Values of Food Leftover Sharing Platforms in the Sharing Economy

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***Abstract*:** For many food products, such as fresh vegetable and fruit, proper handling of product leftovers is critical. In recent years, food leftover sharing (FLS) platforms that can provide a means to collect the unsold food products from individual retailers and create values from them have emerged. Motivated by this real world observation, we build a single supplier multi-retailer analytical supply chain model to explore the value of this kind of FLS platform. In the decentralized supply chain setting, we prove that the presence of FLS platform is beneficial to the retailers, the supplier, the consumers and the environment. Whether it benefits the supply chain economically depends on the logistics costs (incurred from the food product leftover collection by the FLS platform). We extend the analysis to the case with a centralized supply chain and show that the FLS platform is guaranteed to help improve the environment, but the consumers and the supply chain are only benefited when the logistics costs are sufficiently small. Sensitivity analyses are conducted which show that for both centralized and decentralized supply chain settings, the FLS platform is especially helpful in enhancing social welfare when the unit food product leftover cost is higher, the unit benefit derived from reusing the food product leftovers is higher, or the unit logistics cost is lower. We further consider the case when the logistics cost with the use of platform is high and propose the use of government sponsors to help and provide the conditions under which this sponsor is well-justified with respect to social welfare enhancement.

***Keywords*:** Platforms, sharing economy, social welfare, product leftover management.

1. Introduction

For food products, it is natural that from time to time, some unsold food would remain when the season ends. In the past, food product leftovers were either salvaged at a low selling price or simply "thrown away" as garbage. However, nowadays, the world has changed and proper handling of the unsold food product leftovers is non-trivial because governments around the world are imposing taxes or service charges on the proper handling of wastes. For example, in Hong Kong, the government is contemplating a rubbish charging scheme in which disposals of both household and industrial wastes will be charged a fee. In addition, mass media as well as many NGOs will also complain about the wastage of food products when they can still be consumed if the sellers properly handle them.

In fact, around the world, we can see different scenarios regarding the use of food product leftovers. For instance, in some cities in mainland China, like Beijing and Shanghai, NGOs have even provided fridges storing the leftover food products collected from some companies for charity. Oasiseco[1], which is a food bank in China, has cooperated with lots of big supermarkets (such as Carrefour) and food companies (like Kraft Heinz, Maxim's, and Earth's Best) to collect the leftover foods. By collecting the unsold foods from manufacturers and retailers, Oasiseco has filled the gap between food waste and food shortage, and also helped people with lower income and people in need. On the platform OLIO App, leftover food products can be provided to others. This helps both sides: People who are lack of food can get the food easily from this platform, and the surplus and leftovers will not be wasted. Outside Asia, in Caldako of Spain, the government has set up a food bank to collect food from the food companies that cannot be sold but can still be eaten and distribute it centrally and then distribute it as quickly as possible. In Berlin of Germany, two large food agencies organized volunteers to go to supermarkets and restaurants to collect leftover foods that they were about to throw away. People who need food can collect food from the agencies for free. In the US, Starbucks has made a project called FoodShare project, in which the company will donate all unsold fast food to the food banks in the

[1] See http://www.oasiseco.org/ [accessed 29 December, 2018]

United States. They use refrigerated trucks to collect food from Starbucks stores across the country every day, and then distribute them to relief sites and relief stations for the people in need.

The handling of product leftovers is easier said than done because individual retailers may not have the resources, incentive and ability to better utilize the food product leftovers. It is reported that in Hong Kong, over 3000 tonnes of food products are classified as food wastes and sent to landfills every single day[2]! This is a big deal as the corresponding cost and damage to the environment are huge for a well-developed and small city like Hong Kong.

In the sharing economy era, different forms of platforms arise (Anderson et al. 2014; Bellos et al. 2017; Cachon et al. 2017; Benjaafar et al. 2018; Choi and He 2018). Among them, one form of platforms would help provide a means to collect the unsold food product leftovers from individual retailers, establish a sizeable amount of collected food leftovers and create good values from them. For instance, in Hong Kong, there are platforms such as feedinghk.org which collect season-end food of all kinds and use them in a better way (including donation for charity or proper re-use). In mainland China, Oasiseco offers a similar platform for collecting food product leftovers from supermarkets. In this paper, we focus on exploring the operations and values of this kind of platforms and we call them the *Food Leftover Sharing* (FLS) platforms.

Motivated by the above examined real world industrial observations, we explore values of FLS platforms for both the supply chain and its agents, the consumers as well as the environment. We adopt the theoretical modelling approach. We create the newsvendor problem based analytical models to investigate the respective supply chains. The supply chain includes a food product supplier and multiple retailers. To be specific, we analytically prove that the presence of FLS platform is beneficial to the retailers, the supplier, the consumers and the environment. We further show that whether or not the FLS platform benefits the supply chain economically depends on the respective logistics cost incurred during the food product leftover collection process by the FLS platform.

[2] See https://www.feedinghk.org/ [accessed 24 December 2018]

To show robustness of results, we extend the analysis to the case with a centralized supply chain. We analytically demonstrate that similar to the decentralized setting, the FLS platform is guaranteed to help improve the environment by bringing a positive value. However, different from the decentralized setting, under the centralized setting, the consumers and the supply chain are only benefited when the logistics costs are sufficiently small. We further consider the case when the logistics cost with the use of platform is high which means the FLS platform may not be beneficial to the supply chain. To generate more insights, sensitivity analyses are conducted which show that for both centralized and decentralized supply chain settings, the FLS platform is especially helpful in enhancing social welfare when the unit food product leftover cost is higher, the unit benefit derived from reusing the food product leftovers is higher or the unit logistics cost is lower.

Finally, we propose and show how the use of government sponsors can help to make the use of FLS platform a good scheme to the supply chain. In particular, we analytically determine the sufficient, and necessary and sufficient conditions under which the FLS platform is a good scheme to the social welfare. These findings help the government to justify its sponsorship scheme and decisions.

The remaining parts of this paper are arranged as follows. We first examine some related studies in the literature in Section 2. Then, based on the newsvendor problem, we develop the basic model (decentralized supply chain) in Section 3. We examine the expected values of platforms for different parties under the decentralized supply chain in Section 4. We extend the analysis to the centralized supply chain setting in Section 5. We establish and explore in the extended model the case when the presence of platform may not be beneficial to the supply chain owing to a high logistics cost in Section 6. We conclude this paper and propose future research directions in Section 7. As a common norm in operations management, all technical proofs of this paper are shown in the Appendix to enhance presentation of results.

