a\left(w-c\right)-\left(w-c\right)\left(m+w\right)+e\left(w-c\right)E\left[\gamma\right]$, respectively. Through backward induction, we take the first-order and second-order partial derivatives of $E\left[\Pi_{ESP}\left(w\right)\right]$ with respect to w: $\frac{\partial E[\Pi_{ESP}(w)]}{\partial w}=a-2w-m+E\left[\gamma\right]e+c$, and the second-order partial derivative is negative. By setting the first derivative equal to 0, we obtain the optimal response functions of the ESP: $w^*_{IS}=\frac{E(\gamma)e+a+c-m}{2}$. Taking w^*_{SI} into the equation $E\left[\Pi_{ESI}\left(m,e\right)\right]$, then taking the first-order partial derivative of $E\left[\Pi_{ESI}\left(m,\ e,\ w^*_{IS}\right)\right]$ with respect to m and e, respectively. The Hessian matrix can be obtained: $H_1=\begin{bmatrix}-1 & E\left[\gamma\right]/2\\ E\left[\gamma\right]/2 & -\left(1-E\left[\gamma\right]\right)^2\end{bmatrix}$. The Hessian matrix is negative definite with the assumption $3E^2\left[\gamma\right]-8E\left[\gamma\right]+4>0$, then $E\left[\Pi_{ESP}\left(w,e\right)\right]$ is jointly concave in w and e. The optimal marginal profits of the ESI can be expressed as $m=\frac{2(a-c)(E(\gamma)-1)^2}{3E^2(\gamma)-8E(\gamma)+4}$. The optimal decisions of the ESI and ESP can be obtained and their maximal expected profits is obtained at $(p^*_{IS}, w^*_{IS}, e^*_{IS})$, (iii) is proved. The expected social welfare is $SW_{IS}=\frac{(a-c)^2\left(6E^2[\gamma]-14E[\gamma]+7\right)(E[\gamma]-1)^2}{2(3E[\gamma]-2)^2(E[\gamma]-2)^2}$.

Proof of Insight 1. The insight can be easily proved: $\frac{\partial p^*_{IS}}{\partial E[\gamma]} = -\frac{6E[\gamma](a-c)(E[\gamma]-1)}{(3E^2[\gamma]-8E[\gamma]+4)^2} > 0$, $\frac{\partial w^*_{IS}}{\partial E[\gamma]} = -\frac{2E[\gamma](a-c)(E[\gamma]-1)}{(3E^2[\gamma]-8E[\gamma]+4)^2} > 0, \frac{\partial e^*_{IS}}{\partial E[\gamma]} = -\frac{(a-c)\left(3E^2[\gamma]-4\right)}{(3E^2[\gamma]-8E[\gamma]+4)^2} > 0$ and $\Pi^{IS}_{ESI} - \Pi^{IS}_{ESP} > 0$.

Proof of Proposition 4.2. Through backward induction, first, we take the first-order partial derivative of $E\left[\Pi_{ESI}(p,e)\right]$ with respect to $p$and e. The Hessian matrix is obtained: $H_2 = \begin{bmatrix} -2 & E[\gamma] \\ E[\gamma] & -(1-E[\gamma])^2 \end{bmatrix}$. The Hessian matrix is negative definite with the assumption $E^2[\gamma] - 4E[\gamma] + 2 > 0$. Then we can get the response functions of the ESI: $p^*_{PS} = \frac{E^2[\gamma]a-2aE[\gamma]-2wE[\gamma]+a+w}{E^2[\gamma]-4E[\gamma]+2}$ and $e^*_{PS} = \frac{E[\gamma](a-w)}{E^2[\gamma]-4E[\gamma]+2}$. Taking p^*_{PS} and e^*_{PS} into the equation $E\left[\Pi_{ESP}(w)\right]$, then taking the first-order and second-order partial derivative of $E\left[\Pi_{ESP}(w, e^*_{PS}, p^*_{PS})\right]$ with respect to w, the second-order partial derivative is negative. By setting the first derivative equal to 0, we can obtain the optimal wholesale price. Then the optimal price and service level can be obtained. (iii) can also be proved. The expected social welfare is $SW_{PS} = \frac{(a-c)^2\left(4E^2[\gamma]-14E[\gamma]+7\right)(E[\gamma]-1)^2}{8(E^2[\gamma]-4E[\gamma]+2)^2}$.