2. Literature Review

This paper relates to food product supply chains, leftover inventory management, and platform operations in the sharing economy. We concisely review some related studies as follows.

Food product supply chains are very important in practice. In recent years, there are some published review papers on the topic. For example, Beske et al. (2014) conduct a literature review and systematic analysis on sustainable food supply chain management. The authors focus on uncovering how the dynamic capabilities relate to the proper management of supply chains in the food industry. Eksoz et al. (2014) review the literature on collaborative forecasting schemes in food supply chains. The authors build a conceptual framework and highlight the future research trend on the topic. In addition to review papers, original studies on food product supply chains are also reported, For instance, Flores and Villalobos (2013) study from an operations-marketing interface perspective how the opportunistic shipment policy affects farmers in a food supply chain. The authors build theoretical models and verify the findings via a case study. Validi et al. (2014) conduct a case study on sustainable food supply chains. The authors argue that a proper multi-objective optimization approach should be adopted in order to achieve the sustainability goal for food supply chain management. Chen et al. (2014) study product quality challenges in food supply chains. The authors explore the adulterated milk problem and argue that insufficient vertical control may be responsible for the quality problem. Sgarbossa and Russo (2017) discuss new models for closed-loop supply chain management in the food industry. The authors focus on meat processing operations and establish a profitability indicator to help measure the performance of the closed-loop meat supply chain. Govindan (2018) establishes a framework for sustainable food supply chain management. The author identifies various theories that are critical and highlights the challenges around the topic. Similar to the above reviewed studies, this paper also relates to the food supply chains. However, different from all of them, we focus on the use of platform in the sharing economy to hand food leftovers. The role of government sponsorship is also highlighted in this paper.

For product leftover management, various studies have been published in recent years. For instance, Mitra and Chatterjee (2018) explore the newsvendor problem with stochastic end-of-season demand. The authors derive the optimal stocking quantity and show that it is lower than the one under the classic newsvendor problem with deterministic end-of-season salvage value. Chan et al. (2018) explore the use of environmental taxes, including the ones imposed on leftover products, in the newsvendor supply chain. The authors employ the mean-risk formulation in relating how risk aversion affects the effectiveness of environmental taxes. Mitra (2018) studies the newsvendor problem with the consideration on the optimal clearance price. The author develops different analytical models to study how the end-of-season clearance prices can be optimally set under different situations. Devlin et al. (2018) uncover why many firms simply use the wholesale pricing contract and hesitate to use the more sophisticated contracts. They argue that the contract which provides end-of-season sponsors like buyback will reduce the retailer’s motivation to work hard on sales effort. This paper also explores the end-of-season product leftovers and employs the commonly used newsvendor model. However, different from the above reviewed studies, we consider the multiple retailers supply chain and investigate the values of platforms in collecting the food product leftovers to create values. This aspect is novel and has never been examined in the literature.

The third stream of study which relates to this paper is the platform operations. As the topic is very popular nowadays, we only review some recently published ones related to the sharing economy concept. Jha et al. (2016) conduct a case study on platform operations based innovation. The authors establish a theoretical framework to study how different constraints affect the platform operations and the respective innovation. Wang et al. (2016) examine the taxi-hailing platform operations. The authors derive the optimal pricing strategies and reveal the respective insights. Kung and Zhong (2017) study the optimal pricing decision for the grocery delivery service platforms in the presence of independent service agents. The authors explore various pricing strategies. They highlight the situation when all pricing strategies are equal. Cenamor et al. (2017) explore the advanced service offers with the use of platforms. The authors conduct multiple case studies and advocate the adoption of the “information modules” approach with the use of platforms. Taylor (2018) studies the on-demand service platform. The authors explores the situation when there are many independent service agents and highlights how to optimally price the on-demand service. Zhang et al. (2018) investigate the flash sale platform operations. The authors attempt to explain why companies adopt the flash sale approach on platforms. They build a two-period problem and characterize the company's optimal strategy for implementing the flash sale platform. Choi et al. (2019) study the on-demand service network with hired agents. They show how the blockchain technologies can be used to help improve optimal pricing for the on-demand services. Different from all these reviewed platform operations studies, this paper looks into the use of platforms for managing and enhancing values of food product leftovers in the sharing economy. The role played by the government as well as how to justify for the government’s sponsorship have not been explored in the above reviewed platform studies.

3. Basic Model: Decentralized Supply Chain

We first build the food supply chain model using the newsvendor problem[3]. We consider the case when there is a supplier (*S*) providing a single type of food product (e.g., fresh food like pork or cabbage) to multiple retailers using a wholesale pricing contract. To be specific, we have *n* retailers, and each retailer faces its own market demand. In other words, Retailer *i* faces a market demand x_i, which is a random variable following a distribution $F_i(\cdot)$. We consider the distribution has finite moments and there is a one to one mapping between its argument and the function value. We represent the inverse function of $F_i(\cdot)$ by $F_i^{-1}(\cdot)$. The food product’s cost and revenue parameters follow the standard newsvendor setting: The unit retail price for the food product is *p*, the unit wholesale price is *w*, the unit product cost for the supplier is *c*. For the food product leftovers, in the absence of the FLS platform,

[3] Since the newsvendor problem can well capture the features of food products, it is an ideal model for our analysis.

each unit of product leftovers incurs a cost h, which refers to the environment related tax imposed by the government. In the presence of the FLS platform, we argue that the FLS platform can help collect and consolidate the food product leftovers and create a unit value u. However, the FLS platform has to bear a unit logistics cost l_i for this collection and consolidation process from Retailer i. In the decentralized supply chain, the order quantities are decided by the retailers.

We denote the scenarios with and without the FLS platform by PL and $\overline{PL}$, respectively. For the supply chain, we represent the supplier, retailer and supply chain by S, R and SC, respectively. We further denote the product quantity for the supply chain branch with Retailer i as $q_{j,i}^{k}$, where $k \in (PL, \overline{PL})$, $j \in (S, R, SC)$ and $i = 1, 2, ..., n$. We use an asterisk * to denote the case with the optimal decision.