Proof of Insight 2. The insight can be easily proved: $\frac{\partial p^*_{PS}}{\partial E[\gamma]} = -\frac{E[\gamma](a-c)(E[\gamma]-1)}{(E^2[\gamma]-4E[\gamma]+2)^2} > 0, \frac{\partial e^*_{PS}}{\partial E[\gamma]} = -\frac{(a-c)\left(E^2[\gamma]-2\right)}{2(E^2[\gamma]-4E[\gamma]+2)^2} > 0$ and $\Pi^{PS}_{ESP} - \Pi^{PS}_{ESI} = \frac{(E[\gamma]-1)^2(a-c)^2}{8(E^2[\gamma]-4E[\gamma]+2)} > 0$.

Proof of Proposition 4.3. Based on Propositions 4.1 and 4.2, we can easily obtain the difference in the optimal results, profits and social welfare under different channel power structures. The simplified results are as follows:

$e^*_{IS} - e^*_{PS} = -\frac{E[\gamma]^3(a-c)}{2(3E^2[\gamma]-8E[\gamma]+4)(E^2[\gamma]-4E[\gamma]+2)} < 0,$

$w^*_{IS} - w^*_{PS} = -\frac{\left(E^2[\gamma]-4E[\gamma]+2\right)(a-c)}{2(3E^2[\gamma]-8E[\gamma]+4)} < 0,$

$p^*_{IS} - p^*_{PS} = \frac{E[\gamma]^2(a-c)(1-2E[\gamma])}{2(3E^2[\gamma]-8E[\gamma]+4)(E^2[\gamma]-4E[\gamma]+2)} > 0$,

$\Pi^{IS}_{ESP} - \Pi^{PS}_{ESP} = -\frac{(E[\gamma]-1)^2(a-c)^2\left(5E^4[\gamma]-24E^3[\gamma]+12E^2[\gamma]+8(1-2E[\gamma])^2\right)}{4(3E^2[\gamma]-8E[\gamma]+4)(E^2[\gamma]-4E[\gamma]+2)} < 0$,

$\Pi^{IS}_{ESI} - \Pi^{PS}_{ESI} = \frac{(E[\gamma]-1)^2(a-c)^2\left(E^2[\gamma]-8E[\gamma]+4\right)}{8(3E^2[\gamma]-8E[\gamma]+4)(E^2[\gamma]-4E[\gamma]+2)} > 0$,

$\Pi^{IS}_{SC} - \Pi^{PS}_{SC} = -\frac{E^2[\gamma](E[\gamma]-1)^2(a-c)^2\left(7E^2[\gamma]-16E[\gamma]+8\right)}{8(3E^2[\gamma]-8E[\gamma]+4)^2(E^2[\gamma]-4E[\gamma]+2)} < 0$, and

$SW^{IS} - SW^{PS} = -\frac{E^2[\gamma](E[\gamma]-1)^2(a-c)^2\left(12E^4[\gamma]-70E^3[\gamma]+35E^2[\gamma]+24(1-2E[\gamma])^2\right)}{8(3E^2[\gamma]-8E[\gamma]+4)^2(E^2[\gamma]-4E[\gamma]+2)^2} < 0.$

Proof of Proposition 4.4. Through backward induction, substituting $p = w + m$ into the expression of the expected profits, then taking the first-order and second-order partial derivative of $E\left[\Pi^{GSI}_{ESP}(w)\right]$ with respect to w. $\frac{\partial E\left[\Pi^{GSI}_{ESP}(w,e)\right]}{\partial w} = a - 2w - m + s + E[\gamma]e + c$ is obtained and the second-order partial derivative is negative. By setting the first derivative equal to 0, we obtain the optimal response functions of the ESP: $w^*_{GSI} = \frac{E[\gamma]e+a+c+s-m}{2}$. Taking w^*_{GSI} into the equation $E\left[\Pi^{GSI}_{ESI}(m,e)\right]$, then taking the first-order partial derivative of $E\left[\Pi_{ESI}(m,\, e,\, w^*_{GSI})\right]$ with respect to m and e, respectively. The Hessian matrix is $H_3 = \begin{bmatrix} -1 & \frac{E[\gamma]-h}{2} \\ \frac{E[\gamma]-h}{2} & hE[\gamma] - (1-E[\gamma])^2 \end{bmatrix}$ and it is negative definite with the assumptions $3E^2[\gamma] - 2hE[\gamma] - 8E[\gamma] + 4 - h^2 > 0$ and $hE[\gamma] - (1-E[\gamma])^2 < 0$. The optimal marginal profit of the ESI is