3.1. Without FLS Platform

With the above details, for the case without the FLS platform, the profit function for Retailer i is:

$$\pi_{R,i}^{\overline{PL}}(q_{R,i}^{\overline{PL}}) = p\min(q_{R,i}^{\overline{PL}}, x_i) - wq_{R,i}^{\overline{PL}} - h\max(q_{R,i}^{\overline{PL}} - x_i, 0).$$

Taking expectation yields the expected profit for Retailer i:

$$\Pi_{R,i}^{\overline{PL}}(q_{R,i}^{\overline{PL}}) = (p-w)q_{R,i}^{\overline{PL}} - (p+h)\int_0^{q_{R,i}^{\overline{PL}}} F_i(x_i)dx_i.$$

It is easy to show that $\Pi_{R,i}^{\overline{PL}}(q_{R,i}^{\overline{PL}})$ is concave and the optimal ordering quantity which maximizes $\Pi_{R,i}^{\overline{PL}}(q_{R,i}^{\overline{PL}})$ can be found by solving the first order condition: $d\Pi_{R,i}^{\overline{PL}}(q_{R,i}^{\overline{PL}}) / dq_{R,i}^{\overline{PL}} = 0$, we have:

$$q_{R,i}^{\overline{PL}*} = F_i^{-1}\left(\frac{p-w}{p+h}\right). \tag{3.1}$$

With (3.1), in the decentralized supply chain without the FLS platform, the expected profits for the retailer, the supplier and the supply chain at the retailers' optimal ordering quantities are given as follows (the subscript D = decentralized supply chain):

$$\Pi_{R,i,D}^{\overline{PL}*}=\Pi_{R,i}^{\overline{PL}}(q_{R,i}^{\overline{PL}*}) = (p-w)q_{R,i}^{\overline{PL}*}-(p+h)\int_0^{q_{R,i}^{\overline{PL}*}} F_i(x_i)dx_i .$$

$$\Pi_{S,D}^{\overline{PL}*}= \sum_{i=1}^{n}\Pi_{S,i}^{\overline{PL}}(q_{R,i}^{\overline{PL}*}) = (w-c)\sum_{1}^{n} q_{R,i}^{\overline{PL}*} , \tag{3.2}$$

$$\Pi_{SC,D}^{\overline{PL}*}=\sum_{i=1}^{n}\Pi_{SC,i}^{\overline{PL}}(q_{R,i}^{\overline{PL}*}) = \sum_{i=1}^{n}\left[(p-c)q_{R,i}^{\overline{PL}*}-(p+h)\int_0^{q_{R,i}^{\overline{PL}*}} F_i(x_i)dx_i\right]. \tag{3.3}$$

In addition to the benefits of the retailers and supplier, we also explore the consumer surplus (CS) and the environmental value (EV). For the consumer surplus, we quantify it using the inventory fill-rate:

$$CS_D^{\overline{PL}*} = G(F_1[q_{R,2}^{\overline{PL}*}],F_1[q_{R,2}^{\overline{PL}*}],...,F_n[q_{R,n}^{\overline{PL}*}]) = G\left(\frac{p-w}{p+h},\frac{p-w}{p+h},...,\frac{p-w}{p+h}\right). \tag{3.4}$$

where $G(\cdot)$ is an increasing function of its arguments.

For the environmental value, we define it with respect to the expected amount of food product leftovers:

$$EV_D^{\overline{PL}*} = \sum_{i=1}^{n}\left[-e\int_0^{q_{R,i}^{\overline{PL}*}} F_i(x_i)dx_i\right], \tag{3.5}$$

where e is the unit cost to the environment brought by the food product leftovers which are sent to landfill, and $e>0$.

As a remark, it is obvious that $EV_D^{\overline{PL}*}$ is a cost and this point is reflected by the negative sign added in (3.5).

3.2. With FLS Platform

Similar to Section 3.1, for the case with the FLS platform, the profit function for Retailer *i* is:

$$\pi_{R,i}^{PL}(q_{R,i}^{PL}) = p\min(q_{R,i}^{PL},x_i)-wq_{R,i}^{PL}.$$

Taking expectation yields the expected profit for Retailer *i* for the case when the FLS platform is present:

$$\Pi_{R,i}^{PL}(q_{R,i}^{PL}) = (p-w)q_{R,i}^{PL} - p\int_0^{q_{R,i}^{PL}} F_i(x_i)dx_i \ . \tag{3.6}$$

It is straightforward to find the optimal ordering quantity which maximizes $\Pi_{R,i}^{PL}(q_{R,i}^{PL})$ and also the respective expected profit for Retailer i:

$$q_{R,i}^{PL*} = F_i^{-1}\left(\frac{p-w}{p}\right). \tag{3.7}$$

$$\Pi_{R,i,D}^{PL*}=\Pi_{R,i}^{PL}(q_{R,i}^{PL*}) = (p-w)q_{R,i}^{PL*} - p\int_0^{q_{R,i}^{PL*}} F_i(x_i)dx_i \ .$$

With (3.7), in the decentralized supply chain with the FLS platform, the expected benefit for the platform is listed below:

$$\Pi_{FLS,D}^{PL*}=\sum_{i=1}^{n}\Pi_{FLS,i}^{PL}(q_{R,i}^{PL*}) = \sum_{i=1}^{n}(u-l_i)\int_0^{q_{R,i}^{PL*}} F(x_i)dx_i \ . \tag{3.8}$$

Moreover, the expected profits for the supplier and the supply chain at the retailers' optimal ordering quantities are given below:

$$\Pi_{S,D}^{PL*}= \sum_{i=1}^{n}\Pi_{S,i}^{PL}(q_{R,i}^{PL*}) = (w-c)\sum_{1}^{n} q_{R,i}^{PL*} \ , \tag{3.9}$$

$$\Pi_{SC,D}^{PL*}=\sum_{i=1}^{n}\Pi_{SC,i}^{PL}(q_{R,i}^{PL*}) = \sum_{i=1}^{n}\left[(p-c)q_{R,i}^{PL*} - (p-u+l_i)\int_0^{q_{R,i}^{PL*}} F(x_i)dx_i\right]. \tag{3.10}$$

Similar to the case without FLS platform, we can also derive the consumer surplus (CS) and the environmental value (EV) as follows. For the consumer surplus, we have:

$$CS_D^{PL*} = G(F_1[q_{R,2}^{PL*}], F_1[q_{R,2}^{PL*}], ..., F_n[q_{R,n}^{PL*}]) = G\left(\frac{p-w}{p}, \frac{p-w}{p}, ..., \frac{p-w}{p}\right). \tag{3.11}$$

For the environment, instead of having a cost, we create a unit value v which is defined as follows:

$$EV_D^{PL*} = \sum_{i=1}^{n}\left[v\int_0^{q_{R,i}^{PL*}} F_i(x_i)dx_i\right], \tag{3.12}$$

where v is the unit benefit to the environment brought by the proper collection and handling of food product leftovers by the FLS platform, and $v > 0$.

4. Values of FLS Platform

With the basic model defined in Section 3, we can explore the expected value of platform (EVPL). In this section, we examine the decentralized supply chain.

Define:

$$EVPL^{*}_{R,i,D} = \Pi^{PL*}_{R,i,D} - \Pi^{\overline{PL}*}_{R,i,D}, \tag{4.1}$$

$$EVPL^{*}_{S,D} = \Pi^{PL*}_{S,D} - \Pi^{\overline{PL}*}_{S,D}, \tag{4.2}$$

$$EVPL^{*}_{SC,D} = \Pi^{PL*}_{SC,D} - \Pi^{\overline{PL}*}_{SC,D}. \tag{4.3}$$

$$EVPL^{*}_{CS,D} = CS^{PL*}_{D} - CS^{\overline{PL}*}_{D}. \tag{4.4}$$

$$EVPL^{*}_{ENV,D} = EV^{PL*}_{D} - EV^{\overline{PL}*}_{D}. \tag{4.5}$$

Lemma 4.1 below summarizes the structural properties of EVPLs.

Lemma 4.1. *(a)* $EVPL^{*}_{R,i,D} > 0$*, and* $EVPL^{*}_{S,D} > 0$*. (b)* $EVPL^{*}_{SC,D} > 0$ *if* $h > l_i - u, \forall i = 1, 2, ..., n$.

Lemma 4.1 indicates a few important facts. First of all, the presence of FLS platform is always beneficial to each retailer and the supplier. This is logical because the logistics cost is taken by the FLS platform and the retailers can save the cost on food product leftovers. In addition, as the cost for food product leftovers is smaller, the retailers will order more which implies that the supplier is benefited. Then, how about the whole supply chain? Lemma 4.1 (b) shows that the whole supply chain is benefited if $h > l_i - u, \forall i = 1, 2, ..., n$, i.e., the unit cost for the food product leftovers under the case without the FLS platform is larger than the unit cost for the food product leftovers under the case with the FLS platform. This condition is mild and should very likely be satisfied (if the unit logistics cost is not too large). Observe that for the supply chain in the presence of the FLS platform, its expected profit includes the FLS platform's benefit and cost. As a result, even though both the retailers and the supplier are guaranteed to be better off after using the FLS platform under the decentralized supply chain setting, the whole supply chain may still suffer a loss owing to the high cost incurred in collecting and processing the food product leftovers by the FLS platform.

Regarding the consumer surplus and the environmental value, we have Lemma 4.2.

Lemma 4.2. $EVPL_{CS,D}^{*} > 0$, and $EVPL_{ENV,D}^{*} > 0$.

It is crystal clear from Lemma 4.2 that, under the decentralized supply chain setting, the FLS platform improves consumer surplus as well as the environment. The finding on environmental impact is intuitive as the FLS platform mainly aims to enhance the environment. For the result on consumer surplus, it is interesting because as a "by-product", the FLS platform actually helps the consumers to get a higher utility as quantified by the product availability (i.e. inventory fill rate).

From Lemma 4.1 and Lemma 4.2, we can establish several important managerial insights and we summarize them in Proposition 4.1.

Proposition 4.1. *In the decentralized supply chain setting, the presence of FLS platform is beneficial to the retailers, the supplier, the consumers and the environment. If the unit cost incurred for food product leftovers is larger than the respective logistics cost required to collect the food product leftovers by the FLS platform, the supply chain is also guaranteed to be benefited by the FLS platform.*

Proposition 4.1 reveals that the supply chain is not always benefited with the use of the FLS platform. In Section 5, we will propose measures to help enhance supply chain performance and make the FLS platform a beneficial scheme to the whole supply chain.

To generate additional insights, we conduct an analytical sensitivity analysis and the results are summarized in Table 4.1. Regarding the results on the EVPLs on the retailers, the supplier and the supply chain, they are very logical. For instance, a higher unit leftover cost *h* would lead to higher EVPLs for the retailer, the supplier and the supply chain. The same applies for the FLS platform's related cost (l_i) and benefit (*u*). Regarding the EVPLs for the consumers and the environment, we have found that the results follow the same pattern as the ones for the supply chain and its members. This highlights the beauty behind the use of the FLS platform: The values of FLS platform are basically "consistent" among all the supply chain agents, the consumers and the environment. When the value is higher for one party, the others are also benefited. This is a highly desirable situation as it means that a situation under which the FLS platform is more beneficial to the companies (e.g., supply chain agents), is also more beneficial to the consumers and the environment.

Table 4.1. Sensitivity analysis on EVPLs (decentralized case)

	$EVPL^*_{R,i,D}$	$EVPL^*_{S,D}$	$EVPL^*_{SC,D}$	$EVPL^*_{CS,D}$	$EVPL^*_{ENV,D}$
$h\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$l_i\uparrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
$u\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$

Define the EVPL for social welfare at the decentralized supply chain setting as follows:

$$EVPL^*_{SW,D} = EVPL^*_{SC,D} + EVPL^*_{CS,D} + EVPL^*_{ENV,D}, \tag{4.6}$$

We have Proposition 4.2.

Proposition 4.2. *In the decentralized supply chain setting, if (i) the unit food product leftover cost increases, (ii) the unit benefit derived from reusing the food product leftovers increases or (iii) the unit logistics cost decreases, the expected value of FLS platform for social welfare (* $EVPL^*_{SW,D}$ *) will increase.*

Proposition 4.2 is an important one as it reveals the situations under which the FLS platform is especially helpful in enhancing social welfare. Among them, if one situation arises, the expected value of using the FLS platform on social welfare will be higher.

5. Extended Model: Centralized Supply Chains

In Section 4, we explore the decentralized supply chain. Now, suppose that the supply chain is centralized and controlled by the supply chain controller, which means it is vertically integrated or coordinated by a properly set incentive alignment scheme (such as supply contracts)[4]. Then, what will be the impacts brought by the presence of the FLS platform?