$m = \frac{\left(2E^2[\gamma]-hE[\gamma]-h^2-4E[\gamma]+2\right)(a-c+s)+e_0h\left(E^2[\gamma]-hE[\gamma]-4E[\gamma]+2\right)}{3E^2[\gamma]-2hE[\gamma]-8E[\gamma]+4-h^2}$. Then, we obtain the optimal response functions of the ESI:

$p^*_{GSI} = \frac{(3a+c+3s)(2E[\gamma]-1)+(a+s)\left(h^2-3E^2[\gamma]\right)+E[\gamma]h(a+c+s)+e_0h(E[\gamma]h+2E[\gamma]-1)}{(h+3E[\gamma]-2)(h-E[\gamma]+2)}$ and

$e^*_{GSI} = \frac{(a-c+s-e_0h)(E[\gamma]+h)}{3E^2[\gamma]-2hE[\gamma]-h^2-8E[\gamma]+4}$,

($w^*_{GSI} = \frac{(he_0-a-2c-s)E^2[\gamma]+((2c-2e_0)h+2a+6c+2s)E[\gamma]+ch^2+e_0h-a-3c-s}{(h+3E[\gamma]-2)(h-E[\gamma]+2)}$). Taking e^*_{GSI}, w^*_{GSI} and p^*_{GSI} into the expected social welfare function. Then, taking the first-order and second-order partial derivative of $E\left[SW_{GSI}(s, p^*_{GSI},\, e^*_{GSI},\, w^*_{GSI})\right]$ with respect to s. We obtain

$\frac{\partial^2 E[SW_{GSI}(s,p^*_{GSI},\, e^*_{GSI},\, w^*_{GSI})]}{\partial s^2} = (E[\gamma]-1)^2\left(-h^2+2E[\gamma]-1\right) < 0$. By setting the first derivative equal to 0, we obtain the optimal subsidy level: $s_{GSI}^{*}=\frac{(a-c)\left(3E^{2}[\gamma]-2E[\gamma]h-2h^{2}-6E[\gamma]+3\right)+e_{0}h\left(h^{2}+1-2E[\gamma]\right)}{h^{2}+1-2E[\gamma]}$. Proposition 4.3 is proved.

Proof of Insight 3. The insight can be easily proved: $\frac{\partial e_{GSI}^{*}}{\partial E[\gamma]}=\frac{(h+1)^{2}(a-c)}{(h^{2}-2E[\gamma]+1)^{2}}>0, \frac{\partial p_{GSI}^{*}}{\partial e_{0}}=h>0, \frac{\partial s_{GSI}^{*}}{\partial e_{0}}=h>0$.

Proof of Proposition 4.5. Taking the first-order partial derivative of $E\left[\Pi_{ESP}(p,\,e)\right]$ with respect to p and e, respectively. The Hessian matrix is $H_{4}=\begin{bmatrix}-2 & E[\gamma]-h\\ E[\gamma]-h & 2hE[\gamma]-(1-E[\gamma])^{2}\end{bmatrix}$ and it is negative definite with the assumptions $E^{2}[\gamma]-2hE[\gamma]-h^{2}-4E[\gamma]+2>0$ and $2hE[\gamma]-(1-E[\gamma])^{2}<0($ since$E[\gamma]<0.5,\,h<0.25$ is obtained). By setting the first derivative equal to 0, we obtain the optimal response functions of the ESI: p_{GSP}^{*} and e_{GSP}^{*}. Taking p_{GSP}^{*} and e_{GSP}^{*} into the equation $E\left[\Pi_{ESP}^{GSP}(w)\right]$, then taking the first-order partial derivative of $E\left[\Pi_{ESP}(\,w,p_{GSP}^{*},e_{GSP}^{*})\right]$ with respect to w. We obtain $w_{GSP}^{*}(s)$, $p_{GSP}^{*}(s)$ and $e_{GSP}^{*}(s)$. $e_{GSP}^{*}=\frac{-hE[\gamma]e_{0}-h^{2}e_{0}+aE[\gamma]-cE[\gamma]+sE[\gamma]+ah-hc+hs}{2E^{2}[\gamma]-4hE[\gamma]-2h^{2}-8E[\gamma]+4}$, $p_{GSP}^{*}=\frac{-h^{2}E[\gamma]e_{0}+2aE^{2}[\gamma]+2sE^{2}[\gamma]-3ahE[\gamma]-chE[\gamma]-2e_{0}hE[\gamma]-3hsE[\gamma]-2ah^{2}-2sh^{2}}{2E^{2}[\gamma]-4hE[\gamma]-2h^{2}-8E[\gamma]+4}+\frac{3a+c+3s-6aE[\gamma]-2cE[\gamma]-6sE[\gamma]+he_{0}}{2E^{2}[\gamma]-4hE[\gamma]-2h^{2}-8E[\gamma]+4}$, $w_{GSI}^{*}=-\frac{he_{0}}{2}+\frac{a}{2}+\frac{c}{2}+\frac{s}{2}$. Taking $w_{GSP}^{*}(s)$, $p_{GSP}^{*}(s)$ and $e_{GSP}^{*}(s)$into the expected social welfare function and then taking the first-order and second-order partial derivative of $E\left[SW_{GSP}(s,p_{GSP}^{*},\,e_{GSP}^{*},\,w_{GSP}^{*})\right]$ with respect to s. $\frac{\partial^{2}E[SW_{GSP}(s,p_{GSP}^{*},\,e_{GSP}^{*},\,w_{GSP}^{*})]}{\partial s^{2}}=(E[\gamma]-1)^{2}\left(-h^{2}+2E[\gamma]-1\right)<0$ is obtained. By setting the first derivative equal to 0, the optimal subsidy can be obtained. Then the other optimal decisions can be easily obtained.