It is easy to find that the expected profit for each supply chain branch with Retailer *i* in the absence of the FLS platform is:

$$\Pi_{SC,i}^{\overline{PL}}(q_{SC,i}^{\overline{PL}}) = (p-c)q_{SC,i}^{\overline{PL}} - (p+h)\int_0^{q_{SC,i}^{\overline{PL}}} F(x_i)dx_i .$$

$\Pi_{SC,i}^{\overline{PL}}(q_{SC,i}^{\overline{PL}})$ is concave and the optimal ordering quantity which maximizes it is given as follows:

$$q_{SC,i}^{\overline{PL}*} = F_i^{-1}\left(\frac{p-c}{p+h}\right). \tag{5.1}$$

In the centralized supply chain without the FLS platform, the expected profit for the whole supply chain at the supply chain's optimal ordering quantities are given as follows (the subscript C = centralized supply chain):

$$\Pi_{SC,C}^{\overline{PL}*} = \sum_{i=1}^{n}\left[(p-c)q_{SC,i}^{\overline{PL}*} - (p+h)\int_0^{q_{SC,i}^{\overline{PL}*}} F(x_i)dx_i\right]. \tag{5.2}$$

The consumer surplus and environmental value are derived as follows:

$$CS_C^{\overline{PL}*} = G(F_1[q_{SC,2}^{\overline{PL}*}], F_1[q_{SC,2}^{\overline{PL}*}], ..., F_n[q_{SC,n}^{\overline{PL}*}]) = G\left(\frac{p-c}{p+h}, \frac{p-c}{p+h}, ..., \frac{p-c}{p+h}\right). \tag{5.3}$$

$$EV_C^{\overline{PL}*} = \sum_{i=1}^{n}\left[-e\int_0^{q_{SC,i}^{\overline{PL}*}} F_i(x_i)dx_i\right]. \tag{5.4}$$

Similarly, for the case with the FLS platform, the expected profit for each supply chain branch with Retailer *i* in the presence of the FLS platform is:

$$\Pi_{SC,i}^{PL}(q_{SC,i}^{PL}) = (p-c)q_{SC,i}^{PL} - (p+l_i-u)\int_0^{q_{SC,i}^{PL}} F(x_i)dx_i . \tag{5.5}$$

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[4] It is straightforward to show that measures like the markdown sponsor contract or the two-part tariff contract can achieve coordination for the supply chain under study. For this paper, we are not interested in exploring the supply chain coordination contracts, which are already well-known in the literature. Instead, we focus on exploring how the FLS platform affects the supply chain's performance under both the decentralized (and uncoordinated) and centralized (i.e. coordinated) settings.

Note that $\Pi_{SC,i}^{PL}(q_{SC,i}^{PL})$ is concave and the respective expected profit maximization optimal ordering quantity is:

$$q_{SC,i}^{PL*} = F_i^{-1}\left(\frac{p-c}{p-u+l_i}\right). \tag{5.6}$$

Put (5.6) into (5.5) yields the optimal centralized supply chain's expected profit with the FLS platform:

$$\Pi_{SC,C}^{PL*} = \sum_{i=1}^{n}\left[(p-c)q_{SC,i}^{PL*} - (p-u+l_i)\int_0^{q_{SC,i}^{PL*}} F(x_i)dx_i\right]. \tag{5.7}$$

The consumer surplus and environmental value can be found below:

$$CS_C^{PL*} = G(F_1[q_{SC,2}^{PL*}], F_1[q_{SC,2}^{PL*}], ..., F_n[q_{SC,n}^{PL*}]) = G\left(\frac{p-c}{p+l_1-u}, \frac{p-c}{p+l_2-u}, ..., \frac{p-c}{p+l_n-u}\right). \tag{5.8}$$

$$EV_C^{PL*} = \sum_{i=1}^{n}\left[v\int_0^{q_{SC,i}^{PL*}} F_i(x_i)dx_i\right]. \tag{5.9}$$

Define:

$$EVPL_{SC,C}^{*} = \Pi_{SC,C}^{PL*} - \Pi_{SC,C}^{\overline{PL}*}. \tag{5.10}$$

$$EVPL_{CS,C}^{*} = CS_C^{PL*} - CS_C^{\overline{PL}*}. \tag{5.11}$$

$$EVPL_{ENV,C}^{*} = EV_C^{PL*} - EV_C^{\overline{PL}*}. \tag{5.12}$$

Lemma 5.1 below summarizes the structural properties of EVPLs.

Lemma 5.1. *(a)* $EVPL_{ENV,C}^{*} > 0$. *(b)* $EVPL_{SC,C}^{*} > 0$ *and* $EVPL_{CS,C}^{*} > 0$ *if* $l_i < h+u, \forall i = 1,2,...,n$.

Lemma 5.1 (the centralized supply chain case) is similar to Lemma 4.1 (the decentralized case) in which the environment is definitely benefitted by the use of FLS platform. However, in the centralized supply chain scenario, it is interesting to note that whether the consumers are benefited by the presence of FLS platform depends on value of the unit logistics cost, which is also the condition governing whether the FLS platform brings a positive benefit to the whole centralized supply chain.

We summarize the core insights in Proposition 5.1.

Proposition 5.1. *In the centralized supply chain setting, the presence of FLS platform is beneficial to the environment. If the unit cost incurred for food product leftovers is larger than the respective logistics cost required to collect the food product leftovers, then both the whole supply chain and the consumers are also guaranteed to be benefited by the FLS platform.*

Proposition 5.1 uncovers the fact that under the centralized supply chain setting, the consumers and the supply chain system are not always benefited by the use of the FLS platform. The findings on consumers are different from the decentralized "uncoordinated" case.

Table 5.1 shows the sensitivity analysis findings on EVPLs under the centralized case. Compared to the decentralized case (see Table 4.1), we can see that the results are consistent.

Table 5.1. Sensitivity analysis on EVPLs (centralized case)

	$EVPL^*_{SC,C}$	$EVPL^*_{CS,C}$	$EVPL^*_{ENV,C}$
$h\uparrow$	↑	↑	↑
$l_i\uparrow$	↓	↓	↓
$u\uparrow$	↑	↑	↑

Define the EVPL for social welfare at the centralized supply chain setting as follows:

$$EVPL^*_{SW,C} = EVPL^*_{SC,C} + EVPL^*_{CS,C} + EVPL^*_{ENV,C}.$$

We have Proposition 5.2.

Proposition 5.2. *In the centralized supply chain setting, if (i) the unit food product leftover cost increases, (ii) the unit benefit derived from reusing the food product leftovers increases or (iii) the unit logistics cost decreases, the expected value of FLS platform for social welfare ($EVPL^*_{SW,C}$) will increase.*

Proposition 5.2 reports findings very similar to the ones shown in Proposition 4.2. To be specific, we can see that for both centralized and decentralized supply chain settings, the FLS platform is especially helpful and useful in enhancing social welfare when (i) the unit food product leftover cost is higher, (ii) the unit benefit derived from reusing the food product leftovers is higher, or (iii) the unit logistics cost is lower.

6. High Logistics Cost Scenario: Government Sponsor

In the above analyses, we note that for the case when the logistics costs for collecting food product leftovers by the FLS platform are sufficiently small, i.e., $l_i < h+u, \forall i = 1,2,...,n$, then the supply chain will be benefited by the presence of the FLS platform under both decentralized and centralized settings, and the consumers are benefited under the centralized setting. However, this condition cannot be guaranteed for all cases. In particular, for a crowded city like Hong Kong, Singapore and Tokyo, the logistics cost (including manpower) is non-trivial. In this section, we explore the case when $l_i > h+u, \forall i = 1,2,...,n$ does not hold. Proposition 6.1 shows how a simple government sponsorship scheme can ensure the supply chain to be benefited by the presence of FLS platform.

Proposition 6.1. *In both the decentralized and centralized supply chain settings, if* $l_i > h+u, \forall i = 1,2,...,n$, *the presence of FLS platform is beneficial to the whole supply chain if the government provides a unit sponsor to the FLS platform* $s_i = l_i - h - u, \forall i = 1,2,...,n$, *to support its collection and processing of food product leftovers from each Retailer i. Under this sponsor, the consumers are also guaranteed to be benefited by the FLS platform.*

Proposition 6.1 shows a clean and neat result on how the government sponsor can be set to help ensure the whole supply chain is benefited under both centralized and decentralized settings. This is critical as it means that from the supply chain perspective, the presence of FLS platform is economically viable and helpful. Moreover, this government sponsor can also guarantee that the consumers are also benefited by the FLS platform.

However, is this setting justified for the government? In other words, should the government provide such a sponsor $s_i = l_i - h - u$ for the case when $l_i > h+u, \forall i = 1,2,...,n$? To answer this question, we investigate the effect of FLS platform on social welfare.

First, for the case when $l_i > h+u, \forall i = 1,2,...,n$, we set $s_i = l_i - h - u, \forall i = 1,2,...,n$, and the government provides a unit sponsor s_i, to the FLS platform for its collection and processing of food product leftovers from Retailer *i*. The expected spending of the government under the decentralized supply chain setting is (we use the superscript \$ to represent the case with government sponsor):

$$ES_{GOV,D}^{*,\$} = \sum_{i=1}^{n}\left[s_i \int_0^{q_{R,i}^{PL*}} F_i(x_i)dx_i \right]. \tag{6.1}$$

Similarly, the expected spending of the government under the centralized supply chain setting is:

$$ES_{GOV,C}^{*,\$} = \sum_{i=1}^{n}\left[s_i \int_0^{q_{SC,i}^{PL*}} F_i(x_i)dx_i \right]. \tag{6.2}$$

We define the expected values of FLS platform under the decentralized and centralized supply chain settings in the presence of government sponsor as follows:

$$EVPL_{SW,D}^{\$} = EVPL_{SC,D}^{*,\$} + EVPL_{CS,D}^{*,\$} + EVPL_{ENV,D}^{*,\$} - ES_{GOV,D}^{*,\$}, \tag{6.3}$$

$$EVPL_{SW,C}^{\$} = EVPL_{SC,C}^{*,\$} + EVPL_{CS,C}^{*,\$} + EVPL_{ENV,C}^{*,\$} - ES_{GOV,C}^{*,\$}, \tag{6.4}$$

where the EVPLs in (6.3) and (6.4) respectively follow the ones defined in (4.3) – (4.5) and (5.10) to (5.12) with $s_i = l_i - h - u, \forall i = 1,2,...,n$ under the case when $l_i > h+u, \forall i = 1,2,...,n$.

For a notational purpose, we define the following:

$$\Psi_i(q) = \int_0^q F_i(x_i)dx_i .$$

We have Proposition 6.2.

Proposition 6.2. *When* $l_i > h+u, \forall i = 1,2,...,n$: *(a) In the decentralized supply chain setting, offering a sponsor of* $s_i = l_i - h - u, \forall i = 1,2,...,n$ *can enhance social welfare: (i) if* $s_i \le v + e\left(\dfrac{\Psi_i(q_{R,i}^{\overline{PL}*})}{\Psi_i(q_{R,i}^{PL*})}\right), \forall i = 1,2,...,n$ *[sufficient condition], (ii) if and only if*

$\sum_{i=1}^{n}\left[\Psi_i(q_{R,i}^{PL*})\left(s_i - v - e\left(\frac{\Psi_i(q_{R,i}^{\overline{PL*}})}{\Psi_i(q_{R,i}^{PL*})}\right)\right)\right] \le EVPL_{CS,D}^{*,\$}$. *(b) In the centralized supply chain setting, offering a sponsor of* $s_i = l_i - h - u, \forall i = 1,2,...,n$ *can enhance social welfare: (i) if* $s_i \le v + e, \forall i = 1,2,...,n$ *[sufficient condition], (ii) if and only if* $\sum_{i=1}^{n}\left[(s_i - v - e)\Psi_i(q_{SC,i}^{PL*})\right] \le 0$.

Proposition 6.2 (a) shows a critical finding in which if the environmental benefit brought by the FLS platform is sufficiently big, it is already enough to justify for the government sponsor on its spending with respect to $s_i, \forall i = 1,2,...,n$. This point is especially meaningful nowadays as the availability of places and land for landfills is dropping rapidly which implies that *e* is large. This will make the sufficient condition easily met. Proposition 6.2(b) and Proposition 6.2 (c) show the necessary and sufficient conditions for justifying the government's sponsor under the decentralized and centralized cases. As consumers are positively benefited by the FLS platform under the decentralized setting, the necessary and sufficient condition for justifying the government's sponsorship action under the decentralized supply chain case is probably easier to achieve than the centralized supply chain counterpart.

7. Concluding Remarks and Future Research

7.1. Summary

In the sharing economy, operations management places a critical role in enhancing sustainability and social welfare. In this paper, motivated by the observed industrial practices in food leftovers sharing (FLS) platforms, we have conducted an analytical study to explore the values of these FLS platforms. To be specific, we have constructed a single supplier multiple-retailer analytical supply chain. The supply chain sells a newsvendor type of perishable food product and there are product leftovers at the end of the selling season. We have explored the problem from both the decentralized and centralized supply chain perspectives. In particular, we have focused on investigating the expected values of platform (EVPLs) for the supply chain, the consumers and the environment.

For the decentralized supply chain case, we have proven that the presence of FLS platform is beneficial to the retailers, the supplier, the consumers, and the environment. We have shown that whether the FLS platform benefits the supply chain economically depends on the logistics costs (incurred from the food product leftover collection by the FLS platform).