Proof of Insight 4. The insight can be easily proved: $\frac{\partial p_{GSI}^{*}}{\partial e_{0}}=h>0,\ \frac{\partial s_{GSI}^{*}}{\partial e_{0}}=h>0,\ \frac{\partial e_{GSP}^{*}}{\partial E[\gamma]}=\frac{(h+1)^{2}(a-c)}{(h^{2}-2E[\gamma]+1)^{2}}>0$.

Proof of Proposition 4.6. The service level of ESI with or without government intervention under different channel power structures are compared. The simplified results are as follows:

$e_{GSI}^{*}-e_{IS}^{*}=\frac{(a-c)\left(3E^{3}[\gamma]-6E^{2}[\gamma]+3E[\gamma]+3E^{2}[\gamma]h-8E[\gamma]h-E[\gamma]h^{2}+4h\right)}{(h^{2}-2E[\gamma]+1)(3E^{2}[\gamma]-8E[\gamma]+4)}>0$;

$e_{GSP}^{*}-e_{PS}^{*}=\frac{(a-c)\left(E[\gamma]\left(3(E[\gamma]-1)^{2}-E[\gamma](E[\gamma]+h)\right)+\left(3E^{2}[\gamma]h-8E[\gamma]h-E[\gamma]h^{2}+4h\right)\right)}{(h^{2}-2E[\gamma]+1)(3E^{2}[\gamma]-8E[\gamma]+4)}>0$.

Proof of Proposition 4.7. Considering the impact of different channel power structures under government intervention, we compare the optimal retail prices, subsidies, service levels, wholesale prices, and profits under different channel power structures. The simplified results are as follows:

(i)$p_{GSI}^{*}-p_{GSP}^{*}=\frac{(E[\gamma]+h)^{2}(a-c)}{h^{2}-2E[\gamma]+1}>0$,$s_{GSI}^{*}-s_{GSP}^{*}=\frac{(E[\gamma]+h)^{2}(a-c)}{h^{2}-2E[\gamma]+1}>0$,

$e_{GSI}^{*}-e_{GSP}^{*}=0$,$\Pi_{ESI}^{GSI}-\Pi_{ESI}^{GSP}=\frac{(E[\gamma]-1)^{4}(a-c)^{2}}{(h^{2}-2E[\gamma]+1)^{2}}>0$,

$\Pi_{SC}^{GSI}-\Pi_{SC}^{GSP}=\frac{(E[\gamma]-1)^{2}(a-c)^{2}(E[\gamma]+h)^{2}}{(h^{2}-2E[\gamma]+1)^{2}}>0,\ SW_{GSI}-SW_{GSP}=0$.

(ii)$\Pi_{ESP}^{GSI}-\Pi_{ESP}^{GSP}=\frac{(E[\gamma]-1)^{2}(a-c)^{2}\left(2E[\gamma]h+h^{2}+2E[\gamma]-1\right)}{(h^{2}-2E[\gamma]+1)^{2}}$

$=\frac{(E[\gamma]-1)^{2}(a-c)^{2}(h+1)(h+2E[\gamma]-1)}{(h^{2}-2E[\gamma]+1)^{2}}$, $w_{GSI}^{*}-w_{GSP}^{*}=\frac{(h+1)(2E[\gamma]+h-1)(a-c)}{h^{2}-2E[\gamma]+1}$. The Proposition can be easily proved.

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