For the centralized supply chain case, similar to the decentralized case, we have uncovered that the FLS platform is guaranteed to help improve the environment. However, different from the decentralized case, we have shown that the consumers and the supply chain are only benefited when the logistics costs (incurred from the food product leftover collection by the FLS platform) are sufficiently small. Table 7.1 shows a summary of the major findings on EVPLs.

Table 7.1. Summary of findings on EVPLs

Scenarios	**EVPLs**		
	Supply Chain	***Consumers***	***Environment***
Decentralized Supply Chain	Positive if $h > l_i - u, \forall i = 1,2,...,n$	Positive	Positive
Centralized Supply Chain	Positive if $h > l_i - u, \forall i = 1,2,...,n$	Positive if $h > l_i - u, \forall i = 1,2,...,n$	Positive

Moreover, from our analytical sensitivity analyses, we have also uncovered that for both centralized and decentralized supply chain settings, the FLS platform is especially helpful in enhancing social welfare when (i) the unit food product leftover cost is higher, (ii) the unit benefit derived from reusing the food product leftovers is higher or (iii) the unit logistics cost (incurred by the FLS platform during the food product leftover collection and reusing) is lower.

To address the case when the logistics costs are high which imply (i) the supply chains under the decentralized and centralized settings will not be benefited by the presence of FLS platform, and (ii) the consumers under the centralized settings may not be benefited, we have investigated the use of a government sponsorship scheme to help. To be specific, we have found that if the government is willing to sponsor the FLS platform for its logistics expenses, the supply chains and the consumers will definitely be guaranteed to be benefited by the use of FLS platform, under both the decentralized and centralized supply chain settings

Finally, we have established the social welfare functions and demonstrated how the government can make use of them to determine whether the sponsorship schemes are well-justified or not by checking against the social welfare. In particular, we have found that if the unit environmental benefit brought by the FLS platform is sufficiently big, it is straightforward to for the government to vote for our proposed sponsorship scheme. We have argued that this point is especially important nowadays because the availability of places for landfills is dropping rapidly which implies the unit environmental benefit with the use of FLS platform is higher and higher. Table 7.2 shows a summary of major findings on government sponsors for the high logistics cost case.

Table 7.2. Summary of findings on government sponsor

	Details	
Proper Setting	When is the government sponsor needed?	$h < l_i - u, \forall i = 1,2,...,n$
	What is the required government sponsorship?	$s_i = l_i - h - u, \forall i = 1,2,...,n$
Well-Justified?	Sufficient condition (decentralized supply chain)	$s_i \le v + e\left(\frac{\Psi_i(q_{R,i}^{\overline{PL}*})}{\Psi_i(q_{R,i}^{PL*})}\right), \forall i = 1,2,...,n$
	Sufficient condition (centralized supply chain)	$s_i \le v + e, \forall i = 1,2,...,n$
	Necessary and sufficient condition (decentralized supply chain)	$\sum_{i=1}^{n}\left[\Psi_i(q_{R,i}^{PL*})\left(s_i - v - e\left(\frac{\Psi_i(q_{R,i}^{\overline{PL}*})}{\Psi_i(q_{R,i}^{PL*})}\right)\right)\right] \le EVPL_{CS,D}^{*,\$}$
	Necessary and sufficient condition (centralized supply chain)	$\sum_{i=1}^{n}\left[(s_i - v - e)\Psi_i(q_{SC,i}^{PL*})\right] \le 0$

7.2. Future Research

In this paper, following the observed real cases, we examine the scenario when the FLS platform does not aim to make any profit. For future research, it will be interesting to explore the situations when the FLS platform is profit making and compare whether a profit making FLS platform will outperform or under-perform compared to the non-profit making FLS platform. In this paper, the use of FLS platforms is to physically collect and process the food product leftovers. In the future, it will be promising to explore how collaborative consumption (Jiang and Tian 2018), at the consumer level, may help to deal with the food product leftovers issue. Last but not least, other issues such as the use of information (Zhang et al. 2017; Choi et al. 2018), the case with multiple suppliers (Li et al. 2010), the application of supply contracts (Asian and Nie 2014; Shen and Li 2015; Guo et al. 2017; Guo et al. 2018), the analysis of operational risk (Lau 1980), as well as shipping arrangements (Hua et al. 2012a; Hua et al. 2012b) can all be considered in future studies.

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Appendix: Proofs of Lemmas and Propositions

Proof of Lemma 4.1:

(a) Since $q_{R,i}^{\overline{PL}*} = F_i^{-1}\left(\frac{p-w}{p+h}\right)$ and $q_{R,i}^{PL*} = F_i^{-1}\left(\frac{p-w}{p}\right)$, we have:

$$q_{R,i}^{PL*} > q_{R,i}^{\overline{PL}*}. \tag{A1}$$

From (4.1), we have:

$$EVPL_{R,i,D}^{*} = \Pi_{R,i,D}^{PL*} - \Pi_{R,i,D}^{\overline{PL}*} = (p-w)q_{R,i}^{PL*} - p\int_0^{q_{R,i}^{PL*}} F_i(x_i)dx_i - \left((p-w)q_{R,i}^{\overline{PL}*} - (p+h)\int_0^{q_{R,i}^{\overline{PL}*}} F_i(x_i)dx_i\right)$$

$$> (p-w)q_{R,i}^{PL*} - p\int_0^{q_{R,i}^{PL*}} F_i(x_i)dx_i - \left((p-w)q_{R,i}^{\overline{PL}*} - p\int_0^{q_{R,i}^{\overline{PL}*}} F_i(x_i)dx_i\right) = \Pi_{R,i,D}^{PL*} - \Pi_{R,i}^{PL}(q_{R,i}^{\overline{PL}*}). \tag{A2}$$

Since $\Pi_{R,i}^{PL}(q_{R,i}^{PL})$ is concave and $q_{R,i}^{PL*} > q_{R,i}^{\overline{PL}*}$, we have $\Pi_{R,i,D}^{PL*} - \Pi_{R,i}^{PL}(q_{R,i}^{\overline{PL}*}) > 0$. Hence, we have $EVPL_{R,i,D}^{*} > 0$.

(b) From (4.3), we have:

$EVPL_{SC,D}^{*} = \Pi_{SC,D}^{PL*} - \Pi_{SC,D}^{\overline{PL}*}$. It is easy to find that $EVPL_{SC,D}^{*} > 0$ if $h > l_i - u, \forall i = 1,2,...,n$. If $h > l_i, \forall i = 1,2,...,n$, then it is sufficient to have $EVPL_{SC,D}^{*} > 0$. (Q.E.D.)

Proof of Lemma 4.2:

From (4.4), we have:

$$\begin{aligned} &EVPL_{CS,D}^{*} \\ &= CS_D^{PL*} - CS_D^{\overline{PL}*} \\ &= G\left(\frac{p-w}{p}, \frac{p-w}{p}, ..., \frac{p-w}{p}\right) - G\left(\frac{p-w}{p+h}, \frac{p-w}{p+h}, ..., \frac{p-w}{p+h}\right). \end{aligned}$$

Since $\frac{p-w}{p} > \frac{p-w}{p+h}$ and $G(\cdot)$ is an increasing function of its arguments, we have: $EVPL_{CS,D}^{*} > 0$.

From (4.5), we have:

$$
\begin{aligned}
& EVPL_{ENV,D}^{*} \\
& = EV_D^{PL*} - EV_D^{\overline{PL}*} \\
& = \sum_{i=1}^{n}\left[v\int_0^{q_{R,i}^{PL*}} F_i(x_i)dx_i \right] - \sum_{i=1}^{n}\left[-e\int_0^{q_{R,i}^{\overline{PL}*}} F_i(x_i)dx_i \right] \\
& = \sum_{i=1}^{n}\left[v\int_0^{q_{R,i}^{PL*}} F_i(x_i)dx_i + e\int_0^{q_{R,i}^{\overline{PL}*}} F_i(x_i)dx_i \right]. \qquad \text{(A3)}
\end{aligned}
$$

It is obvious that (A3) is positive which implies that $EVPL_{ENV,D}^{*} > 0$. (Q.E.D.)

Proof of Proposition 4.1: In the centralized supply chain setting, from Lemma 4.1(a) and Lemma 4.2, we have: the presence of FLS platform is beneficial to the retailers, the supplier, the consumers and the environment. From Lemma 4.1(b), we can see that if the unit cost incurred for food product leftovers is larger than the respective logistics cost required to collect the food product leftovers, the supply chain is also guaranteed to be benefited by the FLS platform. (Q.E.D.)

Proof of Proposition 4.2: Directly from Table 4.1. (Q.E.D.)

Proof of Lemma 5.1. Similar to the proof of Lemma 4.1 and Lemma 4.2, we can prove that (a) $EVPL_{ENV,C}^{*} > 0$. (b) $EVPL_{SC,C}^{*} > 0$ and $EVPL_{CS,C}^{*} > 0$ if $h > l_i - u, \forall i = 1,2,...,n$. If $h > l_i, \forall i = 1,2,...,n$, then it is sufficient to have $EVPL_{SC,C}^{*} > 0$ and $EVPL_{CS,C}^{*} > 0$. (Q.E.D.)

Proof of Proposition 5.1. In the centralized supply chain setting, using the result from Lemma 5.1(a), we have the finding on the fact that the presence of FLS platform is beneficial to the environment. From Lemma 5.1 (b), we can see that if the unit cost incurred for food product leftovers is larger than the respective logistics cost required to collect the food product leftovers, both the whole supply chain and the consumers are also guaranteed to be benefited by the FLS platform. (Q.E.D.)

Proof of Proposition 5.2: Directly from Table 5.1. (Q.E.D.)

Proof of Proposition 6.1: In both the decentralized and centralized supply chain settings, if $h < l_i - u, \forall i = 1,2,...,n$, the FLS platform will suffer a loss in providing the service of collecting and processing food product leftovers. Thus, the presence of FLS platform is not beneficial to the whole supply chain. However, if the government provides a unit sponsor to the FLS platform $s_i = l_i - h - u, \forall i = 1,2,...,n$, it will offset the loss incurred by the high logistics cost for the FLS platform. Under this sponsorship scheme, the consumers are also guaranteed to be benefited by the FLS platform under the centralized supply chain setting because the respective consumer surplus is also no less than the case without the FLS platform. (Q.E.D.)

Proof of Proposition 6.2: When $h < l_i - u, \forall i = 1,2,...,n$, we try to find the condition in which $EVPL^{\$}_{SW,D}$ and $EVPL^{\$}_{SW,C}$ are zero or positive.

(a) In the decentralized supply chain setting, if the government offers a sponsor of $s_i = l_i - h - u, \forall i = 1,2,...,n$, we have: $EVPL^{*,\$}_{CS,D} = 0$.

Then, from (6.3) we have

$EVPL^{\$}_{SW,D} = EVPL^{*,\$}_{SC,D} + EVPL^{*,\$}_{ENV,D} - ES^{*,\$}_{GOV,D}$, and

$$EVPL^{\$}_{SW,D} \geq 0 \Leftrightarrow EVPL^{*,\$}_{CS,D} \geq \sum_{i=1}^{n}\left[\Psi_i(q^{PL*}_{R,i})\left(s_i - v - e\left(\frac{\Psi_i(q^{\overline{PL}*}_{R,i})}{\Psi_i(q^{PL*}_{R,i})}\right)\right)\right].$$

If $s_i \leq v + e\left(\frac{\Psi_i(q^{\overline{PL}*}_{R,i})}{\Psi_i(q^{PL*}_{R,i})}\right), \forall i = 1,2,...,n$, it is sufficient to claim that $EVPL^{\$}_{SW,D} \geq 0$.

(b) In the centralized supply chain setting, note that under the proposed government sponsorship scheme (i.e., $s_i = l_i - h - u, \forall i = 1,2,...,n$), we have:

$$EVPL_{SC,C}^{*,\$} = 0,$$

$$EVPL_{CS,C}^{*,\$} = 0, \text{ and}$$

$$q_{SC,i}^{PL*} = q_{SC,i}^{\overline{PL}*} = F_i^{-1}\left(\frac{p-c}{p+h}\right).$$

As a result, we have the following result:

$$EVPL_{SW,C}^{\$} = EVPL_{ENV,C}^{*,\$} - ES_{GOV,C}^{*,\$} \text{ and}$$

$$EVPL_{SW,C}^{\$} \geq 0 \Leftrightarrow \sum_{i=1}^{n}\left[(s_i - v - e)\Psi_i(q_{SC,i}^{PL*})\right] \leq 0.$$

If $s_i \leq v + e, \forall i = 1,2,...,n$, then it is sufficient to claim that $EVPL_{SW,C}^{\$} \geq 0$. (Q.E.D.)